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Climate Change Vulnerability Assessment in Informal Urban Settlements

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Abstract

International and national organizations have primarily adopted two policy responses to address climate change. These strategies focus on reducing greenhouse gas emissions to slow the rate of climate change and strengthening the coping capacity of countries, sectors, and communities. Furthermore, rapid and unplanned urbanization, poverty, unemployment, lack of alternative housing opportunities, social and economic exclusion of rural migrants, and the need to stay close to resources and opportunities have led to a growing population of the urban poor living in informal slum settlements.

Therefore, this research aims to assess the vulnerability of informal slum settlements to climate change in Suklagandaki Municipality. To do this, it applied the Livelihood Vulnerability Index - Intergovernmental Panel on Climate Change (LVI-IPCC) by surveying 89 households from four locations in Suklagandaki Municipality. The LVI-IPCC comprises 11 components under the exposure, sensitivity, and adaptive capacity headings. The analysis was based on indices constructed from 34 indicators. The results show that Maalebagar-8 is the most vulnerable, while Ward-2 is the least vulnerable, with vulnerability falling within a moderate range. The National Adaptation Plan of Action (NAPA) and Local Adaptation Plan of Action (LAPA) focus on climate hazards but neglect the underlying drivers of vulnerability and the needs of the most vulnerable communities. These findings can help inform future climate and disaster management policies tailored to similar urban settlements.

***Keywords*:** Climate Change; Urban Slum; Exposure; Sensitivity; Adaptive Capacity.

1. Introduction

Human-induced climate change is significantly intensifying weather and climate extremes worldwide. The Intergovernmental Panel on Climate Change (IPCC, 2021) confirms that anthropogenic activities have increased the frequency of heatwaves, floods, droughts, and wildfires. In response, global policies have focused on two main strategies: reducing greenhouse gas emissions and enhancing adaptive capacity (Ford & Smit, 2004). Future projections warn of escalating climate hazards affecting social and ecological systems, with rural, mountainous, and agriculture-dependent communities among the most vulnerable (Poudel & Shaw, 2015). Urbanization adds further complexity to climate vulnerability. Over 4.4 billion people live in urban areas, projected to reach 66% of the global population by 2050. Much of this growth will occur in low- and middle-income countries. Approximately one billion urban residents live in informal settlements (Revi, 2008; Revi et al., 2014), mainly due to rapid and unplanned urban expansion, poverty, unemployment, and social exclusion (Williams, Wei, & Zhu, 2020). UN-Habitat (2016) estimated 880 million slum dwellers globally in 2016.

Often excluded from formal legal and regulatory systems, informal settlements typically lack adequate housing, water, sanitation, and tenure security (Satterthwaite et al., 2020). Poor infrastructure and waste management exacerbate environmental degradation and health risks (Porio, 2011), rendering these communities highly vulnerable to climate impacts (Wekesa et al., 2011; Alcayna-Stevens, 2015). Their proximity to high-risk zones and lack of access to recovery resources further heighten vulnerability (Bakrania, 2015). As urbanization continues, informal settlements are expected to accommodate much of the population increase, particularly in the Global South (Satterthwaite et al., 2020). Household-level exposure, sensitivity, and adaptive capacity assessments are essential to identifying vulnerabilities and informing adaptation strategies (Below et al., 2012; Panthi et al., 2016). The IPCC defines vulnerability as the degree to which a system cannot cope with climate impacts, assessed through exposure, sensitivity, and adaptive capacity (Hahn et al., 2009; O'Brien et al., 2004). While experiences of vulnerability vary, they are always locally grounded. Despite existing frameworks, research focusing on informal settlements remains limited (Owusu & Nursey-Bray, 2018), primarily due to data scarcity and exclusion from urban policy (Satterthwaite et al., 2020). Developing countries like Nepal face heightened climate risks due to low adaptive capacity (Kates, 2000). Nepal's mountainous terrain, fragile ecosystems, and unstable geology make it particularly susceptible (MoFE, 2021). The World Bank estimates Nepal could lose up to 2.2% of its GDP annually by 2050 due to climate change. Urban informal settlements in Suklagandaki Municipality are directly exposed to climate change, complicating efforts to manage resources for sustainable livelihoods. Therefore, this study assessed climate change vulnerability in informal urban settlements of Suklagandaki Municipality, Nepal.

2. Methodology

2.1 Study Site

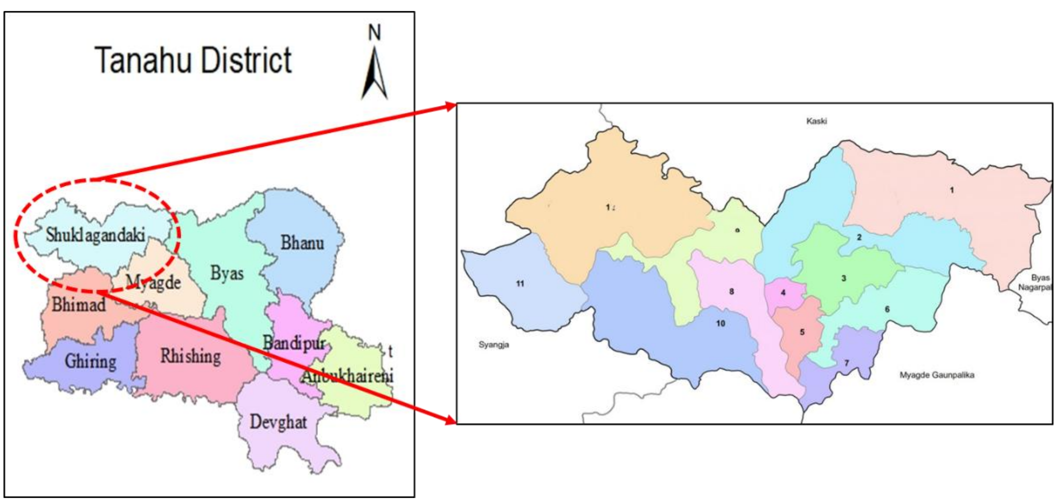

Figure 1: Location of Suklagandaki Municipality in Tanahu District of Nepal

Shuklagandaki Municipality is located in Tanahu District of Gandaki Zone, Nepal. It is surrounded by Pokhara Metropolitan City in the north, Byas Municipality and Myagde Rural Municipality in the east, Syangja District in the west, and Bhimad Municipality in the south. This municipality has a high religious value. Prithvi Highway, along with several small roads, passes through it. Figure 1 shows the location of Suklagandaki Municipality; it covers a total area of 165 sq. km.

2.1.1 Shaakhar, Haledi, Shantitole, Nursery, -02

All areas of study of ward-02 lie in the north-west part of the Dulegauda Bazar of Shuklagandaki Municipality. Shaakhar lies in the river bank of the Seti Gandaki River with latitude of 28° 03' 44.70" N and longitude of 84° 04' 1.30" E. Haledi also lies near the river bank of Seti Gandaki River with the latitude of 28° 4' 21.68" N and longitude of 84° 4' 13.04" E. Similarly, Nursery and Shanti Tole lies at latitude of 28° 5' 7.81" N and longitude of 84° 4' 42.15 "E. Fifteen respondents were taken as a sample to collect the data for the various indicators of exposure, sensitivity and adaptive capacity. Shanti tole and Nursery were the oldest settlements, followed by Haledi and the Shaakhar area. The Nursery tole was established around 40 years of period, whereas Shaakhar was established around 20 years ago. Most of the respondents in this area work as wage labour in a concrete block factory.

Figure 2: Spatial position of the study site on the map.

Approximately 80% of the settlements in this area used to work for river mining for 15-16 years, according to the respondents in this area. Extensive extraction of riverbed materials from the Seti Gandaki River lowered the riverbed by approximately 4–5 meters from its original level, resulting in adverse environmental impacts and increased flood risk. In response, the District Development Committee issued a directive around 8–10 years ago prohibiting further extraction. Previously, the area hosted several businesses such as crusher plants and concrete block factories, contributing to ongoing air and noise pollution, adversely affecting local health conditions. Currently, the Haledi area retains permission to extract riverbed materials, as outlined in recent Environmental Impact Assessment (EIA) and Initial Environmental Examination (IEE) reports. Haledi is particularly vulnerable to urban flooding during the monsoon season due to clogged drainage systems and intense rainfall. Similarly, residents of Shanti Tole reported a high risk of flooding from the nearby Kali Khola River.

2.1.2 Shitalnagar-05

Shitalnagar - 05 lies in the southern part of the Shuklagandaki Municipality office. Slum area lines the left bank of the Seti River. It lies at a latitude of 28° 01'18.29" N and a longitude of 84° 04'54.80" E. Most residents rely on wage labor and are dependent on seasonal employment. Some individuals are also engaged in riverbed material extraction to sustain their livelihoods. The area lacks a consistent water supply, relying on a pump-based system. During power outages, residents face acute water shortages and must depend on a nearby spring for drinking water. One respondent noted that they still travel nearly half an hour to collect water from the spring, as underground borewell water is considered unsafe for consumption. On a positive note, most respondents reported having access to the nearby G.P. Koirala National Center for Respiratory Diseases, contributing to reducing health vulnerabilities in the area.

2.1.3 Maalebagar-08

Maalebagar - 08 lies in the southern part of the Shuklagandaki Municipality office with the latitude of 28° 01'06.35" N and longitude of 84° 04'42.10" E. Respondents participated through a structured questionnaire administered via Google Forms, and additional insights were gathered through Focus Group Discussions (FGDs). One respondent, an elderly woman, shared that she relies solely on her old-age allowance for her livelihood. She says disputes over water sources are a major concern due to limited availability. This community is particularly affected by the Kyangdi River, which flows upstream of Bhimad Municipality. This river poses a significant threat of a downside landslide. The local government has supported them by distributing gabion boxes for slope protection. Respondents also noted that they lack sufficient funding and technical expertise to implement proper river training and long-term mitigation measures.

2.1.4 Ghari-09

It lies in the north-west part of the Suklagandaki Municipality office with the latitude of 28° 04'12.54" N and longitude of 84° 03'50.49" E. It lies on the right bank of the Seti River. Respondents were asked questions related to exposure, sensitivity, and adaptive capacity. Most reported wage labor as their primary occupation, with employment largely dependent on seasonal availability. Open defecation was commonly practiced in the area, indicating inadequate sanitation facilities. Waste disposal methods included open dumping, with composting used for organic waste and incineration for plastic waste.

2.2 Data Collection

Based on the established theoretical framework, a household-level questionnaire was designed and administered between August and September 2022. The questionnaire was developed using Google Forms and primarily consisted of yes/no questions, multiple-choice items, checkboxes, and Likert scale responses. Before finalization, the questionnaire underwent a validation process incorporating detailed feedback from the expert group. The finalized survey was structured into four key sections. The first section gathered general household information, including demographic characteristics and socio-economic status. The second section focused on exposure-related variables, capturing respondents' perceptions of climate variability, such as perceived changes in temperature, rainfall patterns, hot and cold days, water availability, and human health conditions over the past five years. Additional exposure indicators were derived from hydrometeorological data from the Department of Hydrology and Meteorology, Gandaki Province, using the Khairenitar station as a reference point.

The third section addressed sensitivity components, encompassing health, food security, and water access indicators. The final section assessed household adaptive capacity, focusing on both internal and external factors that enable communities to support, cope with, and adjust to the adverse impacts of climate change. This included external support from government bodies, civil society organizations, and local agencies; access to technology and infrastructure; and individual and institutional coping strategies. A random sampling method was employed to determine the number of households to be surveyed. The sample size for each flood- and landslide-prone area was calculated using Raosoft software. With a 10% margin of error and a 90% confidence interval, the required sample size was derived from the population data of landless slum settlements within Suklagandaki Municipality. The population figures were based on fiscal year 2077/78 B.S. records, as presented in Table 1.

Table 1. Sample population and sample size taken in this study.

Ward No.	Place surveyed	Population of the slum	Sample size
5	Settlements on the riverbank of the Shitalnagar area	42	27
8	Settlements at the riverbank of the Maalebagar area	40	26
9	Settlements at the riverbank of the Ghaari area	28	21
2	Settlements near the river banks of Nursery, Shakhar, Gachhepani, Haledi	18	15
	Total	**128**	**89**

2.3 Calculation of LVI-IPCC

The LVI includes eleven major dimensions: (Natural disasters, climate variability, and Hygiene) under exposure condition, (Health, Food, and Water) under sensitivity condition, and (Social networks, Livelihood, Socio-demographic profile, Resource, Infrastructure, Coping strategy, Technology) under adaptive capacity condition (IPCC, 2021). Each was further developed with several indicators as per Table 2. At the same time, Hahn (2009) includes seven major components: Socio-Demographic Profile, Livelihood Strategies, Social Networks, Health, Food, Water, and Natural Disasters and Climate Variability for calculating LVI. The indicators were developed based on an extensive review of relevant literature, consultations with the research supervisor, inputs from municipal representatives, and contextual requirements specific to the survey. Detailed descriptions of each indicator facilitated their quantification. Data were collected through field surveys using a combination of Key Informant Interviews (KIIs), Focus Group Discussions (FGDs), and personal interviews conducted in flood- and landslide-prone slum areas within the municipality.

Since each sub-component was measured on a different scale, standardizing them prior to analysis was essential, as shown in Equation 1.

$$\text{index}_{sw}= \frac{Sw-Smin}{Smax-Smin} \qquad (1)$$

where s_w is the original sub-component for the slum area of a specific ward, and s_{min} and s_{max} are the minimum and maximum values, respectively, for each sub-component determined using data from all the slum areas under this study. Once the sub-components were standardized, they were averaged using Equation (2) to compute the value of each major dimension or component.

$$M_w=\sum_{i=1}^{11}\frac{index\ sw\ i}{n} \quad (2)$$

where Mw is one of the eleven major dimension/component for slum area of specified ward Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Infrastructure (I), Coping Capacity (C), Resource (R), Technology (T) Health (H), Food (F), Water (W), Natural Disasters, Climate Variability and Hygiene (NDCVH)), index sw i represents the sub-components, i index make up each dimension/component, and n is the number of sub-components in each major component.

Table 2: Major components and the vulnerability contributing factor based on IPCC (2021).

Exposure	Natural disasters, climate variability, and Hygiene
Adaptive capacity	Socio-demographic profile Livelihood strategies Social networks Infrastructure Coping Capacity Resource Technology
Sensitivity	Health Food Water

Exposure of the study population was assessed based on the frequency of natural disasters that have occurred in the past five years, climate variability, and the hygiene conditions. Adaptive capacity was quantified through socio-demographic profile, social networks, livelihood, resources, infrastructure, coping strategy, and technology. Sensitivity was evaluated by examining the current status of food security, water availability, and health conditions. The indicators detailed in Table 2, alongside Equations (1) and (2), were utilized to calculate the Livelihood Vulnerability Index following the IPCC framework (LVI-IPCC). Rather than aggregating all major components into a single index at once, the components were initially combined according to the categorization outlined in Table 2, employing the specified equations.

$$CF_{sw}=\frac{\sum_{i=1}^{n} wMiMswi}{\sum_{i=1}^{n} wMi} \quad (3)$$

where CF_{sw} is the IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) for the slum area, Mswi is the major component for the slum indexed by i, wMi is the weight of each major component, and n is the number of major components in each contributing factor. After calculating exposure, sensitivity, and adaptive capacity, the three contributing factors were integrated to compute the overall LVI-IPCC score using Equation (4).

$$LVI-IPCC_{SW}= (esw-asw)\times ssw \quad (4)$$

where LVI - IPCCsw is the LVI for the slum area of ward expressed using the IPCC vulnerability framework, e is the calculated exposure score for slum area of ward (equivalent to natural disaster, climate variability and hygiene), a is the calculated adaptive capacity score for slum area of ward and s is the calculated sensitivity score for the slum area. LVI-IPCC scale varies from -1 (least vulnerable) to 1 (most vulnerable).

3. Results and Discussion

3.1 Exposure Assessment

The average number of climate-related and natural hazard events—including floods, landslides, droughts, animal incidents, and thunderbolts—was found to be 3.2 over the past five years across all wards of Shuklagandaki Municipality. Respondents reported a perceived increase in temperature, with the highest responses from Ward 8 (Maalebagar) and Ward 9 (Ghaari), and the lowest from Ward 2 areas such as Haledi, Nursery, Shanti Tole, Shaakhar, and slum settlements near the Prithvi Highway.

Regarding rainfall variability, respondents from Ghaari-9 reported less noticeable changes than those from Ward 2 and Ward 5. All respondents (100%) in Ward 8 noted an increase in the number of hot days, whereas only 66.66% of respondents in Ward 9 observed such a change. A majority of residents in Maalebagar-8 reported noticeable changes in both cold days and water availability over the past five years, while only 11% of respondents from Ghaari-9 reported changes in water availability during the same period. Perceptions of changes in human health across seasons were also higher among respondents from Maalebagar-8 and Ghaari-9. Additionally, Maalebagar-8 was reported to have the highest number of households practicing open and scattered solid waste disposal compared to other study areas.

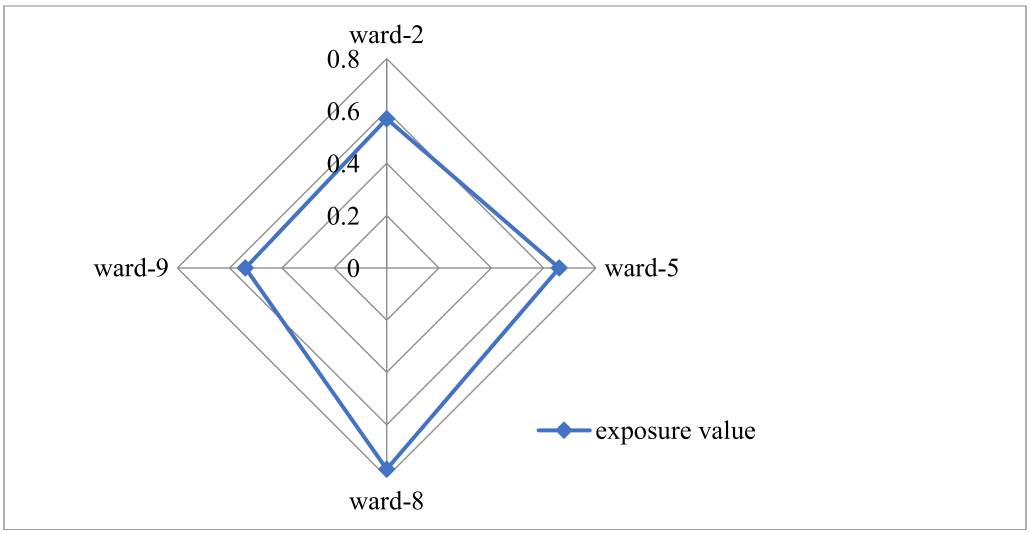

Figure 3. Exposure values in different wards of Suklagandaki Municipality

3.2 Sensitivity Assessment

It was observed that respondents from Shitalnagar-05 and Ghaari-09 had to travel approximately 15 minutes to access the nearest health facilities. In contrast, respondents from areas such as Nursery and Haledi reported the longest travel times, averaging 24.5 minutes. Residents of Shitalnagar-05 had access to the G.P. Koirala National Center for Respiratory Diseases, enabling them to undergo regular health checkups. Conversely, respondents from Ward-02 relied on the health facilities located in Dulegauda Bazar for medical services. Furthermore, 100% of respondents from Ghaari-09 reported having at least one family member suffering from a chronic illness, the highest among all study areas. Maalebagar-08 reported the lowest percentage of households with chronically ill family members.

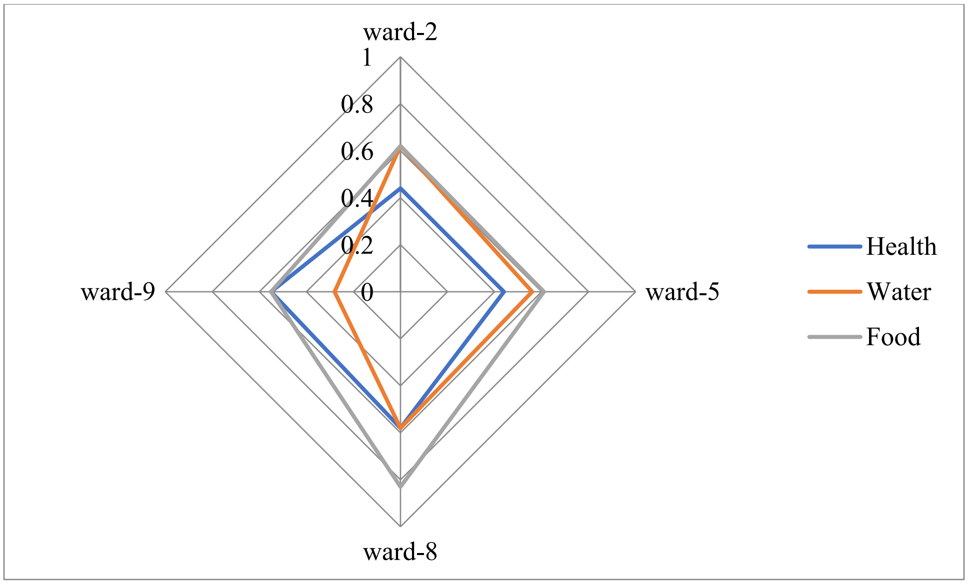

Figure 4. Sensitivity values in different wards of Suklagandaki Municipality.

Regarding water—a key component of sensitivity—respondents from Ward 9 reported no disputes over access to water facilities. However, during supply interruptions, residents of Maalebagar-8 and Ghaari-09 relied on natural water sources to meet emergency needs. Shitalnagar-05 experienced the most frequent disruptions in water supply, primarily due to its reliance on a water-lifting system. This system became inoperable during power outages, leading to significant water scarcity. In contrast, residents of Nursery, Shaakhar, and Haledi reported fewer water supply interruptions than other slum areas. These findings suggest that Ward 8 was more sensitive regarding food security, while Ward 9 exhibited the lowest sensitivity concerning water availability.

3.3 Adaptive Capacity Assessment

The adaptive capacity assessment used 15 indicators under seven major components: social networks, livelihood, socio-demographic profile, resources, infrastructure, coping strategies, and technology. The Receive: Give ratio, which reflects the balance of social support, was highest in Ward 02 (including areas such as Haledi, Nursery, and Shaakhar) and lowest in Ghaari-09. Similarly, the Borrow: Lend ratio peaked at 1.33 in Ward 02 and was lowest in Ghaari-09, indicating stronger social exchange dynamics in Ward 02 compared to Ghaari. Interestingly, households that had not approached their local government for assistance in recent months exhibited relatively higher adaptive capacity, particularly in socio-economic terms. In Ghaari-09, none of the households had sought government support. Although local leaders had promised land ownership documentation to slum dwellers following the recent local elections, no such provision had been implemented as of the time of the study. In contrast, approximately 53.8% of respondents from Ward 8 (Maalebagar) reported having approached local authorities for assistance, including applications for land ownership certificates, old-age allowances, and disability benefits.

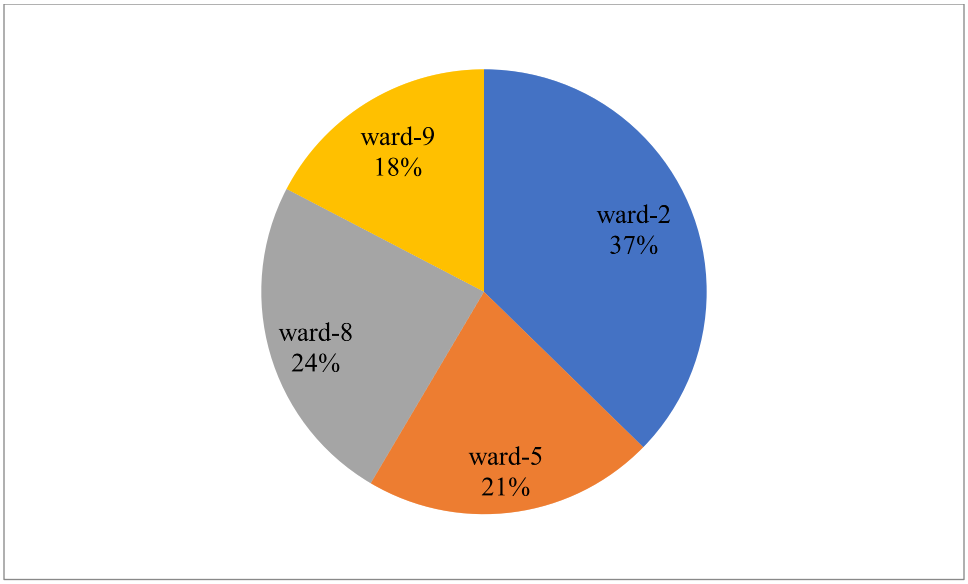

Figure 5. Adaptive capacities of different wards in the study area.

The study revealed that nearly all surveyed areas showed minimal dependency on agriculture as a primary source of income. Instead, residents primarily relied on alternative livelihoods such as small businesses, wage labor, river-bed material extraction, and driving-related occupations. In Ward 9 (Ghaari), many households were actively involved in local social organizations, including Tole Development Committees and Water User Committees. Most Wards 2 and 9 respondents reported having at least one family member working outside the community to support household income. Notably, Ward 2 had the highest proportion of household heads who had attended school, indicating relatively stronger socio-demographic characteristics. Areas such as Nursery, Haledi, and Shaakhar reported no current water scarcity, unless spring sources were damaged or contaminated during disasters. Across all study locations, there was a lack of training and institutional support to cope with water-induced disasters such as floods and landslides. However, housing structures in Maalebagar-8 were predominantly of the permanent type, offering greater protection against extreme weather events and climate variability. Households in Ward 2 demonstrated greater familiarity with adaptive technologies such as river training structures and retaining walls. Shanti Tole, a neighborhood in Ward 2, was particularly vulnerable to urban flooding caused by the overflow and blockage of the Kali Khola during the monsoon season. However, the construction of retaining walls along the river, supported by the local government, has significantly improved the community's coping capacity. As illustrated in Figure 5, Ward 2 exhibited the highest overall adaptive capacity, followed by Ward 8. Ward 9 demonstrated the lowest adaptive capacity based on the indicators applied across the seven major components of adaptive capacity.

3.4 Vulnerability Assessment

Due to higher exposure and sensitivity and lower adaptive capacity, the residents of the informal urban slum settlements of Ward-8 Maalebagar were found to be most vulnerable with respect to other wards of the study area. Ward-2 area was seen to have the least vulnerability among other wards because of its higher adaptive capacity, although it had high sensitivity and exposure conditions, as per Figure 6.

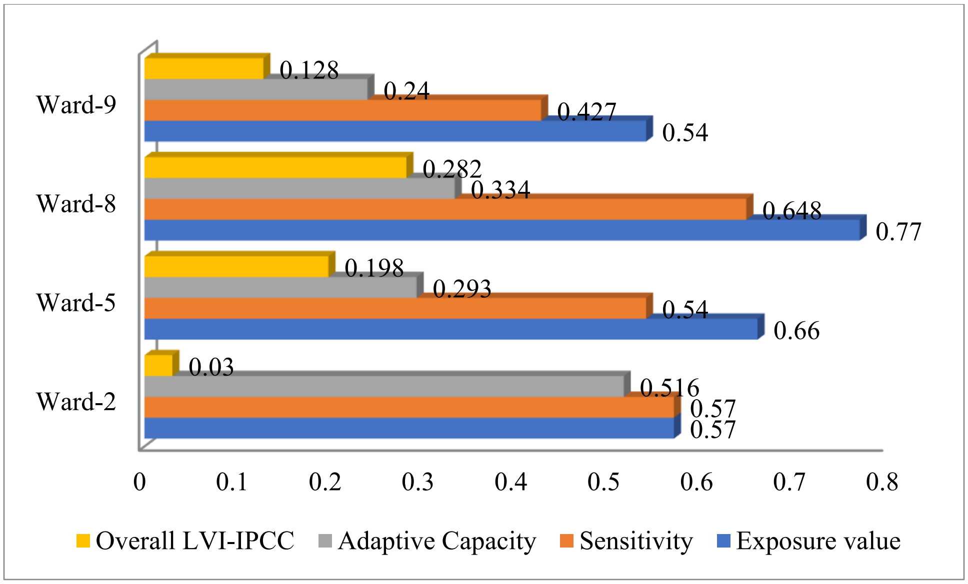

Figure 6. Values of exposure, sensitivity, adaptive capacity, and overall vulnerability value of the study areas.

4. Conclusion

The impacts of climate change are increasingly evident across sectors, affecting both rural and urban areas. This study assessed climate change vulnerability in informal settlements within Suklagandaki Municipality, Gandaki Province, Nepal. Findings indicate that Ward 8 (Maalebagar) exhibits the highest level of vulnerability, primarily due to the highest exposure and sensitivity, particularly in relation to food insecurity. In contrast, areas such as Shaakhar, Haledi, and Nursery in Ward 2 demonstrated the strongest adaptive capacities, making them the least vulnerable among the urban slum settlements studied. The overall assessment classifies the study area as moderately vulnerable, with average exposure, sensitivity, and adaptive capacity levels on a scale ranging from -1 to +1. Although current adaptive mechanisms can still respond to floods, landslides, and erratic climatic patterns, the municipality remains in the early stage of disaster preparedness. Core components such as hazard mapping, contingency planning, and dedicated funding mechanisms remain underdeveloped or inadequately implemented.

Understanding the interaction among exposure, sensitivity, and adaptive capacity offers valuable insights for identifying enabling factors—such as social networks, infrastructure, technology, and policy support—that can strengthen resilience. While national frameworks like MoFE's 2021 assessment exist, studies targeting informal urban slums remain limited. The findings of this study carry important implications for refining and operationalizing local adaptation strategies, including the Local Adaptation Plan of Action (LAPA) and the National Adaptation Program of Action (NAPA), both of which have historically underemphasized differentiated vulnerabilities and socio-political dynamics. This bottom-up, household-level assessment underscores the urgency of integrating informal urban communities into climate adaptation planning. It calls for expanded, locally grounded vulnerability assessments across municipalities, utilizing more nuanced indicators and methodologies. Extending such assessments to include cultural and rural contexts could enrich Nepal's climate policy landscape and support a transition from moderate to minimal vulnerability by strengthening adaptive capacity.

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