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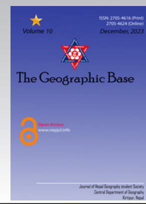

Topographical Characteristics, Human Interactions, and Resource Boundaries in Tila Watershed, Nepal

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Article info

Keywords:
adaptation, agriculture practices, human interaction, capability constraints, sustainable land use,

Received: 9th Sept. 2023

Accepted: 19th Oct. 2023

DOI: https://doi.org/10.3126/tgb.v10i01.71745

Abstract

The geo-ecological fragility of rugged mountain topography with limited infrastructure development, and land capability constraints limit agriculture-based livelihood options. The Tila Watershed of the Karnali region in Nepal with a high degree of fragility, marginality, and limited accessibility is no exception. A limited systematic analysis of dynamic interaction regarding land resources exists within the environmental (topography) and spatiotemporal (site distribution) contexts. This study explores the dynamic human-environment interaction regarding land capability, and land resource utilization in traditional society vis-à-vis topographic limitations. An exploratory and analytical framework is adopted for assessing natural and human interrelationships. The primary data source includes Key Informant Interviews (KIIs) and informal discussions with locals from the study watershed. The secondary sources are mostly existing maps and derived products besides literature reviews. Land use change between 2000-2010, 2010-2019, and 2000-2019 show that the watershed has come under moderate pressure on forest *and grassland while the built-up area has gradually increased. Among eight land cover classes, there is positive change (gain) in five classes and negative change in three classes. It is found that agriculture between 2000-2010 has shifted towards higher topographic and climatic constraints areas. Slope aspect and elevation are the determinants of diverse cropping patterns on two sides of the Tila River. There is a shift in agriculture patterns from more traditional subsistence farming towards commercial practice indicating adaptation to the agro-forestry-based agriculture system. Local policy and regulation play a vital role in promoting sustainable land use and agricultural practices. The study concludes that a dynamic adaptive approach based on proven traditional practices as evident in the Tila watershed and improvement and refinements in malpractices offers positive effects on both the environment and human life.*

Introduction

People depend on and modify the environment to adapt to natural resource-based livelihoods, particularly in rural mountain areas. The mountain resources are important to the subsistence and livelihoods of the local population. However, the geo-ecological fragility of rugged mountain topography with limited infrastructure development positions constrains land capability and limit agriculture-based livelihood options (Acharya and Kafle, 2009; FAO, 2019 p. 233). Limited agricultural land, forests, grasslands, and pastures are important land resources for people's livelihoods in mountain region. Due to variations in topographic and agro-climatic characteristics, land capability for agriculture practice is limited and mountain agriculture is very marginal. Besides, the difficult mountainous terrain also contributes to development and land management challenges. The Tila Watershed of the Karnali region in Nepal with a high degree of fragility, marginality, and limited accessibility is no exception. Still, it offers diversity and specific niche resources leading to specific adaptation mechanisms (Jodha, 2005). The limited physical accessibility has caused isolation and limited spatial interaction with other areas (Karnali Province Planning Commission, 2019). Besides, it is reported that around 40% of the population faces multidimensional poverty in the Karnali Region, the highest among all seven provinces.

The gradual natural processes and disturbances like landslides and erosion besides development-induced environmental changes exert pressure on the mountain resource and ecosystem making it one of the highly vulnerable regions with dominant marginalized populations (Adler et al., 2022). The human adaptation process to such geo-environmental characteristics is a complex interplay between local unique knowledge and resource management strategies. Local people have relied on traditional knowledge and farming practices and have been adjusting their socio-economic conditions with an understanding of natural resource dynamics within topographic and altitudinal limitations. The interaction between people and the natural and built environment has remained dynamic though the resultant rural mountain landscape appears less transformative as compared to lowland and urban landscapes.

The interaction between land resources and human activities for livelihood is dynamic. Such interactions in environmental and spatio-temporal contexts lead to changes in forest cover, livelihoods, and overall ecosystem services. This transition also represents environmental, economic, and socio-cultural changes and provides the trajectory for human adaptations and livelihood strategies in mountain watersheds. However, a limited systematic analysis of such dynamic interaction regarding land resources and human livelihood activities exists in the western mountain watersheds of Nepal. This study aims to explore the dynamic human-environment interaction regarding land capability, and land resource utilization in traditional society vis-à-vis topographic limitations in the Tila Watershed.

Conceptual Frame

Land can be classified into different classes based on its suitability for specific use under different management forms, referred to as land capability. The purpose of land capability classification is to provide a tool for the relevant combination of land use and conservation measures permitting intensive, sustainable, and most appropriate use of land without significant environmental degradation and long-term productivity (Yadav, 2023).

There is an intrinsic relationship between topography, land capability, and land use. Land capability ranks an area's ability to sustainably support a range of human activities and intensity of specific use (LRMP, 1986). Nepal's land capability is classified into eight classes ranging from Class I to Class VIII, with increased limitations and hazards, decreased adaptability, and decreased choice of use respectively (Figure 1). Capability classes are identified based on the degree of limitation regarding topography, climate, soil, and landforms (LRMP, 1986). Capability class I consists of lands with very few or no physical use limitations. The land under this class is suitable for a wide range of cropping, grazing, or forestry. Capability class II has few physical limitations and terracing or contouring is necessary to control soil erosion when used for diversified crops. Land capability class III has moderate limitations for cropping and requires careful consideration regarding the choice of crops and management practices and terracing is mandatory for sustainable use. Land under capability class IV is either too steep for terracing and cultivation (>30o slope) or a gentle slope but is unsuitable for agriculture. Similarly, class V has severe limitations that restrict its use for agriculture and forestry, and is prone to hazards like flooding on lower slopes. Classes VI and VII are fragile with extreme erosion hazard susceptibility and have limited regeneration potential. Elevation, slope, and slope aspects together with soil play a determinant role in conditioning agricultural practices in the mountainous region. Farmers in this region face diverse challenges to adapt to harsh climate and rugged topography for agricultural livelihoods with limited choices.

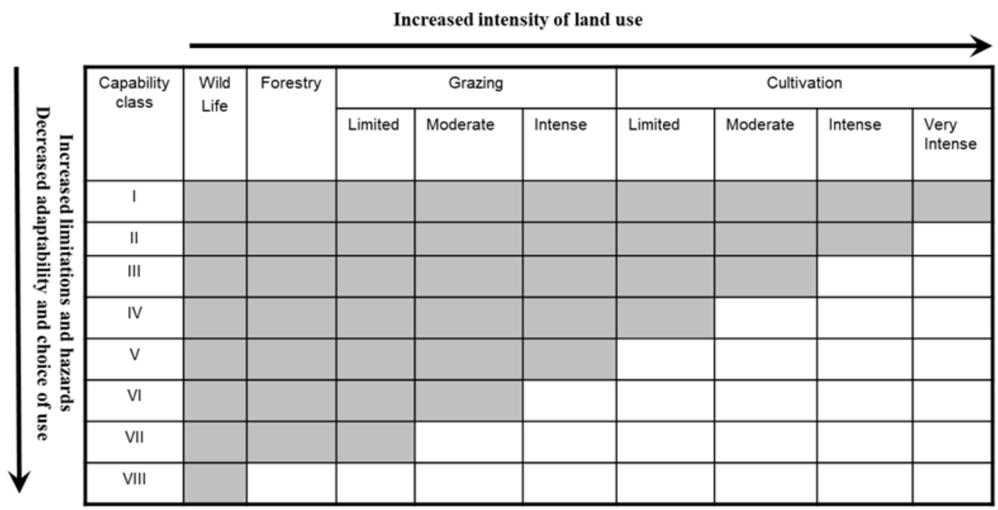

Figure 1: The relationship between land capability classification and intensity to specific land use (adopted from LRMP, 1986)

This section discusses the relationship between land capability, altitudinal variation, and existing agriculture practices to explore socio-cultural tradition-nature interrelations regarding agricultural practices in mountain regions. Based on the concepts outlined above and presented in Figure 1, the factors and determinants of agriculture practices in mountain regions are adopted. The present study is an integrated approach to exploring the interrelationship between land capability, altitudinal variation, and existing agriculture practices in the mountain watershed regions of Nepal.

Methods and Materials

Study Area

The Tila River watershed is selected as the study area which lies within the Karnali Basin of the north-western mountain region of Nepal and comprises 3322.87 km^2 (Figure 2). It covers the whole of Jumla district (eight municipal units) and the southeastern part of Kalikot district (four municipal units out of nine).

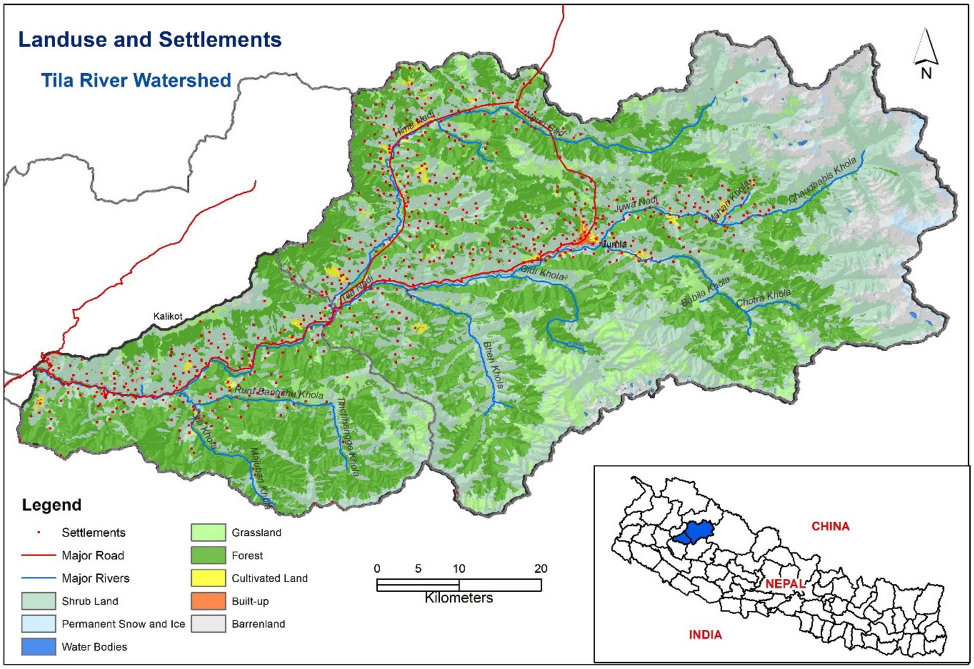

Figure 2: Location map of Tila Watershed

The biophysical and socio-cultural characteristics of the study watershed are presented in Table 1. Diversity in bio-physical and socio-demographic characteristics in the study area is visible from the table. The topographic complexities are evident in elevation, slope, and climate which largely determine the agriculture practices. Whereas the population growth rate of Jumla

Table 1: Selected Characteristics of the Study Watershed

Physical Characteristics		Socio-Cultural Characteristics	
*Area (Km^2)	3322.87	*No of local units (wards) (within Watershed)	Jumla: 8, Kalikot:4
$^{\$}$Elevation range (m)	749 – 6514 meter 49% area between 3000-4000m	**Population	Jumla: 119,377 (HH: 24,501), Kalikot: 144,917 (HH: 26,956)
***Climate	Sub-Tropical-Temperate - Alpine	**Population Density Person/Km^2	Jumla:47, Kalikot: 83
*Topography	Moderate to a steep slope, Slope area: 15-25^0 (26%), 25-30^0 (36%), >45^0 (27%)	**Literacy (5 years of age & above) and Education	The overall literacy rate is 76.1 (Nepal is 76.2 percent) The largest percentage (30.9%) have a primary-level education and 15.8 percent have higher levels of education (Above school level).
$^{\#}$Dominant Geology	Higher Himalayan Crystalline: Schist, quartzite, gneiss and migmatite	**Population growth rate (2021)	Jumla: 0.88, Kalikot: 0.54
$^{\$}$Dominant Land cover (%)	Forest (39), Shrub/Grass (31), Agriculture (14), Barren/rock (7), Snow/Glacier(4), and other (5)		
***Dominant Crop	Paddy (Red rice), Wheat, Barley, Millet, Potato, Beans, Apples, Medicinal herbs		

Source: **NSO, 2021; *Survey Department, Nepal, 1998; $^{\#}$Department of Mines and Geology, 1998; $^{\$}$ICIMOD, 2020; ***LRMP, 1986, and $^{\$}$USGS, 2024.

Data and Methods

This study has used an integrated methodology. An exploratory and analytical framework is adopted for assessing physical and human interrelationships. The primary data source includes five Key Informant Interviews and informal discussions with locals from the study watershed. The secondary sources are mostly existing maps and derived products besides literature reviews, and socio-economic and demographic data collected from different institutions including the population census 2021. Digital data sets like land cover land use maps of 2000, 2010, and 2019 were downloaded from the

Regional database system of ICIMOD and reclassified into seven classes, vegetation map was collected from the Department of Forestry Research and Survey. Settlements, roads, and river networks were derived from topographical sheets of the Survey Department. A 10-meter resolution Sentinel 2 (ESA data) land cover data of 2021 was derived from the USGS website for the existing land use overview. The geological map from the Department of Mines and Geology was also used. Similarly, the slope and slope aspect were derived from a 30-meter SRTM DEM from NASA.

Land cover land use change detection over three decades (from 2000 and 2019) was carried out using 30-meter resolution Landsat imagery-based land cover maps. Land cover classes were reclassified to adjust to the existing land use practices. It was carried out in the ArcGIS platform by overlaying landuse data layers. The change in the area of each land cover landuse class between two years was calculated and the rate of change was derived. Spatial analysis was carried out based on the output map and tables. The spatial overlay method was adopted to explore the interrelationship between land capability and topographic characteristics like slope, aspect, elevation, and land cover use. An informal gathering of seven local people from the Tila watershed was organized in Kathmandu to explore the information on traditional landscape classification systems and agriculture practices in the study area.

Results and Discussion

Land Cover Land Use Change

The dominant land cover (classification based on Sentinel-II imagery of 2021) in the study area is forest (40%) followed by grassland (31%). Agriculture land comprises around 15% of the total area while built-up coverage is less than one percent (1568 ha). Bare rock and soil cover around seven percent while snow and glaciers occupy around four percent of the watershed. Land use change between 2000-2010, 2010-2019, and 2000-2019 show that the watershed has come under moderate pressure on forest and grassland with area loss while the built-up area has gradually gained. The statistics show variable agricultural coverage with a gain between 2000 and 2010 but a loss in-between 2010 and 2019. The gain is from forest and grass while the loss is to the built-up classes. The overall area coverage in percent share for the years 2000 to 2019 is presented in Figure 3 where the gain of glacier and snow area and other land cover in recent decades is visible while water body and built-up coverage show limited coverage.

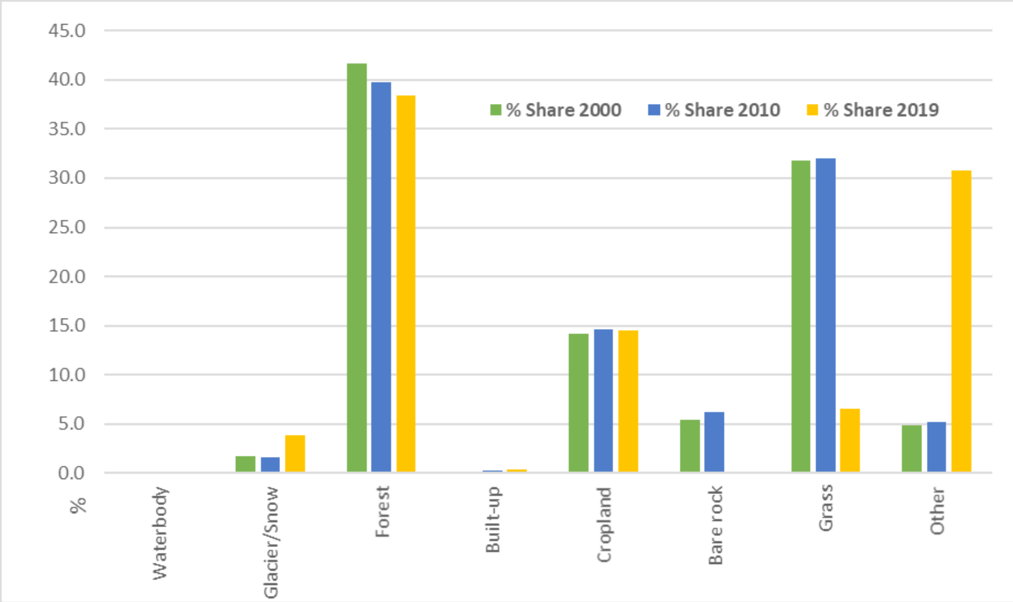

Figure 3: Land Cover Classes and Coverage between 2000-2019

The rate of change among different land cover classes is diverse in the study area (Table 2). Among eight land cover classes, there is positive change (gain) in five classes and negative change in three classes between 2000-2010. Within this decade, negative change (decrease in coverage) is found among water bodies, glaciers/snow, and forests. This elucidates the increasing pressure on the environment due to human interactions like increasing built-up and agriculture areas. Such negative rates of change characteristics of urban areas could be associated with the loss of ecosystem services resulting in a negative impact on humans and the environment (Wang, 2023). Ecosystem-based adaptation and mitigation are suggested measures for sustainability. Land-use changes generally led to a decline in ecosystem services (Schirpke et. al., 2023).

Table 2: Rate of Landuse Change between 2000 2010 and 2019

Landuse	2000-2010	2010-2019	2000-2019
Waterbody	-0.12	0.01	-0.11
Glacier/ Snow	-0.05	1.38	1.26
Forest	-0.04	-0.04	-0.08
Built-up	0.49	0.62	1.41
Cropland	0.03	-0.01	0.02
Bare rock	0.14	0.05	0.20
Grass	0.01	-0.04	-0.03
Other	0.05	0.04	0.09

Source: Calculated using Land Cover Data 2000-2019, ICIMOD 2023,

Spatial relationship between land capability and agriculture practice

Tila watershed comprises all seven types of land capability classes identified for Nepal. However, the majority of the area (33.6%) falls under class VI followed by class IV (30%). Under class IV the topography is too steep for agriculture practice and requires mandatory terracing and appropriate management practices but suitable for forestry. Similarly, class VI has severe limitations that restrict its use for agriculture and forestry, and is prone to hazards like flooding on flatter and lower slopes. Classes VI is fragile with extreme erosion hazard susceptibility. In the study watershed around three percent (2.6%) of the agricultural area is under class IV and 62 percent of the agricultural area is under capability class III. This class is suitable for agriculture and requires mandatory terracing to control soil erosion. Agroforestry is suggested suitable practice within this class zone. The agriculture area under classes I and II comprises 17 percent of the total watershed area which are the most suitable classes for agriculture practice with the least limitations.

Land capability classes indicate constraints and deficiencies to different land uses. In the Tila watershed, nearly 34% of the total area is under high topography and climate constraints (Figure 4) with very severe limitations to rough grazing, forestry, and recreation. Moderately suitable land for agriculture with mandatory terracing comprises 30% of the total area. On the other hand, less than one percent of land is comprised of no constraint for any type of use and is highly suitable for agriculture.

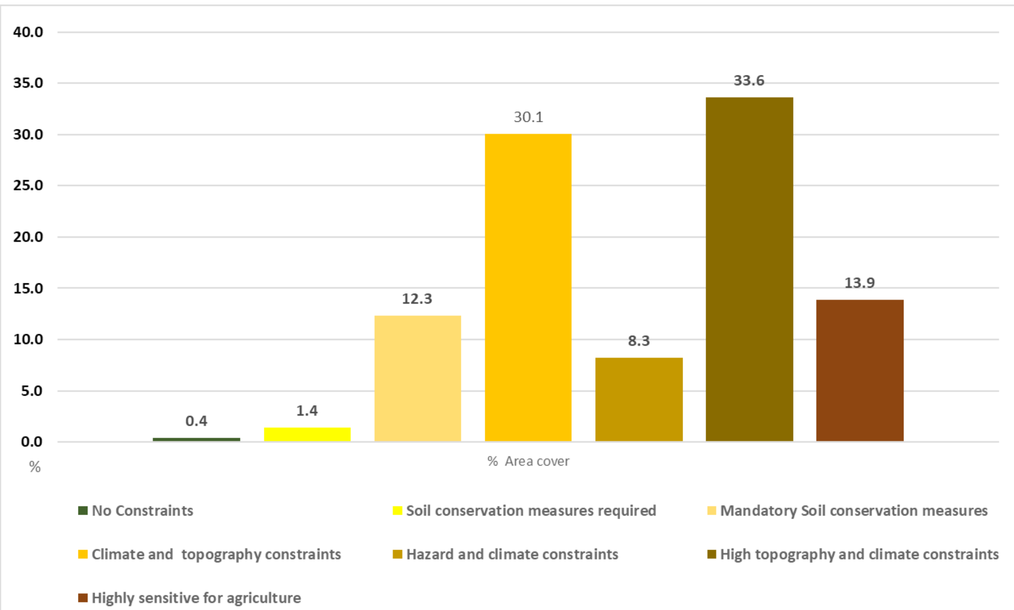

Figure 4: Percent Share of Land Capability Constraints to Land Use

As far as spatial distribution capability constraints and agricultural land between 2000 and 2010 are concerned, it is found that agriculture has shifted towards higher topographic and climatic constraint classes, i.e. IV, V, and VI (Table 3). A similar pattern is found between 2010 and 2019. This indicates the stress of potential soil erosion and degradation on sloping terrain with severe limitations that restrict its use for agriculture and forestry. However, there is a slight increase in agricultural land under the no-constraints class (0.03%). and under moderately suitable class (0.24).

Table 3: Agriculture Land by Land Capability Class

	Percent coverage			Percent change		
Capability class	2000	2010	2019	2000-2010	2010-2019	Constraints
I	1.4	1.3	1.4	-0.02	0.03	No Constraints
II	6.1	6.0	6.0	-0.05	-0.03	Soil conservation measures required
III	44.1	44.0	43.8	-0.17	-0.20	Mandatory Soil conservation measures
IV	42.3	42.5	42.7	0.21	0.24	Climate and topography constraints
V	0.04	0.03	0.03	-0.003	0.002	Hazard and climate constraints
VI	6.2	6.2	6.1	0.02	-0.04	High topography and climate constraints

Source: LRMP 1986 and Land Cover Data 2000-2019, ICIMOD 2023

Spatial relationship between Agriculture and Topographic Characteristics

Major topographic characteristics that determine agricultural practices are elevation zones, slope, slope aspect, and climatic/vegetation zones. This section explores the relationship between these four environmental factors and agricultural land distribution in the Tila watershed.

Agriculture Land and Elevation

The elevation of the Tila watershed ranges from 749 meters in the south-western part to 6514 meters in the northern part. Nearly 50% of the total watershed area (49.5) falls under a 3000-4000 meter elevation zone. Likewise, most of the agricultural land is located within a 2500-3000-meter elevation zone and has remained stable over two decades (Table 4). Similarly, more than 30% of the agricultural land is within a 3000-3500-meter elevation zone. When the ratio of agriculture land to elevation zone 2500-3000m is considered, agriculture land increased by a ratio of 0.014 between 2000 and 2010 whereas it decreased by 0.006 between 2010 and 2019.

Table 4: Distribution of Agriculture Land Within 2500-3000m

Year	Total agriculture area (Ha)	Agriculture area within 2500-3000m elevation range(majority)	% within 2500-3000m elevation	Ratio of agriculture area to elevation 2500-3000m area
2000	54138.78	23871.24	44.1	0.338
2010	55998.09	24908.85	44.5	0.352
2019	55446.93	24438.24	44.1	0.346

Source: Land cover data 2000-2019, ICIMOD 2023 and USGS 2023

Agriculture Land and Slope

When spatial distribution of agricultural land regarding slope is concerned, 35% of the total agricultural land is located within a 15 to 25-degree slope (Table 5), which is considered moderately suitable for agricultural practices requiring soil conservation measures. However, the positive percent change value of agriculture area between 2000-2010 and 2010-2019 indicates that agriculture practices are shifting towards higher slopes, which makes it more vulnerable to potential hazards indicating unsustainable farming. A study carried out in Nepal (Chalise, 2019) also states the shift toward higher slopes due to population pressure and subsistence rural farming.

Table 5: Agriculture Land by Slope

	% Area Coverage			Change	
Slope (degree)	2000	2010	2019	2000-2010	2010-2019
<=15	19.9	19.3	19.1	-0.57	-0.23
15-25	35.2	35.2	34.9	-0.01	-0.23
25-35	32.0	32.4	32.5	0.40	0.10
35-45	10.7	10.8	11.1	0.14	0.23
>45	2.2	2.2	2.4	0.04	0.12

Source: Land Cover Data 2000-2019, ICIMOD 2023 and USGS 2023

Agriculture land and slope-aspect

The slope aspect is one of the dominant factors in determining agriculture practice in mountainous terrain. In Nepal, the southern mountain slopes are the most intensely cultivated area (Shrestha, 1992; Aase et. al., 2010). Invariably, nearly 60% of agricultural land in the Tila watershed is located in the south, southeast, and southwest aspects of which 21% consists of the southern aspect. (Figure 5). It is followed by eastern and western slope aspects comprising another 25% of the total agricultural land.

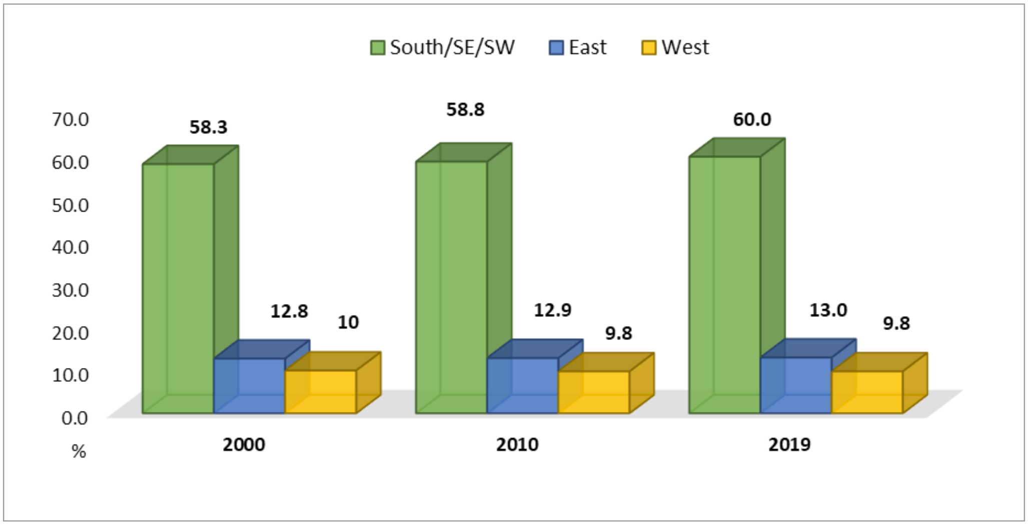

Figure 5: Agriculture land by slope aspect

Agriculture land and climate/vegetation

Five types of climate zones are found in the Tila watershed (TISC, 2002). The Sub-tropical climate is found in the southern and southwestern part which comprises around eight percent of the total watershed area. The Temperate climate is the dominant type comprising 84% of the total watershed area. Sub-alpine climate covers around eight percent area and the Alpine and Nival (Tundra) climate zone is confined to the northern and northeastern parts comprising less than one percent. Agriculture practice in the watershed is dominant within Sub-tropical, Temperate, and Sub-alpine climate zones. The spatial distribution of topographic characteristics in the Tila watershed is presented in Figure 6.

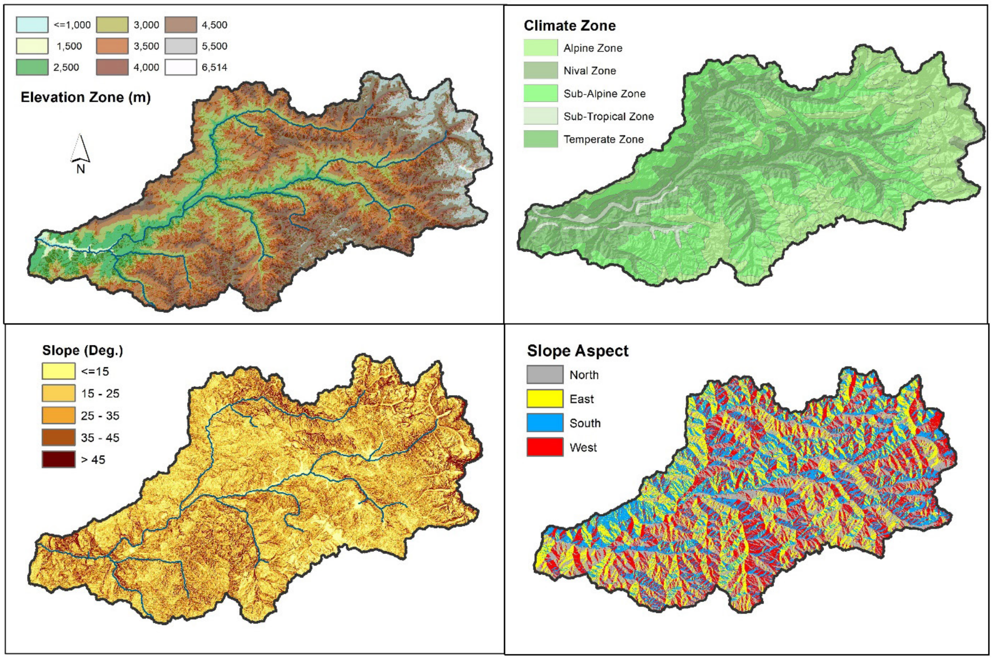

Figure 6: Topographic characteristics of the Tila watershed

Resource Interaction Dynamics

The common agriculture practice in the middle mountain region of Nepal is different crop combinations in different elevation zones and slope aspects adhering to different climatic zones. Similarly, there are two major types of farmland based on water and irrigation availability. Khetland is agricultural land with irrigation facilities or having enough water over a year while Bariland is rain-fed without irrigation infrastructure. These two types of terrace farming have unique agricultural and geomorphic characteristics The most common cropping pattern in the *Khetland* within a 1500-meter elevation zone is rice-wheat-fallow or rice-wheat-maize. The most common cropping pattern of *Bariland* is maize-fingermillet-barley or maize-fingermillet-fellow. Potato is a common crop in both types of farmland as a main or alternative to staple crops. In the upper elevation zone, rice is less common and maize, wheat barley, and millet are major staple crops. Farmers in the Tila watershed also follow similar cropping patterns but the agriculture practice is dominant around 2500 to 3000-meter elevation zone. A unique characteristic of this watershed is that the southern and northern sides of Tila River divide the cropping and vegetation pattern in the watershed. On the northern slopes of the southern side of the river, at the lower elevation (up to 2500 meters locally known as *Syala*) staple crops like rice, wheat, and potato have been dominant since 2000 whereas few apple plantations were there in the 3000-3500 meter range. However, with the construction of a strategic road network after 2012, horticulture like apple, walnut, and pear plantations has become more common. In contrast, on the southern slope of the north side of the river, at the lower elevation of 2000-2500 (Locally known as *Pada*), horticulture plantations are becoming more common. Staple crop farming on this side is relatively less after the construction of motor roads. Similarly, cultivation and/or collection of high-value crops like mushrooms and medicinal herbs at higher elevations 3000-3500-metr elevation is also becoming common in current times. Horticulture like apple and walnut plantations in both *Khetland* (as referred to in land capability classification) which is locally known as *Khetbari* and *Bariland,* locally known as *Gharbari* and *Pakhobari* has been increasing since 2012. This shift in agriculture pattern from more traditional subsistence farming towards commercial practice indicates adaptation to the agro-forestry-based agriculture system which is environmentally sustainable, and economically beneficial to farmers. Besides, the increasing use of chemical fertilizers for commercial benefit is another major concern raised by some Key informants and locals of the watershed. A study carried out in Manang, one of the mountainous districts of Nepal also revealed that the slope aspect plays a vital role in agricultural production for instance, the northern slope is too cold and in general, a rain shadow area poses limitations to agriculture (Aase et. al, 2010). The non-linear and elevation-dependent agriculture practices and ecosystem services are also discussed in recent research (Xu et. al., 2022). Several studies show that steep slope farming and shifting cultivation besides deforestation and open/overgrazing are major causes of degrading agricultural land in the mountain region of Nepal (Acharya and Kafle, 2009; Chalise et. al., 2019). Increasing soil erosion (i.e. another form of land degradation) on the mountain slope due to agriculture in marginal slope areas is also noted in another study (Joshi et. al., 2023). Landuse planning and zoning, integrated watershed management, a sustainable land management approach, and conservation agriculture are some major policies and strategies endorsed by the Government to minimize land degradation in Nepal (Chalise et. al., 2019; MoLRM, 2015).

The increasing built-up in agricultural land, increasing rate of soil erosion, and landslide occurrences are major effects of road construction. In a study carried out on the vulnerability assessment of watersheds, in the middle and high mountain regions of Nepal, Lower Tila (rank 8), and Daine Khola (rank 9) sub-watersheds of Tila watershed are ranked most vulnerable among 135 watersheds (Siddiqui, et. al., 2012). Whereas Upper Tila (rank 24), Ruru (rank 25), and

Chaudhabis (rank 26) sub-watersheds are ranked moderately vulnerable (Siddiqui et al., 2012). Hence, the shifting agricultural practices from traditional (Cereal crop farming with two crops/year or one crop/ winter fellow) to modern (multiple cropping, high-value crops like mushroom and asparagus, horticulture, and agro-forestry) requires careful management and adaptation strategies. The intricate interlinkages between bio-physical and socio-cultural in mountain regions have always been neglected on the policy front resulting in ineffective development interventions both at the public and private facade (Bhatta et. al., 2019). Local policy and regulation are vital in promoting sustainable land use and agricultural practices.

Conclusion

There is a reciprocal relationship between the environment and human interactions. Maintaining the balance amidst the reciprocal relationship between the physical environment and human interaction is essential for the sustainability of human-nature coexistence and coherence. The balance between modern agricultural practices, land degradation, and restoration and conservation practices is an immediate call for sustainable land use. Agroforestry and environmentally friendly cropping practices such as rotation of rice and millet crops within a one to five-year period for reducing soil erosion, and horticulture in higher elevation steep slopes are promising sustainable practices in the study watershed. A dynamic adaptive approach based on proven traditional practices as evident in Tila watershed and improvement and refinements in malpractices offers positive effects on both environment and human life. Therefore, there is a challenge to continue and manage agriculture in complex mountain environment but by preserving good cultural practices to reduce and avoid malpractices contributes to sustainable environment management.

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