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Nepal: Building Climate Resilience of Watersheds in Mountain Eco-Regions –

Climate Change and Vulnerability Mapping in Watersheds in Middle and High Mountains of Nepal

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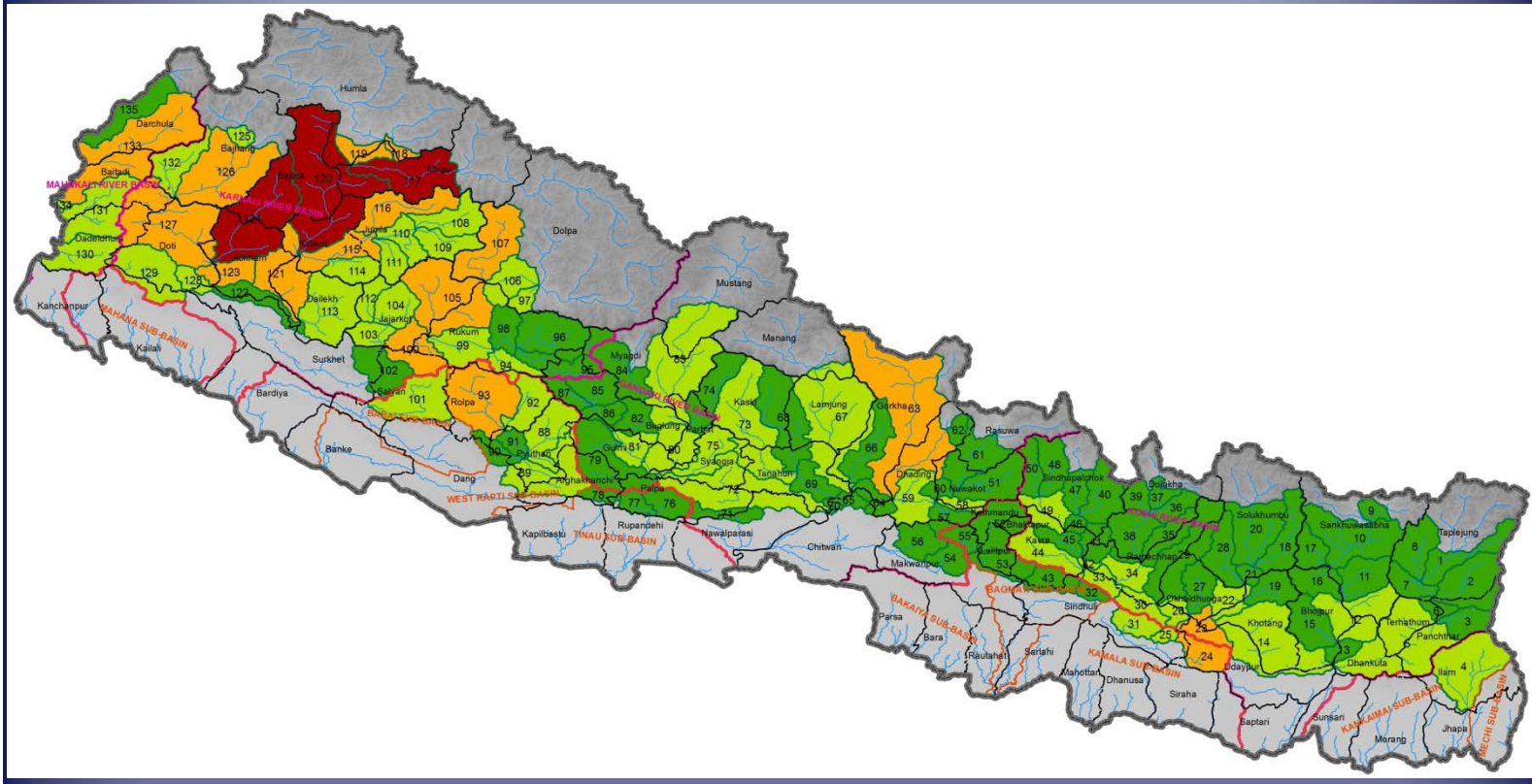

Climate Change and Vulnerability Mapping in Watersheds in Middle and High Mountains of Nepal

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Cover Illustration

Front Cover: Combined multiple-vulnerability map of watersheds in Middle and High Mountain regions of Nepal.

Executive Summary

The Himalayan region is considered to be very sensitive to climate change due to the high variation in altitudes. Changes in cloud cover and rainfall, particularly over land; melting of ice caps and glaciers and reduced snow cover are some of the prominent threats due to rise in temperature. The significant effect of climatic variability in major rivers and their tributaries has already been observed. As a result, rivers and tributaries, catchments, and watersheds are at risk from increased flooding, landslides, soil erosion, drought and more intense rain during the monsoon.

Using watersheds as organizing units for planning and implementation of natural resources management is an approach being followed worldwide because large regions can be divided along topographic lines that transcend administrative boundaries and the status and trends analysis can be done on the basis of entire natural systems in concert with social conditions. The communities within the watersheds can also better track and understand the impacts of their management activities on the larger system.

The main objective of this study was to identify and prioritize subbasins/watersheds in the Middle and High Mountains of Nepal that are significantly vulnerable to Climate Change (CC). The approach of the vulnerability assessment framework of the United Nation's Intergovernmental Panel on Climate Change (IPCC) was the guide for this study. The data integration and aggregation approach, by constructing indices, was adopted to integrate different types of indicators representing the dimensions of sensitivity, exposure and adaptive capabilities of climate change and vulnerability. The National Adaptation Program of Action (NAPA) is a strategic tool and framework used to respond to climate change adaptation issues in Nepal and was mandated to assess the climatic variability and impacts throughout the country. This study has used the NAPA assessment as a starting point but has added several biophysical and socioeconomic criteria, which were seen as relevant at the watershed level. Therefore, although it has been built upon the NAPA assessment, it is more comprehensive and at a higher spatial resolution, which is geared towards management interventions at the watershed level.

The spatial and socioeconomic data sets used for this study were collected and compiled from the government institutions, I/NGOs including the UN agencies and private organizations. The climate data (rainfall and temperature data for four seasons) used in this study were provided by the Asian Disaster Preparedness Centre. Further analyses were performed to construct the human and ecology sensitivity, climate risk/exposure and adaptive capability index, and on the basis of this information, combined maps of corresponding parameters were produced. Lastly, a combined vulnerability assessment was done and a map was produced with watersheds ranked according to their vulnerability.

This study indicates that the Karnali River Basin and its watersheds are most vulnerable, followed by watersheds in the Koshi River Basin. The watersheds under East Rapti and Tinau river basins are the least vulnerable.

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Chapter 1

Context of Climate Change and Vulnerability Mapping in Nepal

1.1. Introduction

The frequency, duration and intensity of extreme events such as floods, droughts, heavy rains, hurricanes and typhoons are expected to increase due to global warming. Emission of large quantities of greenhouse gases into the Earth's atmosphere as a result of rising fossil fuel burning, land use change and deforestation is the main causes of global warming. Increase of heat in the atmosphere over time has led to the greenhouse effect, resulting in climate change. Rise in average global temperature; changes in cloud cover and rainfall, particularly over land; melting of ice caps and glaciers and reduced snow cover; and increase in ocean temperatures and ocean acidity – due to seawater absorbing heat and carbon dioxide from the atmosphere - are the main characteristics of climate change (UNFCCC 2007). There are vulnerable regions and populations throughout the globe, with some regions being specifically vulnerable to climate change. People who live in arid or semiarid regions, in low-lying coastal areas, in water-limited or flood-prone areas, or on small islands are particularly most vulnerable to climate change (Watson et al. 1996 cited in Olmos 2001).

It is realized that climate change has an effect on water resources, agricultural production systems, forestry, fisheries, human settlements and health in many parts of the world. Developing countries are more vulnerable to climate change because they have lesser capacity to adapt and have other stresses (IPCC 2001). The South Asian region faces alarming environmental and socioeconomic challenges in its effort to protect valuable natural resources. Furthermore, the uncertainty and risks associated with climate change are likely to exacerbate these challenges. Diarrhoea and malnutrition attributable to the global burden of climate change were already highest in Southeast Asian countries including Bangladesh, Bhutan, India, Maldives, Myanmar and Nepal in 2000 (UNFCCC 2007). Throughout Asia one billion people could face water shortage leading to drought and land degradation by the 2050s (Christensen et al. 2007; Cruz et al. 2007). Hence, an overwhelming body of scientific evidence now clearly indicates that climate change is a serious and urgent issue (Stern 2007). The IPCC (2007) concludes that the warming of the climate system is unequivocal. IPCC Special Report on Emission Scenarios (SRES) 2000 predicts an average global warming of about 0.2°C per decade for the next two decades for a range of emission scenarios (MoE 2010).

In this context, the issue of climate change and its impacts in Nepal is a serious concern for policymakers. An independent and highly commended risk analysis organization, Maplecroft, ranked Nepal as the fourth most vulnerable country in the world based on 2010 vulnerability assessment and mapping of climate change vulnerable countries. As Nepal is highly vulnerable to the adverse impacts of climate change, adaptation to climate change must be the priority for the country to help poor communities to cope with, and adapt to, the impacts of climate change (Practical Action Nepal 2009). The Himalayan catchments of Nepal including watersheds in mountain regions are considered more vulnerable to risk of flooding, erosion, mudslides and glacial lake outburst floods because the melting snow coincides with the summer monsoon season and any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters. At the other extreme, water scarcity and droughts pose a similar threat to livelihood systems.

Nepal had prepared its National Adaptation Programme of Action (NAPA) in accordance with decision 29/CP7 of the UNFCCC. NAPA was the first comprehensive strategic tool developed to respond to climate change adaptation issues and was mandated to assess climatic variability and impacts throughout the country. The NAPA of Nepal had explored ample opportunities to mainstream climate change into the national development agenda and maximize the opportunities posed by climate change. The NAPA study and the subsequent report titled 'Climate Change Vulnerability Mapping for Nepal' gives a good general overview of the country (MoE 2010).The present study therefore, has built upon the assessments done

through NAPA but has explored and analyzed additional physical and socioeconomic indicators which are relevant to sensitivity, exposure/risk and adaptive capability at the watershed level.

1.2. Objective and scope of study

The objective of this study is to assess climate change vulnerability at the watershed level and map the severity and extent of vulnerability in order to identify and prioritize the vulnerable watersheds in Middle and High Mountain regions of Nepal. The specific objectives of the study are outlined as below:

- To develop criteria for the assessment of the severity of climate change impacts based on future climate projections.
- To develop multiple criteria and indicators for assessing vulnerability of climate change and rank the watersheds based on the derived composite vulnerability index.
- To prepare GIS-based vulnerability maps based on the aforementioned objectives at the watershed level

Climate change vulnerability is highly contextual and scale-dependent and it reflects variations of socioeconomic, physical and institutional infrastructure, access to natural resources and technology (WERF 2009). The vulnerability assessment and mapping for this study were done based on the IPCC's vulnerability framework (Third/Fourth Assessment Report) taking account of the degree of exposure of a system, its sensitivity and its adaptive capacity to climate change (Yusuf and Francisco 2009).

Under the IPCC vulnerability framework, the scope of work for the aforementioned objectives is designed as follows:

- Assessment of exposure, i.e., the nature and degree to which a system is exposed to significant climatic variations.
- Assessment of sensitivity of the system to climate change, considering population and ecological factors. Sensitivity is defined as the degree to which a system is affected, either adversely or beneficially by climate-related stimuli.
- Assessment of adaptive capacity to the climate change, which is defined as the ability of a system to adjust to climate change (including variability and extremes).
- Development of a composite vulnerability index based on expert workshop/judgment for evaluation of exposure, sensitivity and adaptive capacity.
- Assessment, evaluation, GIS-based mapping and ranking of watersheds based on the developed composite vulnerability index.
- Development of climate change vulnerability map of the watersheds in the middle and high-mountain regions of Nepal.

1.3. Rationale

Among the five physiographic regions of Nepal, the mountain regions is the most vulnerable, because warming trends are growing and the impacts are magnified by the extreme changes due to variation in altitude. The most critical impacts of climate change could be experienced on hydrological systems and water resources. Using watersheds as organizing units for planning and implementation of natural resources management is an approach that is being followed worldwide because large regions can be divided along topographic lines that transcend administrative boundaries, and the status and trends analysis can be done on the basis of entire natural systems in concert with social conditions. The communities within the watersheds can also better track and understand the impacts of their management activities on the larger system. In order to plan/implement adaptation programs, the knowledge and understanding about various risk/exposure factors including climatic variability, ecological hazards and drought or flood risk at watershed level are crucial from the perspectives of livelihoods and the degree of vulnerability.

Development of appropriate methods and generation of relevant data are equally important to reduce the uncertainty in the assessment of climate change and vulnerability at disaggregated spatial units, such as at

watershed units. This includes formulation of diverse spatial and nonspatial indicators/parameters that quantify or are proxies to exposure, sensitivity and adaptive capacities. Furthermore, the indices are required to be normalized and standardized by adopting aggregation approaches to include comprehensive information.

Under this study, vulnerability to climate change has been assessed based on secondary data produced by various government and nongovernmental organizations such as the earlier NAPA project and climate change models/data such as "Data Digitization and Downscaling of Climate Change Projections in Nepal" studies developed by the Asian Disaster Preparedness Center (ADPC). This information is expected to be useful to the Department of Soil Conservation and Watershed Management (DSCWM) for the Project Preparatory Technical Assistance (PPTA) for Building Climate Resilience of Watersheds in Mountain Ecoregions project. The project will support the implementation of the Strategic Program for Climate Resilience (SPCR) which has recently been developed by the Government of Nepal in partnership with ADB, International Finance Corporation (IFC) and the World Bank and was endorsed by the Pilot Program for Climate Resilience (PPCR) subcommittee of the Climate Investment Funds (CIF) on 28 June 2011.

1.4. Description of the study area

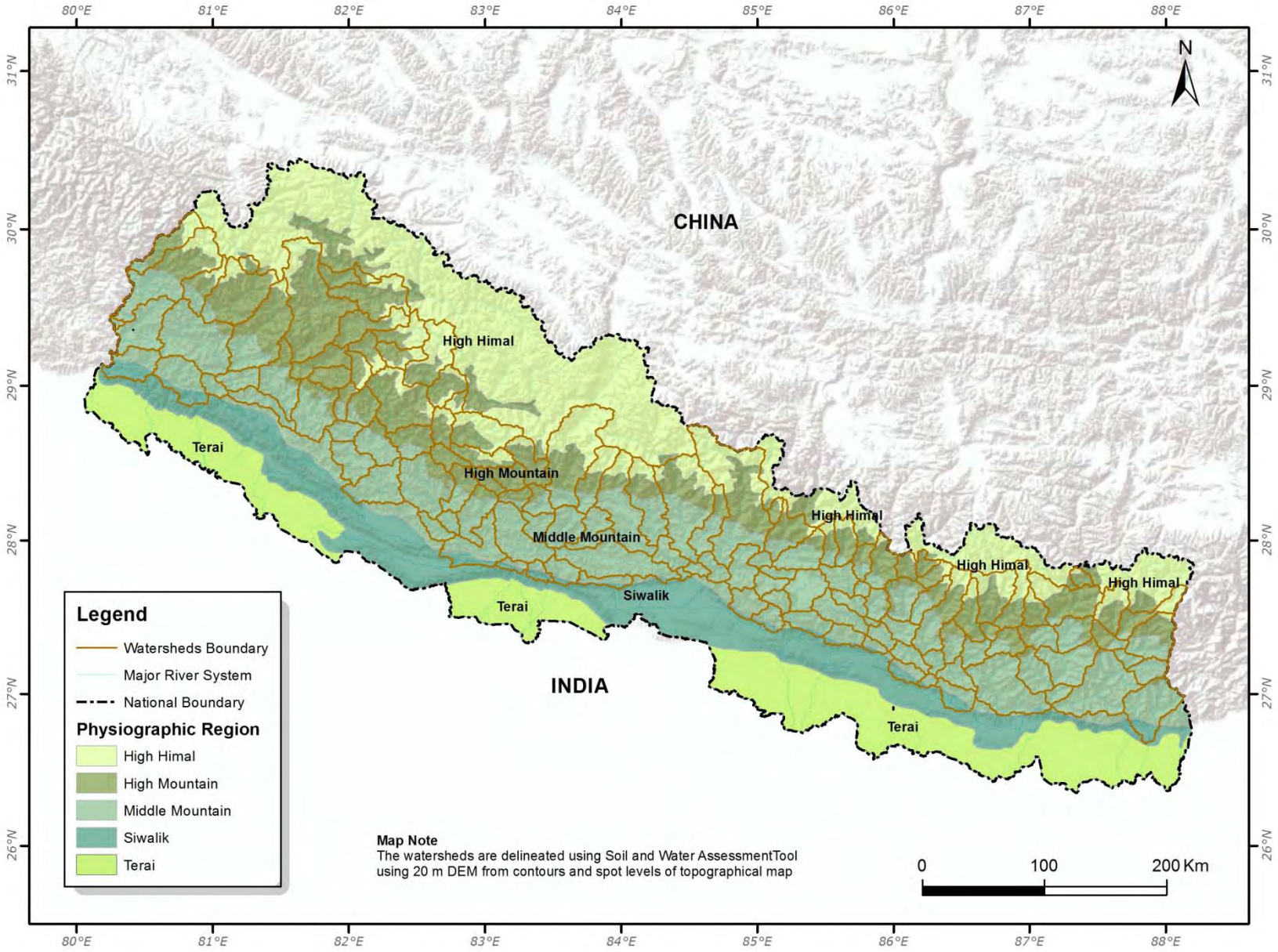
Nepal is located in the central part of the Himalayas and lies between the two giant countries, India and China. It occupies a total land mass area of 147,181 sq. km. The country is located between 26° 22' north and 30° 27' north latitudes and 80° 04'east and 88° 12' east longitudes with the elevation ranging from 60 m MSL in the South to 8,848 m MSL in the North. Nepal is divided into five major physiographic regions, i.e., Terai, Siwalik (the Churia Range), Middle Mountains (the Mahabharat Range), High Mountains and High Himalaya. Globally, Nepal falls within the subtropical climate zone. However, climatic characteristics range from subtropical to arctic in the High Himalaya due to ecological diversity within a lateral span of less than 200 km (LRMP 1986).

The study area under this project is located in both the Middle Mountains (the Mahabharata Range) and High Mountains regions of Nepal (Map 1). The elevation of Middle Mountains ranges from 1,000 to 2,500 m AMSL, while that of the High Mountain regions ranges from 2,200 to 4,000 m AMSL and is located further north of the Middle Mountains. Both regions, Middle Mountains and High Mountains are stretched longitudinally from East to West. The Middle Mountains intersect the Koshi, the Gandaki, the Karnali and the Mahakali rivers.

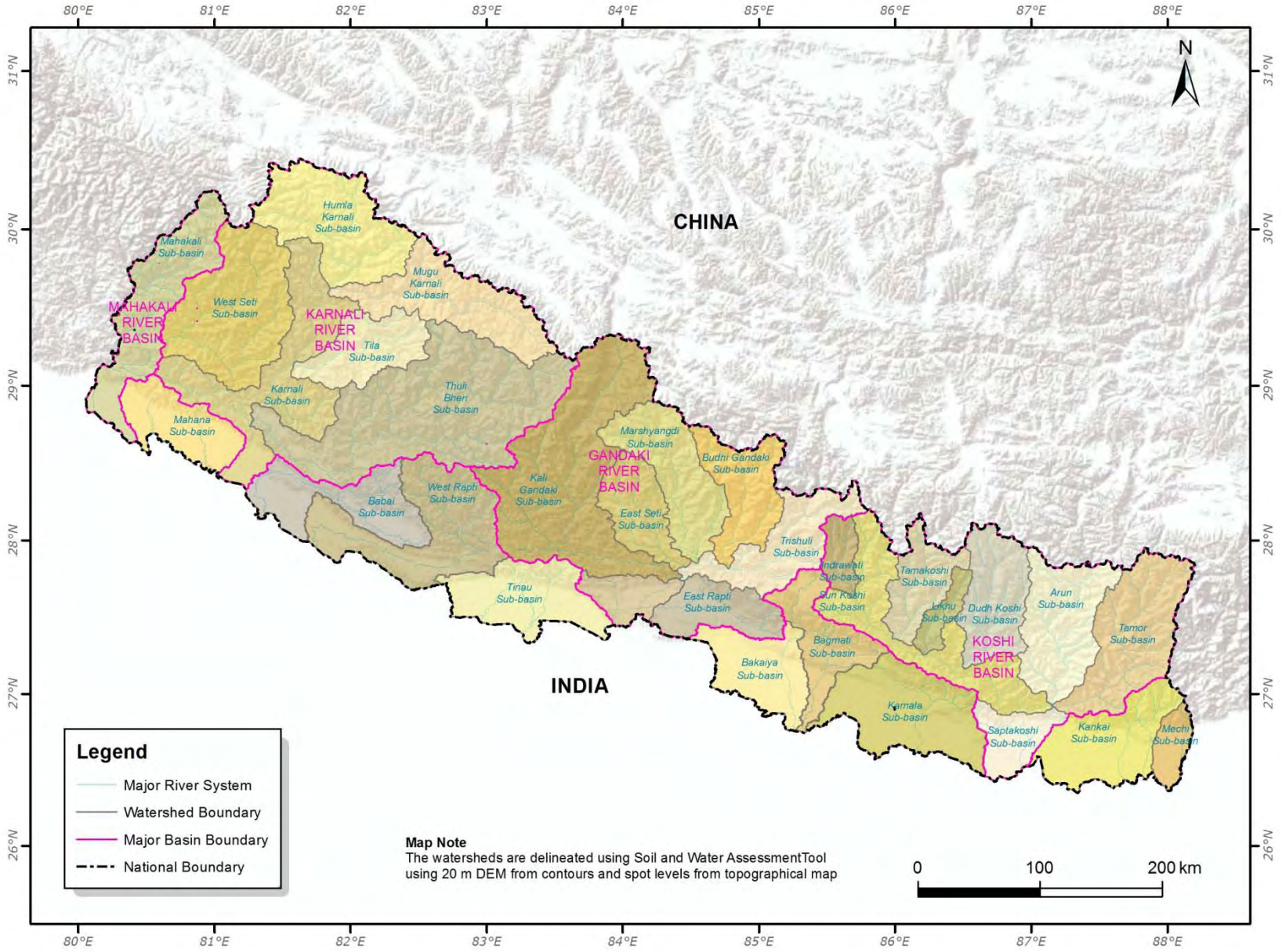
The study area has been divided into 135 watersheds (Map 1). The total area of watersheds is summed at 81,484.20 sq. km and the average size of watersheds is 603.58 sq. km. These watersheds are distributed within the following major river basins, i.e., Kankai, Koshi, Kamala, Bagmati, East Rapti, Gandaki, Tinau, West Rapti, Babai, Karnali, and Mahakali, etc. The watersheds and physiographic regions covering the study area are presented in Maps 1, 2, and 3.

1.1. Limitation of the Study

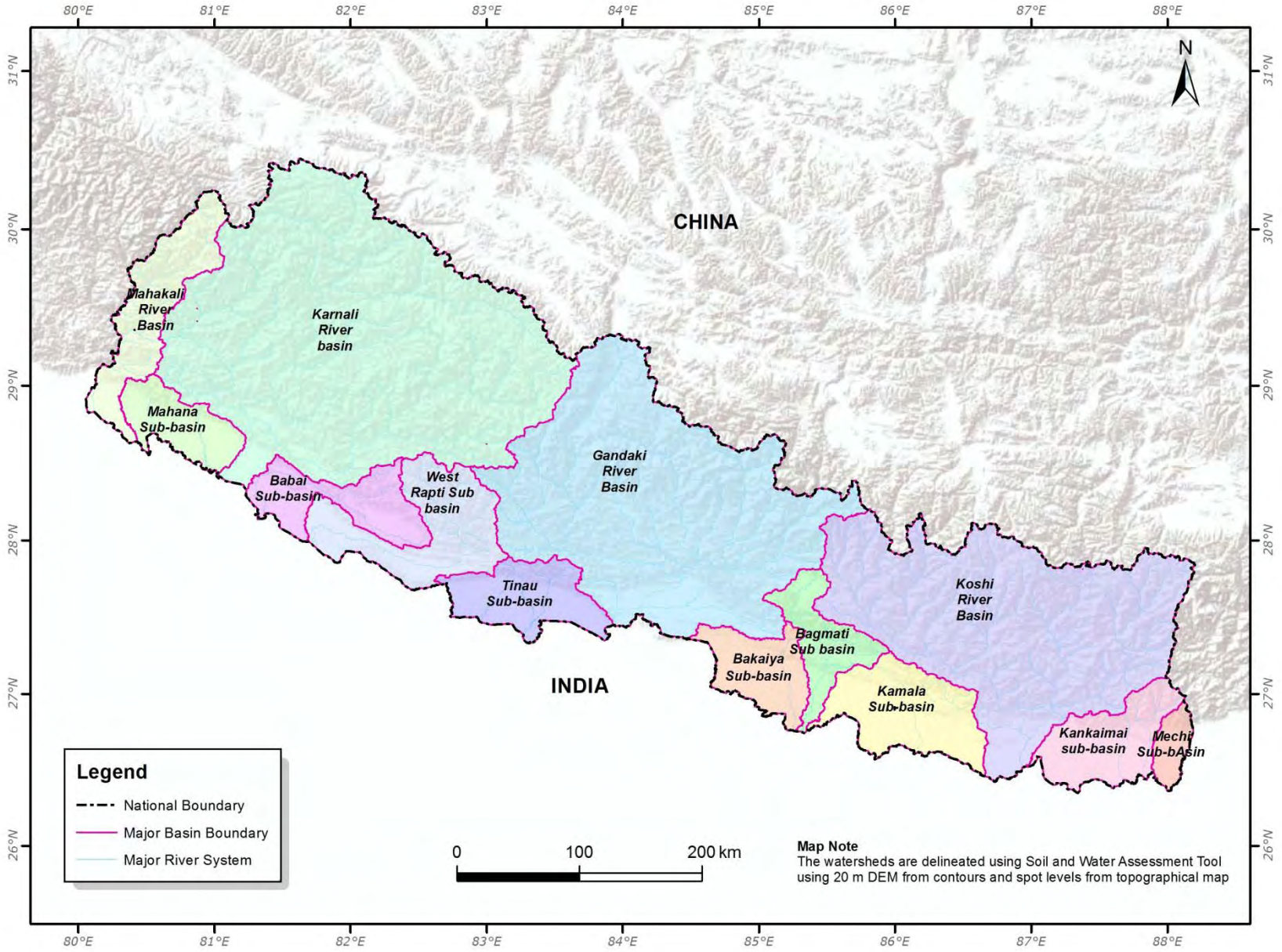
Both spatial and socioeconomic data sets were gathered from secondary sources. Spatial data sets used for this study were produced/updated from the Topographic Map published in 2001 (LRMP 1986) and Soil and Terrain Database of Nepal. Unavailability of relevant data including socioeconomic data for infrastructure, population, human poverty, consumers using electricity, irrigated land and existence of interventions at watershed levels is also a constraint. Available secondary data have been aggregated or projected at the watershed unit level and hence under-/over-projection may have occurred to some extent. Gridded data with a grid size of 12-20 km was used for climate information. Therefore, local climate variations are probably not represented. The short time allocation for the project was also another major constraint.



Map 1. Watersheds in the study area covering the Middle and High Mountain regions of Nepal.



Map 2. Major Sub-basins of Nepal.



Map 3. Major river basins in Nepal

Chapter 2

Methodology and Data Development

2.1. Conceptual Framework of Climate Change Vulnerability

The climate change vulnerability mapping is an imperative approach that enables the representation of a local context within vulnerability assessment while vulnerability assessment is a common tool for indicating the potential for harm to occur within human and ecological systems in response to global climate change (Benjamin et al. 2011). Vulnerability can be viewed from the perspective of the physical, spatial or locational, and socioeconomic characteristics of a region. Physical vulnerability can be referred to as a set of physical conditions or phenomena, such as geology, topography, climate, land use and land cover, and so forth, which renders a place and the people living there susceptible to disaster (Khanal et al. 2007). According to IPCC, the word vulnerability is defined as "the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2001, p.995). Vulnerability is thus defined as a function of exposure, sensitivity, and adaptive capacity as:

$$Vulnerability = f(exposure, sensitivity, adaptive\ capacity) \ldots\ldots\ldots \text{(Eq. 1)}$$

IPCC has defined exposure as "the nature and degree to which a system is exposed to significant climatic variations"; sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli"; and adaptive capacity is defined as "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences".

2.2. Methodological Framework for Climate Change Vulnerability Assessment and Mapping

The following methodological steps have been followed for the current study of "Climate Change Vulnerability Assessment and Mapping". These steps have been briefly described and schematically presented in a flow diagram as shown in Figure 1.

- Creation of Spatial Data: Topographical spatial data sets such as river system, land cover; administrative boundaries have been created from the existing 1:25,000/1:50,000 scale topographical GIS data sets from the Survey Department. Transportation network data set is used from topographical maps and data from the Department of Roads. These data sets have been merged, cleaned up and attribute data added to generate a seamless topographical database covering the study watersheds.
- Creation of Digital Elevation Model (DEM): Hydrologically corrected DEM and 20 m grid interval have been created with existing contours and spot levels from topographical maps using ANUDEM algorithm. This hydrologically corrected DEM is further used to delineate river basins, watersheds and subwatersheds for the study. Terrain parameters such as slope and aspect data sets were also generated from this DEM data.
- Creation of Surface Erosion Data: Surface soil erosion and mass wasting spatial data were created from Land Resources Mapping Project (LRMP) maps and the SOTER database of Nepal.
- Climate Data: Data on dominant climate and projected climatic data (rainfall and temperature data) were acquired from ADPC through IWMI. Average annual positive and negative rainfall data for 30 years (1976-2005) of 161 meteorological stations were gathered from the publication of Practical Action, Nepal (Practical Action 2009). The station-wise rainfall trend data were integrated at watersheds using spatial analysis, i.e., Inverse Distance Weightage (IDW) interpolation method to obtain watersheds-wise rainfall trend data.

- Population Data: The ward-level population data (CBS 2011) were integrated with associated ward boundaries and aggregated at the watershed boundary to produce watershed population data.
- Socioeconomic and Infrastructural Data: Various types of socioeconomic data related to infrastructure at the watershed or district level were gathered from various governmental agencies and institutional sources. The district-level data were aggregated to get watershed-level information. Some of these data were historical records on occurrences of deaths, injured persons, loss of property due to landslides/floods, landline telephones, number of electricity consumers, irrigated land and human development indices. Region-wise average ratios of electricity consumers and telephone line connections were calculated and the regional average ratio obtained. These values were then multiplied with the total population at the watershed. The watershed at the development region was selected in GIS, using the selection query analysis techniques. For the watersheds which share their major parts with multiple development regions, an average value was used. The same procedure was applied to calculate the data on development indices, historical recorded occurrences of deaths, number of injured, and loss of property due to landslide/flood hazards, and irrigated land for watersheds. The ratio of irrigated land to the total cultivated land was calculated based on data on district-level irrigated and total cultivated land.
- Multi-criteria evaluation of exposure, sensitivity and adaptive capacity were done using weighted and ranking techniques for each direct and proxy indicator. The weights and ranking of the indicators were done based on expert judgement from the stakeholders.
- Based on weightage of three combined indices of vulnerability, i.e., combined sensitivity, combined exposure/risk and combined adaptive capacity indices, vulnerability at watersheds was assessed and mapped in GIS.

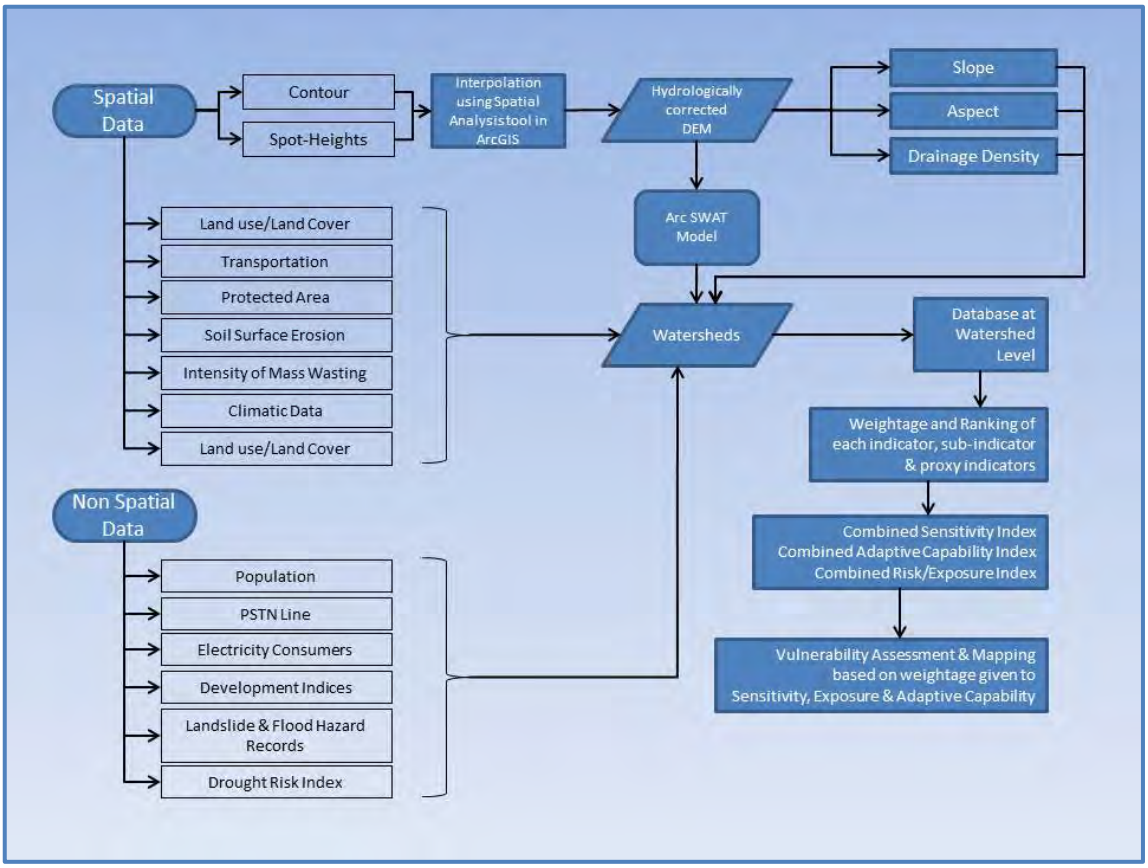


Figure 1. Methodological framework of CC vulnerability assessment and mapping.

2.3. Methodological Step for Setting of Indicators

2.3.1. Indicators Considered for Vulnerability Assessment and Mapping

The methodological gaps still remain on the subject of scales and integration of adaptation and the human dimensions of climate change. The assessment methods and tools that have been developed and applied for the vulnerability mapping around the world range from methods development, risk identification, decision making and determinants of vulnerability (Yusuf and Francisco 2009; Kienberger et al. 2009; Luers et al. 2003; MoE 2010). This study has adopted the methodology that Yusuf and Francisco (2009) used for the vulnerability mapping in Southeast Asia. The indicators considered for the analysis are presented in Tables 1-3.

Table 1. Indicators considered for sensitivity assessment of watersheds.

Parameters	Direct indicators/Indices	Proxy indicators/Indices
Ecology		Land Use and Land Cover (LULC)
		Area
		Protected area coverage
		Area
		Topography (slope, aspect)
		Area
		Drainage density
		Area
		Dominant climate
		Area
Human		Population
		Area

Table 2. Indicators considered for risk/exposure assessment of watersheds.

Parameters	Direct indicators/Indices	Proxy indicators/Indices
Temperature and rainfall	Mean seasonal temperature trend	
	Mean seasonal rainfall trend	
Landslide and flood	Death	
	Injured	
	Property loss	
	Occurrence	
	Positive annual rainfall trend	
Drought/ flood risk index	Daily precipitation	Population pressure on forest land
	Food surplus and deficiency	
Human ecology		Human poverty index
		Accessibility
Physical ecology		Surface soil erosion
		Mass wasting

Table 3. Indicators considered for adaptive capacity assessment of watersheds.

Parameters	Direct indicators/Indices	Proxy indicators/Indices
Socioeconomic	Human development index	
	Human poverty index	
	Gender development index	
	Human empowerment index	
Infrastructure	Road length	

	Area	
	PSTN landline phone	
	Population	
	Electricity consumers	
	Population	
Technology	Irrigated land	
	Area	
	Terraced	
	Area	
	Existence of intervention	
	Number	

2.3.2. Normalization and Standardization of Indicators

Indicators were normalized and values of the indicators were converted between 0 and 1 to rank the watersheds. The weightage from experts representing various governmental departments was also assigned for the standardization considering the importance and sensitivity of the indicators. To construct a single index from different sub-indicators, aggregation methods were adopted. The aggregated standardized value of the combined indicator was then normalized to rank the watersheds. The mean value of the combined index was used as the basis to make classes of each indicator making threshold values (mean plus standard deviation). Normalization of indicators was done by using the following identity.

——————..... (Eq. 2)

where, is standardized indicator/sub-indicator of the type i of the location j; is the nonstandardized indicator/sub-indicator/index type of i of location j, is the maximum value of the indicator/subindices/index over the region j, and is the minimum value of the indicator subindices/index over region j (for details see UNDP 2004).

2.4. Procedure for Data Acquisition and Integration at Watersheds

2.4.1. Spatial Data Set

Spatial data sets were developed/updated from existing 1:25,000 and 1:50,000 scale topographical data from the Survey Department 2001; Land Resources Mapping Project (LRMP 1986) data and various other data sources. Vector and raster data sets were integrated with aforementioned indicator data for further spatial analysis of watersheds. Spatial statistical tools such as raster calculator/combination and zonal statistics were applied to integrate the data at the watershed level.

2.4.2. Socioeconomic and Other Data Sets

Various types of socioeconomic data and data sets related to infrastructure at the watershed or district level were gathered from various institutional sources. The district-level data were aggregated/merged to get watershed-level information. Some of these data were on population, landline telephones, electricity consumers, irrigated land and human development indices. Population data of 2011 were acquired from the Central Bureau of Statistics (CBS).

The total number of electricity consumers and landline telephone connections were available at district level. To proceed with the data integration process, districts were first regrouped into development regions. The region-wise average ratio of the number of electricity consumers and telephone line connections was calculated and the regional average ratio obtained. These values were then normalized (multiplied) with total population at the watershed. For the watersheds which share their boundaries with

multiple development regions, an average value was used. The same procedure was applied to calculate the data on development indices and irrigated land for watersheds. The ratio of irrigated land to the total cultivated land was calculated based on data on district-level irrigated land and total cultivated land.

2.5. Watersheds Delineation

2.5.1. SWAT Model

Soil and Water Assessment Tool (SWAT) model (Arnold et al. 1998) was used to delineate watersheds. SWAT is a river-basin or watershed scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts.

SWAT Model seeks hydrologically corrected DEM (Digital Elevation Model) to delineate river basins and subbasins (watersheds). It is an automated process where the model creates a DEM-based flow direction and accumulation to define streams. The user has the freedom to put a threshold for the average size of the watershed. In this study, the threshold value for the average size has not been used in order to delineate the watershed, based on the actual hydro-physical boundary. SWAT creates a stream network and outlets. The outlets are basically the confluence points of different order of streams. The user can manually edit, add or delete the outlet or pour point. Based on selection of outlet points, SWAT delineates the watershed boundary of, and between, each outlet or pour point.

2.5.2. Selection of Watersheds

Mountains host diverse vegetation and varied microclimatic and ecological conditions, due in part to the extreme heterogeneity and rapid changes in soils and climates, to the rapid elevation changes that give rise to a variety of altitudinal vegetation belts, and to the variable directional orientation with rapid changes in aspect and slope (Hamilton 2002; Körner 2004; Spehn et al. 2002). Further, Singh et al. (2011) noted that the International Year of Mountains and the World Summit on Sustainable Development (WSSD) also discussed mountain ecosystems and advocated that mountains should be considered as special places in the global sustainable development agenda. Paragraph 42 of the Plan of Implementation of the WSSD focuses on mountains, stating:

Mountain ecosystems support particular livelihoods, and include significant watershed resources, biological diversity and unique flora and fauna. Many are particularly fragile and vulnerable to the adverse effects of climate change and need specific protection.

As such, in this study, the watersheds were selected in the mountain ecosystem located in the Middle and High Mountain regions of Nepal. Using the SWAT method, altogether 135 watersheds covering a total area of 81,484.21 sq. km were selected for the study. The coverage areas of these watersheds range from a maximum of 2,960 sq. km to a minimum of 46.38 sq. km with an average coverage area of 603.59 sq. km. The location map of selected watershed is shown in Map 1 above and the details are presented in appendix 1.

2.6. Climate Change Models

General Circulation Models or GCMs, representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Their resolution is however, quite coarse relative to the scale of exposure units in most impact assessments. Therefore, climate information derived from GCMs need to be downscaled for country-level analysis. Regional Climate Model (RCM) is the most reliable option for downscaling coarse resolution GCM outputs to fine resolutions. For this study, data from future climate projections were made available through a project led by The Asian

Disaster Preparedness Center (ADPC) on downscaling climate change projections in Nepal (TA 7173-NEP: Strengthening Capacity for Managing Climate Change and the Environment). In this project, PRECIS, RegCM4 and WRF models were used for downscaling of GCM climate information over Nepal. The future climate projections were downscaled for 2030 to 2060 (Mid-21st century) for Nepal with A1B and A2 scenarios. A1B is regarded as a "medium" and A2 as a "high" emission trajectory as proposed under emission scenarios (SRES). Details of the projected data obtained from ADPC are summarized in Table 4.

Table 4. Climate change data.

Current climate monthly data grids

Climate variable	Data period	Resolution		
Rainfall (mm)	1971-2009	12 km, 20 km, 25 km		
Temperature (Min and Max, ^{0}C)	1971-2009	12 km, 20 km, 25 km		
Projected climate monthly data grids				
RCM	Climate variable	Data period	GCM	SRES family
PRECIS	Rainfall (mm) Temperature (Max and Min, ^{0}C)	1970-2000 (BL) 2030-2060 (projected)	HadCM3Q0	A1B
RegCM4	Rainfall (mm) Temperature (Max and Min, ^{0}C)	1960-1990 (BL) 2040-2070 (projected)	ECHAM5 ECHAM4	A1B A2
WRF	Rainfall (mm) Temperature (Max and Min, ^{0}C)	1970-2000 (BL) 2030-2060 (projected)	ERA40 CCSM3, ECHAM5, GFDL-V2, HADCM3	A1B

Source: ADPC.

Note: Min = Minimum; Max = Maximum.

Chapter 3

Assessing and Analyzing Climate Change and Vulnerability

3.1. Developing Indicators for Climate Change and Vulnerability Assessment

3.1.1. Sensitivity Indicators

The sensitivity indicators were developed considering the sensitivity of population and ecology to climate change. With the assumption that the regions with a low population density will be less vulnerable than those with a high population density, given the same degree of exposure to the climate hazards, the sensitivity of the population was assessed using population density and distribution in the watersheds as the proxy indicator for human sensitivity to climate-hazards exposure. Human sensitivity is more profound where there is scarcity of natural resources; therefore, a proxy indicator to represent the population was used to analyze human sensitivity. Ecological sensitivity of the watersheds was assessed based on the proportion of the total area under protected area, LULC, topography (slope and aspect), dominant climate and drainage density in the watersheds.

Topographic relief of a landscape plays an important role in the development of soil in the region. Change in relief is the dominant factor in the landscape and therefore of soil stability. Thus, areas with steeper slopes are less stable when all other features are constant. The steeper the slope, the shallower the unconsolidated material on the slope and the more likely any material on the slope to be removed by erosion processes. Conversely, the gentler the slope, the more stable is the landscape, and the soil forming process proceeds relatively unhindered. Similarly, southern aspects receive considerably more direct sunlight than northern aspects, particularly in the winter. Evapotranspiration rates may be considerably higher on south aspects, resulting in significant differences in soil and vegetation types as well.

The climate of Nepal is extremely diverse with its altitudinal variations, encompassing subtropical, warm temperate, cool temperate to subalpine, alpine and arctic-like conditions. Two main factors responsible for the variability are high relative relief and a pronounced wet and dry monsoon season (LRMP 1986). Considering the present context of climate change and global warming, the alpine region is more likely to be sensitive and vulnerable than the subtropical. As some research and literature noted, the annual growth in temperature is rising by 0.08 ^{0}C in alpine than in subtropical by 0.06 ^{0}C. The drainage density is also sensitive with its physical existence as higher the drainage density, the higher the surface soil erosion and mass wasting. Drainage density of the stream network has long been recognized as a topographic characteristic of fundamental significance. The network density is a sensitive parameter which, in many ways, provides the link between the form attributes of the basin and the process operating along the stream course. R.E. Horton (1945) defined drainage density as the ratio of total length of all stream segments in a given drainage basin to the total area of that basin. The spatial variation in drainage density has been also related to precipitation effectiveness, vegetation index (R.J. Chorley 1957) and permeability of terrain.

3.1.2. Exposure/Risk Indicators

Geologic processes play a major role in the most hazardous process. Geologic processes affect every human being on earth all the time, but are most noticeable when they cause loss of life or property. If the process that poses the hazard occurs and destroys human life or property, then a natural disaster has occurred. In general, developing/less-developed countries are more vulnerable to natural hazards than the developed countries because of lack of adaptive capacity. Human poverty and source of livelihood at the community level also play a crucial role to induce ecological risk. Factors such as landslides, floods, droughts, and food surplus and deficiency were considered for this analysis.

The land system map provides an initial framework with which one can understand the variation in sediment contribution from different Himalayan landscape. Land system map units are delineated based on geology, geomorphology and climate. Although limited research has been carried out on specific landforms in Nepal, a land system map will provide an ideal basic for preliminary assessment of sediment production from different landscapes within a watershed (LRMP 1986). In this regard, surface soil erosion and mass wasting were generated by considering the land system units which are delineated based on geology, geomorphology and climate.

The dominant climate risk/exposure that affects the land systems are rainfall and temperature variability, ecology, landslides and floods, droughts and food production risks, etc. Climate change is very likely to intensify the water cycle, reinforcing existing patterns of water scarcity and abundance and increasing the risk of floods. Increased flooding is likely to lead to an increase in associated deaths, injuries and also to have adverse effects on the quality of surface water and groundwater (Andrew and Mark DB 2008).

Landslide/flooding caused by extreme rainfall and droughts caused by low precipitation and high temperature are equally harmful to the natural system and human livelihoods. The system is related with various hazardous parameters and affected by one another. For instance, climate is also an important factor affecting the paedogenesis of a soil. Generally, the hotter and the wetter the climate, the greater the chemical weathering. The variability and intensity of precipitation, apart from total precipitation, will affect the stability of landscape surface. Areas of high-intensity precipitation are much more prone to severe surface erosion than areas of low-intensity rainfall. There is also a direct/indirect relationship between rainfall, drainage density, and slope and soil erosion. The higher the drainage density and steeper the slope, the higher the surface erosion and mass wasting. On the other hand, if rainfall events are less-intense on moderately sloping mountain terrain one might expect low rates of surface erosion. Similarly, the impact of erosion in well-managed forests could be less than in barren lands.

3.1.3. Adaptive Capacity Indicators

Developing countries are considered to have limited adaptive capacity due to their limited endowment of technology, education, wealth and access to resources. And, the poor are expected to excessively suffer the impacts of climate change. Olmos (2001) also noted that vulnerability to climate change is closely related to poverty, as the poor are least able to respond to climatic stimuli. A majority of the population is exposed to multiple stresses and low adaptive capacity to impacts of climate change. Therefore, adaptation options at the local level should be identified and prioritized to ensure development and livelihoods security. Strengthened Actions for Governance in Utilization of Natural Resources (SAGUN) Program however mentioned that the external support and interventions also affect the vulnerability of communities during disaster and relief operations and that they are further linked to exposure and access to information, knowledge, technology and resources to cope with climate risks and disasters. Adaptive capacity is the degree to which adjustments in practices, processes, or structures can moderate or offset potential damage or take advantage of opportunities (IPCC 2001). Adaptive capacity is the function of state of socioeconomic factors, technology and infrastructure and can be written as:

$$\textit{Adaptive Capacity} = f(\textit{socioeconomic factors, technology, infrastructure}) \ldots . \text{(Eq. 3)}$$

Adaptive capacity of the communities in the watersheds has been assessed based on the expert judgement of the parameters related to the human development, poverty incidence, income/social inequality, electricity coverage, road density, communication and other access to infrastructure and technology services. The following parameters and assessment framework were used:

- Human development index (HDI)
- Human poverty index (HPI)
- Gender development index (GDI)
- Human empowerment index (HEI)
- Extent of electric coverage
- Road length/density
- Communication
- Extent of irrigation coverage
- Existence of intervention
- Terracing

3.1.4. Evaluation of Indicators through Expert Judgement

The vulnerability assessment was made using different indices that were drawn from comprehensive indicators of three main parameters, i.e., sensitivity, exposure/risk and adaptive capacity. Indicators were assigned weightage and ranked through consultation with the stakeholders' and experts' group discussion based on their expert judgement and evaluation of each indicator for sensitivity, exposure and adaptive capability. The weighted indicators were evaluated, verified and accepted by the 1st Technical Working Group meeting prior to developing combined climate change vulnerability indexing. The experts assigned for this task were representatives from different governmental agencies which included the Ministry of Local Development (MLD), Department of Irrigation (DoI), Department of Agriculture (DoA), Department of Water Supply and Sanitation (DWSS) and Association of District Development Committees of Nepal (ADDCN). The list of experts involved in the evaluation of the indicators is presented in appendix 3.

3.1.5. Vulnerability Ranking and Classification of Watersheds

The ranked weighted indicators (based on their values) are then classified into four categories and designated as 'low', 'moderate', 'high' and 'very high' based on the deviation of their values from the mean values. The function used is shown in Eq.4. The classes are designated as shown in Table 5.

$$Threshold\ value = Std.\ Deviation + Mean\ Value \ldots. \quad \text{(Eq. 4)}$$

Table 5. Vulnerability classification and weighted ranking values.

Vulnerability classes	Weighted ranking values
Very high	Threshold value + Std. Deviation
High	>=Threshold value
Moderate	Threshold value – Std. Deviation
Low	<= Threshold value – Std. Deviation

The statistical analysis of each of the indicators and subindices is presented in appendix 4.

Chapter 4

Status of Climate Change and Vulnerability at Watersheds

4.1. Vulnerability Mapping at Watersheds Level

4.1.1. Sensitivity Analysis

Considering the watershed as a geomorphic unit, the sensitivity of on-going process or system and elements of watersheds were analyzed. The sensitivity feature of the watersheds was classified on the basis of two subindices, which were ecological and human sensitivity. Ecological sensitivity refers to sensitivity of different natural elements, forms and processes under any climate change whereas human sensitivity is a relation of human activity for livelihood and its sensitivity to ecology. Assuming the population density as a proxy indicator and considering the other human behaviour as constant, human sensitivity was derived.

4.1.2. Ecological Sensitivity Subindices

Various parameters such as land use and land cover (LULC), coverage of protected areas, topography (slope and aspect), dominant climate and drainage density were considered under ecological sensitivity. LULC includes nine subclasses and the protected area includes national parks, wildlife reserves and buffer zones which are considered more balanced ecosystems from the management point of view. The ecological sensitivity was considered on the basis of their contribution to the land degradation process in the form of soil erosion, forest degradation, waterlogging and any other form of disturbance to natural balance (Figure 2).

Different weights were given to the LULC classes by the experts, based on their impact and sensitivity to the system (Figure 3). The normalized value of each LULC class was then multiplied with the assigned weight for standardization and aggregated to get the combined index of LULC. This procedure was also adopted for other sub-indicators as aforesaid. All aforementioned indices were then combined to construct the ecological sensitivity subindices. Combined ecological sensitivity subindices were normalized to get values between [0 and 1] and mapped to produce an ecological sensitivity map (Map 4).

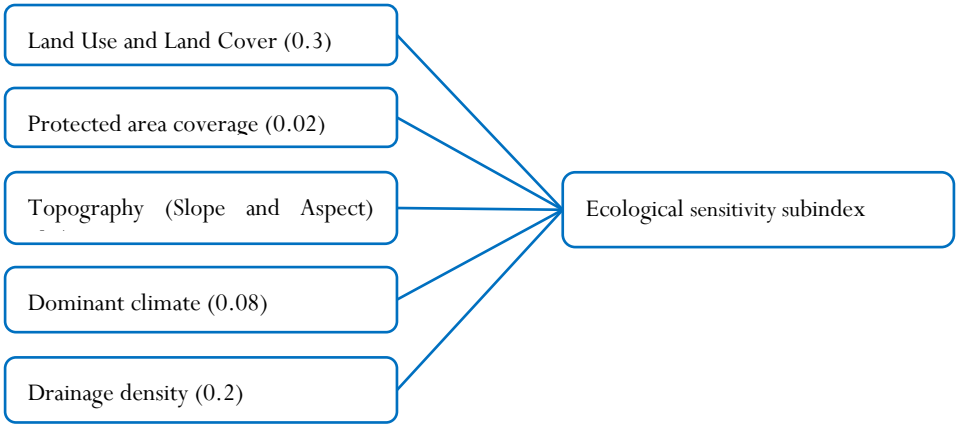
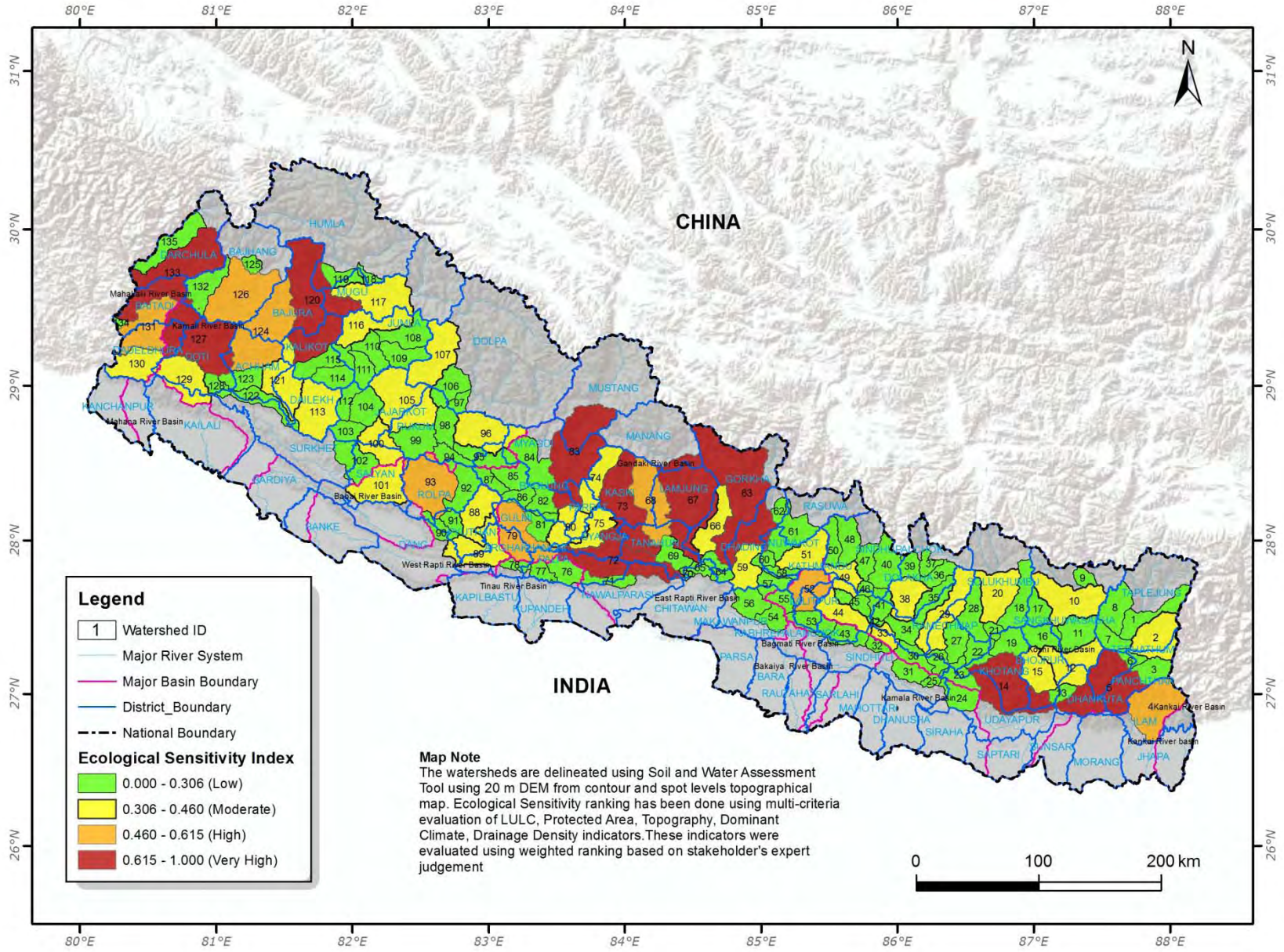


Figure 2. Ecological sensitivity subindices and their weightages (in parentheses).



Map 4. Ecological sensitivity map of watersheds in Middle and High Mountain regions.

From the ecological sensitivity point of view, the watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 6. The Mahakali, Karnali, Gandaki, West Rapti, Bagmati and Koshi river basins and their watersheds are relatively more sensitive compared to other basins. However, in the Mahakali River Basin--Chamaliya Watershed, in the Karnali River Basin--Upper Karnali Watershed and Lower West Seti Watershed, in the Gandaki River Basin--Budhi Gandaki Watershed, Marsyangdi Watershed, Upper Kali Gandaki Watershed, Lower Kali Gandaki Watershed and Upper Seti Watershed, and in the Koshi River Basin--Tamor Watershed and Sun Koshi Watershed are highly sensitive compared to other watersheds.

The Table 6 presents the watersheds ranked based on ecological sensitivity subindices.

Table 6. Watersheds ranked by ecological sensitivity subindices.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.615-1.000)	Gandaki	Budhi Gandaki	Budhi Gandaki	63	1
	Karnali	-	Upper Karnali	120	2
	Gandaki	Marsyangdi	Marsyangdi	67	3
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	4
	Koshi	Tamor	Tamor	5	5
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	6
	Karnali	West Seti	Lower West Seti	127	7
	Gandaki	East Seti	Upper East Seti	73	8
	Koshi	Sun Koshi	Sun Koshi	14	9
	Mahakali	-	Chamaliya	133	10
High (0.460-0.615)	Karnali	West Seti	Budhi Ganga	124	11
	-	Kankai	Mai Khola	4	12
	Karnali	West Seti	Middle West Seti	126	13
	Gandaki	Kali Gandaki	Ridi Khola	79	14
	-	West Rapti	Siban Khola	93	15
	Gandaki	East Seti	Madi	68	16
	-	Bagmati	Upper Bagmati	52	17
	Mahakali	-	Surnaya Gad	131	18
Moderate (0.360-0.460)	Karnali	Thuli Bheri	Upper Bheri	105	19
	Koshi	Likhu	Likhu Khola	29	20
	-	West Rapti	Rapti	89	21
	Koshi	Arun	Piluwa Khola	12	22
	Karnali	-	Lohare Khola	113	23
	-	Babai	Sarada	101	24
	Karnali	Thuli Bheri	Pelma Khola	96	25
	Karnali	-	Middle Karnali	121	26
	Karnali	-	Sera Gad	129	27
	Koshi	Arun	Middle Arun	10	28
	Karnali	Thuli Bheri	Bheri	107	29
	Karnali	Mugu Karnali	Mugu Karnali	117	30
	Gandaki	Trishuli	Middle Trishuli	59	31
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	32
	Koshi	Sun Koshi	Rosi Khola	44	33
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	34
	Gandaki	Trishuli	Tadi Khola	51	35

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Tamor	Kabeli Khola	2	36
	Karnali	Tila	Daine Khola	116	37
	-	West Rapti	Jhimruk Khola	88	38
	Gandaki	Marsyangdi	Daraudi Khola	66	39
	Karnali	Thuli Bheri	Middle Bheri	100	40
	Koshi	Tamakoshi	Middle Tamakoshi	38	41
	Koshi	Indrawati	Lower Indrawati	49	42
	Koshi	Arun	Pikhuwa Khola	15	43
	Gandaki	Kali Gandaki	Aandi Khola	75	44
	Mahakali	-	Ragun Khola	130	45
	Gandaki	Kali Gandaki	Modi Khola	74	46
	Koshi	Sun Koshi	Gangeti Khola	33	47
Low (0.000-0.360)	-	Kamala	Baidyanath Khola	24	48
	Gandaki	Trishuli	Upper Trishuli	61	49
	Karnali	Thuli Bheri	Lower Bheri	102	50
	Koshi	Sun Koshi	Jagarpur Khola	27	51
	-	Bagmati	Kokhajor Khola	43	52
	Koshi	Arun	Sabha Khola	11	53
	-	Kamala	Chandaha Khola	31	54
	Karnali	Tila	Chaudhabis Khola	108	55
	Koshi	Dudh Koshi	Solu Khola	28	56
	Gandaki	East Seti	Lower East Seti	69	57
	Koshi	Dudh Koshi	Hongu Khola	18	58
	-	Bagmati	Lower Bagmati	53	59
	Koshi	Tamor	Hewa Khola	3	60
	Koshi	Tamor	Ghunsa Khola	1	61
	-	West Rapti	Lindri Khola	92	62
	Koshi	Sun Koshi	Yari Khola	23	63
	Koshi	Tamor	Mewa Khola	8	64
	Gandaki	East Rapti	Gorandhi Khola	56	65
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	66
	Koshi	Sun Koshi	Kalunje Khola	42	67
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	68
	Karnali	Thuli Bheri	Sano Bheri	99	69
	-	Tinau	East Tinau	76	70
	Koshi	Indrawati	Upper Indrawati	48	71
	Gandaki	Kali Gandaki	Myagdi Khola	84	72
	Koshi	Sun Koshi	Bandijor Khola	30	73
	Koshi	Arun	Lower Arun	16	74
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	75
	Koshi	Sun Koshi	Bhote Koshi	40	76
	Karnali	West Seti	Chaira Khola	123	77
	Karnali	West Seti	Kalanga Gad	132	78
	Koshi	Tamakoshi	Khimti Khola	35	79
	Koshi	Sun Koshi	Chauri Khola	41	80
	Karnali	Tila	Lower Tila	115	81
	Koshi	Tamakoshi	Lower Tamakoshi	34	82
	Gandaki	Trishuli	Mahesh Khola	57	83

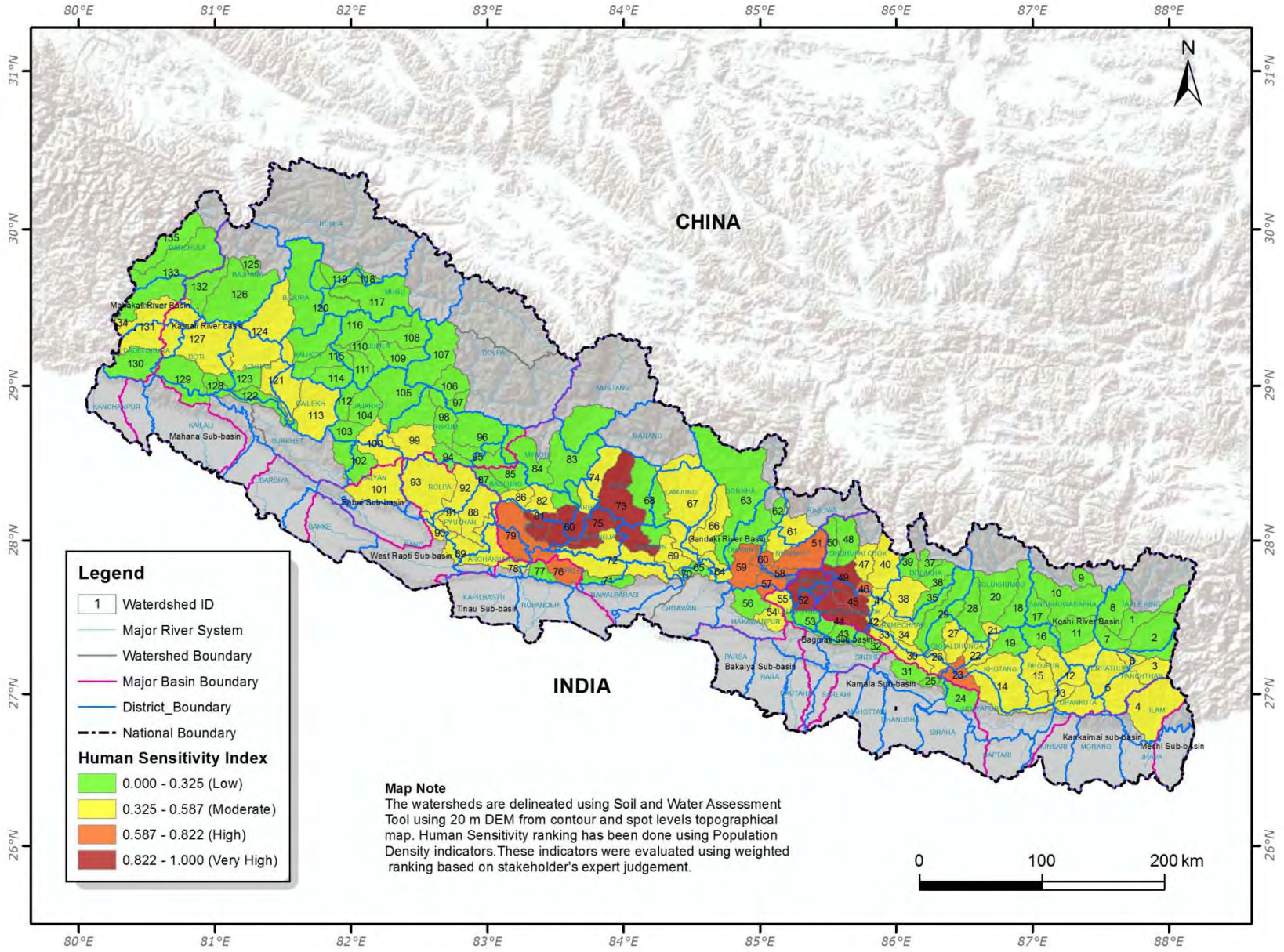
Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Sun Koshi	Khansan Khola	26	84
	Gandaki	Trishuli	Bhyaure Khola	60	85
	Karnali	-	Lower Karnali	122	86
	Karnali	Tila	Juliodar Khola	109	87
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	88
	-	Bagmati	Palun Khola	55	89
	Koshi	Sun Koshi	Jhikhu Khola	45	90
	Karnali	Thuli Bheri	Thuli Bheri	106	91
	Karnali	Thuli Bheri	Ganga	95	92
	Koshi	Dudh Koshi	Rawa Khola	19	93
	Karnali	Tila	Upper Tila	110	94
	Karnali	Thuli Bheri	Sai Kumari Khola	97	95
	-	West Rapti	Madi Khola	91	96
	Gandaki	Trishuli	Trishuli-Seti	70	97
	Karnali	Tila	Ruru Khola	114	98
	Gandaki	Trishuli	Lower Trishuli	64	99
	Karnali	Thuli Bheri	Sani Bheri	98	100
	Gandaki	East Rapti	East Rapti	54	101
	Koshi	Tamakoshi	Sagu Khola	39	102
	Gandaki	Kali Gandaki	Taman Khola	85	103
	Karnali	Thuli Bheri	Saru Khola	104	104
	Karnali	-	Banda Gad	128	105
	-	West Rapti	Arun Khola	90	106
	Koshi	Indrawati	Melamchi	50	107
	Karnali	Tila	Bheri Khola	111	108
	Koshi	Arun	Lower Piluwa Khola	13	109
	Gandaki	Trishuli	Kolpu Khola	58	110
	Koshi	Tamor	Nenwa Khola	7	111
	Koshi	Sun Koshi	Balephi Khola	47	112
	Koshi	Arun	Sankhuwa Khola	17	113
	-	Bagmati	Marin Khola	32	114
	Koshi	Tamakoshi	Khare Khola	36	115
	Gandaki	East Rapti	Arun Khola	71	116
	Gandaki	Kali Gandaki	Daram Khola	82	117
	Karnali	Thuli Bheri	Chhera Khola	103	118
	Mahakali	-	Mahakali	135	119
	Karnali	Thuli Bheri	Lukum Khola	94	120
	-	Tinau	West Tinau	77	121
	Karnali	Humla Karnali	Loti Karnali	118	122
	Gandaki	Kali Gandaki	Nisi Khola	87	123
	Koshi	Sun Koshi	Bhushe Khola	46	124
	Karnali	Thuli Bheri	Mujkot Khola	112	125
	Koshi	Arun	Upper Arun	9	126
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	127
	Karnali	Humla Karnali	Humla Karnali	119	128
	-	Tinau	Banganga	78	129
	-	Kamala	Thakur Khola	25	130
	Karnali	West Seti	Upper West Seti	125	131

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Tamakoshi	Upper Tamakoshi	37	132
	Koshi	Tamor	Shuban Khola	6	133
	Gandaki	Budhi Gandaki	Bhabil Khola	62	134
	Mahakali	-	Gairad Khola	134	135

4.1.3. Human Sensitivity Index

Human sensitivity index was derived considering the population density. To construct the human sensitivity index, ward (smallest unit of Village Development Committee)-level population data were aggregated at watershed level and the total area of the watershed was calculated. The total area of watershed and watershed population were used to derive the human sensitivity per unit area as a measure of the human sensitivity at watersheds by assuming that the higher the population density, the higher the pressure on land, forest and water resources. Consequently, a negative impact on any of the above elements will bring destructive change to the natural system (Map 5).

Figure 3. Human sensitivity index and its weightage (in parenthesis).



Map 5. Human sensitivity map of watersheds in Middle and High Moutnain Regions

From the human sensitivity perspective, the watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 7. The Upper Bagmati Watershed in Bagmati Sub-basin; Upper East Seti Watershed, Lower Badighad Khola Watershed, Aandi Khola Watershed and Middle Kali Gandaki Watershed in Gandaki River Basin; and Rosi Khola Watershed, Lower Indrawati Watershed and Jhikhu Khola Watershed in Koshi River Basin are highly sensitive compared to other watersheds. Tinau River Basin and its watersheds are also sensitive to climate change in comparision to other basins.

Table 7. Watersheds ranked by human sensitivity subindices.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.822-1.000)	-	Bagmati	Upper Bagmati	52	1
	Gandaki	East Seti	Upper East Seti	73	2
	Koshi	Sun Koshi	Rosi Khola	44	3
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	4
	Gandaki	Kali Gandaki	Aandi Khola	75	5
	Koshi	Indrawati	Lower Indrawati	49	6
	Koshi	Sun Koshi	Jhikhu Khola	45	7
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	8
High (0.587-0.822)	Koshi	Sun Koshi	Bhushe Khola	46	9
	Gandaki	Trishuli	Mahesh Khola	57	10
	Gandaki	Trishuli	Kolpu Khola	58	11
	Gandaki	Kali Gandaki	Ridi Khola	79	12
	Koshi	Sun Koshi	Yari Khola	23	13
	-	Tinau	East Tinau	76	14
	Gandaki	Trishuli	Bhyaure Khola	60	15
	Gandaki	Trishuli	Middle Trishuli	59	16
	Gandaki	Trishuli	Tadi Khola	51	17
Moderate (0.352-0.587)	-	West Rapti	Jhimruk Khola	88	18
	Koshi	Tamakoshi	Middle Tamakoshi	38	19
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	20
	Koshi	Tamakoshi	Lower Tamakoshi	34	21
	Koshi	Sun Koshi	Gangeti Khola	33	22
	Koshi	Sun Koshi	Khansan Khola	26	23
	Mahakali	-	Gairad Khola	134	24
	-	Tinau	Banganga	78	25
	Karnali	-	Middle Karnali	121	26
	-	Bagmati	Palun Khola	55	27
	-	Kankai	Mai Khola	4	28
	Koshi	Sun Koshi	Chauri Khola	41	29
	-	West Rapti	Arun Khola	90	30
	Koshi	Sun Koshi	Bandijor Khola	30	31
	Gandaki	Marsyangdi	Daraudi Khola	66	32
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	33
	Karnali	Thuli Bheri	Middle Bheri	100	34
	Gandaki	Trishuli	Lower Trishuli	64	35
	Koshi	Arun	Lower Piluwa Khola	13	36
	Koshi	Tamor	Tamor	5	37
	Koshi	Tamor	Hewa Khola	3	38
	Gandaki	Kali Gandaki	Modi Khola	74	39
	Gandaki	Kali Gandaki	Daram Khola	82	40

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	-	West Rapti	Madi Khola	91	41
	Karnali	-	Lohare Khola	113	42
	Gandaki	East Seti	Lower East Seti	69	43
	Karnali	Thuli Bheri	Sano Bheri	99	44
	Koshi	Sun Koshi	Kalunje Khola	42	45
	Koshi	Tamor	Shuban Khola	6	46
	Gandaki	Trishuli	Upper Trishuli	61	47
	-	Babai	Sarada	101	48
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	49
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	50
	Koshi	Sun Koshi	Sun Koshi	14	51
	Koshi	Sun Koshi	Bhote Koshi	40	52
	Gandaki	East Rapti	East Rapti	54	53
	Koshi	Sun Koshi	Balephi Khola	47	54
	Koshi	Arun	Pikhuwa Khola	15	55
	-	West Rapti	Rapti	89	56
	Karnali	West Seti	Lower West Seti	127	57
	Koshi	Arun	Piluwa Khola	12	58
	Gandaki	Marsyangdi	Marsyangdi	67	59
	Karnali	West Seti	Budhi Ganga	124	60
Low (0.000-0.352)	-	West Rapti	Lindri Khola	92	61
	Koshi	Sun Koshi	Jagarpur Khola	27	62
	Mahakali	-	Surnaya Gad	131	63
	-	West Rapti	Siban Khola	93	64
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	65
	-	Bagmati	Lower Bagmati	53	66
	Karnali	Tila	Lower Tila	115	67
	Karnali	Thuli Bheri	Lower Bheri	102	68
	Karnali	Thuli Bheri	Chhera Khola	103	69
	Mahakali	-	Chamaliya	133	70
	Koshi	Arun	Sabha Khola	11	71
	Koshi	Dudh Koshi	Rawa Khola	19	72
	Gandaki	East Rapti	Gorandhi Khola	56	73
	-	Kamala	Baidyanath Khola	24	74
	Koshi	Tamor	Nenwa Khola	7	75
	-	Kamala	Thakur Khola	25	76
	Karnali	West Seti	Kalanga Gad	132	77
	Gandaki	East Seti	Madi	68	78
	-	Tinau	West Tinau	77	79
	Koshi	Arun	Lower Arun	16	80
	-	Bagmati	Kokhajor Khola	43	81
	Karnali	West Seti	Chaira Khola	123	82
	Koshi	Likhu	Likhu Khola	29	83
	Koshi	Tamakoshi	Khimti Khola	35	84
	Karnali	West Seti	Middle West Seti	126	85
	Karnali	Thuli Bheri	Saru Khola	104	86
	Karnali	Tila	Upper Tila	110	87
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	88

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Mahakali	-	Mahakali	135	89
	Koshi	Tamakoshi	Upper Tamakoshi	37	90
	Koshi	Tamor	Kabeli Khola	2	91
	Koshi	Indrawati	Upper Indrawati	48	92
	-	Kamala	Chandaha Khola	31	93
	Koshi	Tamakoshi	Sagu Khola	39	94
	Gandaki	Trishuli	Trishuli, Seti	70	95
	Mahakali	-	Ragun Khola	130	96
	Karnali	-	Lower Karnali	122	97
	Koshi	Indrawati	Melamchi	50	98
	Karnali	Thuli Bheri	Lukum Khola	94	99
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	100
	Koshi	Dudh Koshi	Solu Khola	28	101
	-	Bagmati	Marin Khola	32	102
	Gandaki	Kali Gandaki	Taman Khola	85	103
	Karnali	Thuli Bheri	Mujkot Khola	112	104
	Koshi	Tamor	Ghunsa Khola	1	105
	Gandaki	Kali Gandaki	Nisi Khola	87	106
	Gandaki	East Rapti	Arun Khola	71	107
	Karnali	-	Banda Gad	128	108
	Karnali	-	Upper Karnali	120	109
	Karnali	Tila	Daine Khola	116	110
	Gandaki	Kali Gandaki	Myagdi Khola	84	111
	Karnali	Thuli Bheri	Upper Bheri	105	112
	Koshi	Tamakoshi	Khare Khola	36	113
	Karnali	-	Sera Gad	129	114
	Karnali	Thuli Bheri	Sani Bheri	98	115
	Karnali	Humla Karnali	Loti Karnali	118	116
	Karnali	Humla Karnali	Humla Karnali	119	117
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	118
	Gandaki	Budhi Gandaki	Bhabil Khola	62	119
	Koshi	Arun	Sankhuwa Khola	17	120
	Karnali	Thuli Bheri	Thuli Bheri	106	121
	Koshi	Dudh Koshi	Hongu Khola	18	122
	Karnali	Mugu Karnali	Mugu Karnali	117	123
	Koshi	Tamor	Mewa Khola	8	124
	Karnali	Thuli Bheri	Ganga	95	125
	Karnali	Tila	Ruru Khola	114	126
	Koshi	Arun	Upper Arun	9	127
	Koshi	Arun	Middle Arun	10	128
	Karnali	Tila	Juliodar Khola	109	129
	Karnali	Thuli Bheri	Sai Kumari Khola	97	130
	Karnali	Tila	Bheri Khola	111	131
	Karnali	Tila	Chaudhabis Khola	108	132
	Karnali	Thuli Bheri	Pelma Khola	96	133
	Karnali	Thuli Bheri	Bheri	107	134
	Karnali	West Seti	Upper West Seti	125	135

4.1.4. Combined/Multiple Sensitivity Index

A combined/multiple sensitivity index was developed by the aggregation of weighted standardized ecological and human sensitivity subindices of the watersheds (see Figure 4). Higher weightage was given to the ecological sensitivity due to more priority given from the conservation point of view at watersheds. The combined/multiple sensitivity index was then used for the generation of the combined/multiple sensitivity map (Map 6).

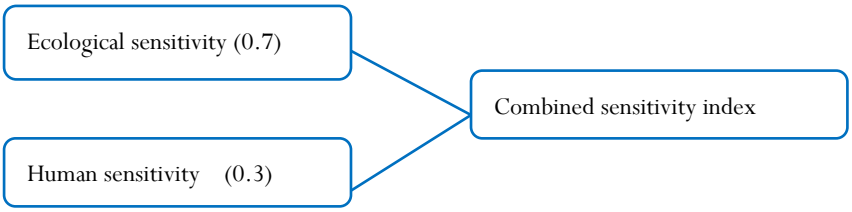
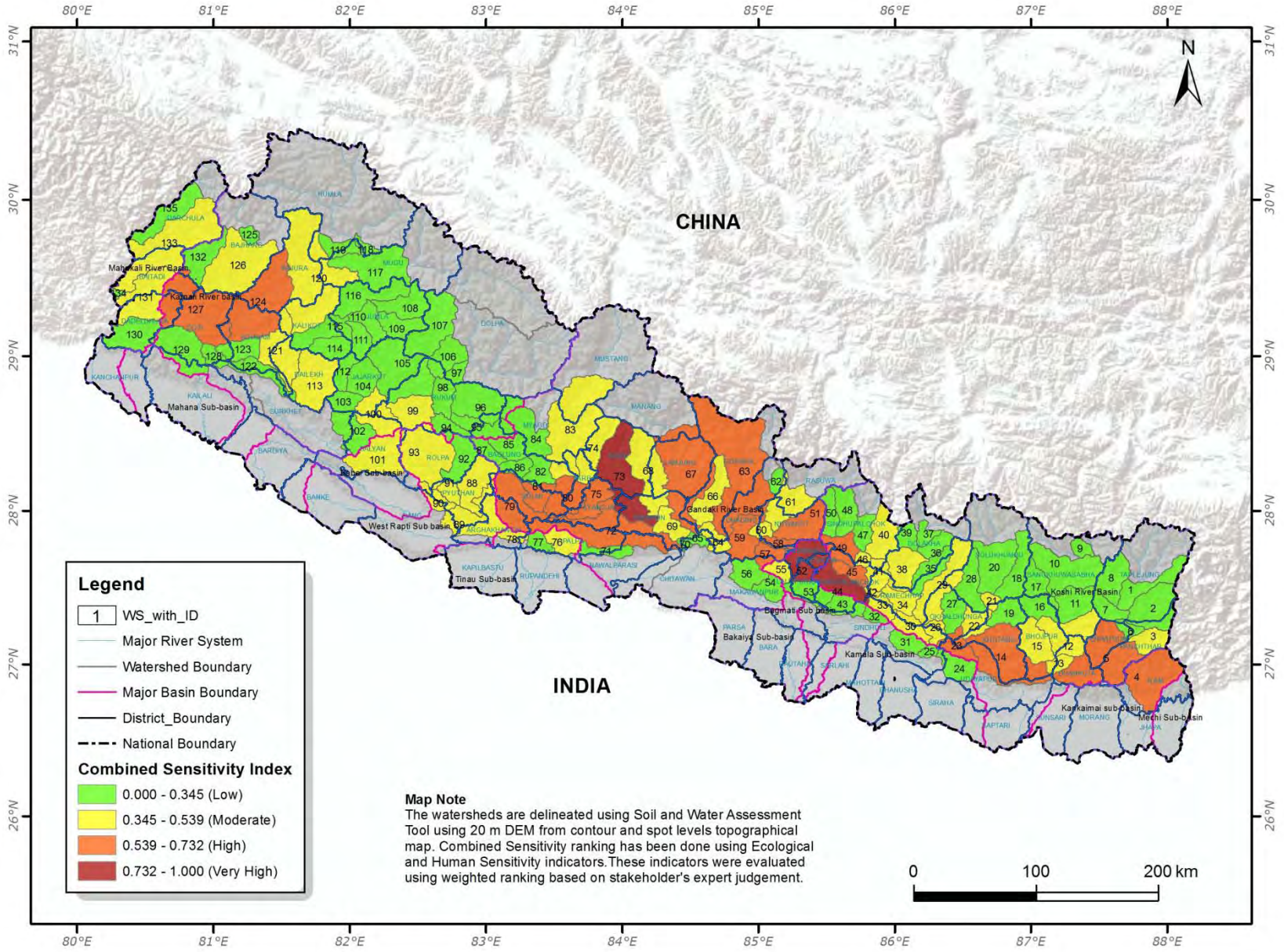


Figure 4. Combined/multiple sensitivity index with its subindices and their weightages (in parentheses).



Map 6. Combined/multiple sensitivity map of watersheds in Middle and High Mountain regions

Based on the combined/multiple sensitivity index, the watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 8. According to this, Upper East Seti Watershed in Gandaki River Basin; upper Bagmati watershed in Bagmati Sub-basin and Rosi Khola watershed in Koshi river basins are highly sensitive, as those watersheds also fall within the districts of high population density. However, the watersheds in Kankai and Karnali river basins are also sensitive compared to others.

Table 8. Watersheds ranked by combined sensitivity index.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.732-1.000)	Gandaki	East Seti	Upper East Seti	73	1
	-	Bagmati	Upper Bagmati	52	2
	Koshi	Sun Koshi	Rosi Khola	44	3
High (0.539-0.732)	Gandaki	Kali Gandaki	Aandi Khola	75	4
	Koshi	Indrawati	Lower Indrawati	49	5
	Gandaki	Kali Gandaki	Ridi Khola	79	6
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	7
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	8
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	9
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	10
	Koshi	Tamor	Tamor	5	11
	Koshi	Sun Koshi	Jhikhu Khola	45	12
	Gandaki	Marsyangdi	Marsyangdi	67	13
	-	Kankai	Mai Khola	4	14
	Koshi	Sun Koshi	Sun Koshi	14	15
	Karnali	West Seti	Lower West Seti	127	16
	Gandaki	Trishuli	Middle Trishuli	59	17
	Gandaki	Trishuli	Mahesh Khola	57	18
	Gandaki	Trishuli	Tadi Khola	51	19
	Gandaki	Trishuli	Kolpu Khola	58	20
	Karnali	West Seti	Budhi Ganga	124	21
	Koshi	Sun Koshi	Yari Khola	23	22
Moderate (0.345-0.539)	Mahakali	-	Chamaliya	133	23
	Koshi	Sun Koshi	Bhushe Khola	46	24
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	25
	Karnali	-	Middle Karnali	121	26
	-	Tinau	East Tinau	76	27
	-	West Rapti	Jhimruk Khola	88	28
	Koshi	Tamakoshi	Middle Tamakoshi	38	29
	Gandaki	Trishuli	Bhyaure Khola	60	30
	Koshi	Sun Koshi	Gangeti Khola	33	31
	Karnali	-	Upper Karnali	120	32
	Karnali	-	Lohare Khola	113	33
	-	Babai	Sarada	101	34
	Gandaki	Marsyangdi	Daraudi Khola	66	35
	-	West Rapti	Rapti	89	36
	-	West Rapti	Siban Khola	93	37
	Mahakali	-	Surnaya Gad	131	38
	Koshi	Tamakoshi	Lower Tamakoshi	34	39
	Karnali	Thuli Bheri	Middle Bheri	100	40

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Arun	Piluwa Khola	12	41
	Koshi	Sun Koshi	Khansan Khola	26	42
	Gandaki	Kali Gandaki	Modi Khola	74	43
	Karnali	West Seti	Middle West Seti	126	44
	Koshi	Sun Koshi	Chauri Khola	41	45
	Koshi	Sun Koshi	Bandijor Khola	30	46
	-	Bagmati	Palun Khola	55	47
	Gandaki	East Seti	Madi	68	48
	Koshi	Tamor	Hewa Khola	3	49
	Gandaki	Trishuli	Upper Trishuli	61	50
	Gandaki	East Seti	Lower East Seti	69	51
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	52
	Koshi	Arun	Pikhuwa Khola	15	53
	-	West Rapti	Arun Khola	90	54
	Karnali	Thuli Bheri	Sano Bheri	99	55
	Koshi	Sun Koshi	Kalunje Khola	42	56
	Koshi	Likhu	Likhu Khola	29	57
	Gandaki	Trishuli	Lower Trishuli	64	58
	-	Tinau	Banganga	78	59
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	60
	-	West Rapti	Madi Khola	91	61
	Koshi	Arun	Lower Piluwa Khola	13	62
	Koshi	Sun Koshi	Bhotekoshi	40	63
Low (0.000-0.345)	Gandaki	Kali Gandaki	Upper Badigad Khola	86	64
	Koshi	Sun Koshi	Jagarpur Khola	27	65
	Gandaki	Kali Gandaki	Daram Khola	82	66
	-	West Rapti	Lindri Khola	92	67
	Karnali	Thuli Bheri	Lower Bheri	102	68
	Gandaki	East Rapti	East Rapti	54	69
	-	Kamala	Baidyanath Khola	24	70
	Koshi	Arun	Sabha Khola	11	71
	-	Bagmati	Lower Bagmati	53	72
	Karnali	Thuli Bheri	Upper Bheri	105	73
	Koshi	Sun Koshi	Balephi Khola	47	74
	Gandaki	Trishuli	Trishuli-Marsyangdi	65	75
	Gandaki	East Rapti	Gorandhi Khola	56	76
	Karnali	Tila	Lower Tila	115	77
	Koshi	Tamor	Shuban Khola	6	78
	Koshi	Tamor	Kabeli Khola	2	79
	-	Bagmati	Kokhajor Khola	43	80
	Mahakali	-	Gairad Khola	134	81
	Koshi	Dudh Koshi	Rawa Khola	19	82
	Karnali	-	Sera Gad	129	83
	Karnali	West Seti	Kalanga Gad	132	84
	Mahakali	-	Ragun Khola	130	85
	Koshi	Arun	Lower Arun	16	86
	Karnali	West Seti	Chaira Khola	123	87
	Koshi	Tamakoshi	Khimti Khola	35	88

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	Thuli Bheri	Chhera Khola	103	89
	-	Kamala	Chandaha Khola	31	90
	Karnali	Tila	Daine Khola	116	91
	Koshi	Tamor	Nenwa Khola	7	92
	Koshi	Indrawati	Upper Indrawati	48	93
	Koshi	Dudh Koshi	Solu Khola	28	94
	Koshi	Arun	Middle Arun	10	95
	Karnali	Tila	Upper Tila	110	96
	Karnali	Mugu Karnali	Mugu Karnali	117	97
	Karnali	Thuli Bheri	Saru Khola	104	98
	Koshi	Tamor	Ghunsa Khola	1	99
	-	Tinau	West Tinau	77	100
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	101
	Karnali	-	Lower Karnali	122	102
	-	Kamala	Thakur Khola	25	103
	Gandaki	Trishuli	Trishuli, Seti	70	104
	Karnali	Thuli Bheri	Pelma Khola	96	105
	Koshi	Tamakoshi	Sagu Khola	39	106
	Karnali	Thuli Bheri	Bheri	107	107
	Gandaki	Kali Gandaki	Myagdi Khola	84	108
	Mahakali	-	Mahakali	135	109
	Koshi	Indrawati	Melamchi	50	110
	Gandaki	Kali Gandaki	Taman Khola	85	111
	-	Bagmati	Marin Khola	32	112
	Karnali	Thuli Bheri	Lukum Khola	94	113
	Karnali	-	Banda Gad	128	114
	Koshi	Dudh Koshi	Hongu Khola	18	115
	Gandaki	East Rapti	Arun Khola	71	116
	Koshi	Tamakoshi	Upper Tamakoshi	37	117
	Karnali	Thuli Bheri	Sani Bheri	98	118
	Karnali	Thuli Bheri	Mujkot Khola	112	119
	Koshi	Tamor	Mewa Khola	8	120
	Gandaki	Kali Gandaki	Nisi Khola	87	121
	Karnali	Tila	Chaudhabis Khola	108	122
	Koshi	Tamakoshi	Khare Khola	36	123
	Karnali	Thuli Bheri	Thuli Bheri	106	124
	Karnali	Thuli Bheri	Ganga	95	125
	Karnali	Tila	Juliodar Khola	109	126
	Karnali	Tila	Ruru Khola	114	127
	Karnali	Thuli Bheri	Sai Kumari Khola	97	128
	Koshi	Arun	Sankhuwa Khola	17	129
	Karnali	Humla Karnali	Loti Karnali	118	130
	Karnali	Tila	Bheri Khola	111	131
	Karnali	Humla Karnali	Humla Karnali	119	132
	Koshi	Arun	Upper Arun	9	133
	Gandaki	Budhi Gandaki	Bhabil Khola	62	134
	Karnali	West Seti	Upper West Seti	125	135

4.2. Climate Risk/Exposure

The assessments of climate risk/hazards, i.e., temperature and rainfall risk, ecology, landslides/floods, droughts and food surpluses or deficiencies were analyzed using historical records and climate change data derived from the existing Regional Climate Model (RCM). The severity of both the impacts and their risks was used as the direct and proxy indicator for the exposure. Their individual exposure as well as combined exposure to the population and ecology was assessed with expert judgement and weightage. The weightage for each index and subindices was assigned based on their impacts. The exposure/risk was also assessed based on the information from the historical records of aforementioned climate-related hazards. The past exposure to the climate risks was used as the best available proxy for the future climate risks. The frequency of occurrences and the severity of these hazards were used as the proxy for the exposure of the climate change hazards.

4.2.1. Temperature and Rainfall Risk/Exposure

The six different Regional Circulation Model (RCM) climate data were available from Asian Disaster Preparedness Center (ADPC). The gridded future projections and baseline data were included in the models. Then the projected data of the temperature and rainfall were first aggregated according to four seasons (premonsoon, monsoon, post-monsoon and winter). The projected data (which are the future data for 30 years) were then subtracted from the baseline data (which are data for the past 30 years) separately for each season. The difference whether positive or negative (more rain/temperature or less rain/temperature) was used in the assessment. The assumption was made that any change from the baseline whether positive or negative will make the watersheds vulnerable and the greater the difference from the mean, the greater the impact on vulnerability (for both positive and negative).

To construct the rainfall-temperature risk/exposure subindices, the gridded data on temperature and rainfall of four seasons were integrated at the watershed level. The weightage for each season was assigned by experts for standardization. More weightage was given to the monsoon followed by the premonsoon and winter rainfall and less weightage was given to the post-monsoon (as shown in Figure 5). This procedure was also applied for the temperature data to get the temperature index. Then, both rainfall and temperature indices were aggregated after standardization to derive the rainfall and temperature subindices. The derived subindices values were then plotted to produce the rainfall and temperature risk map (Map 7).

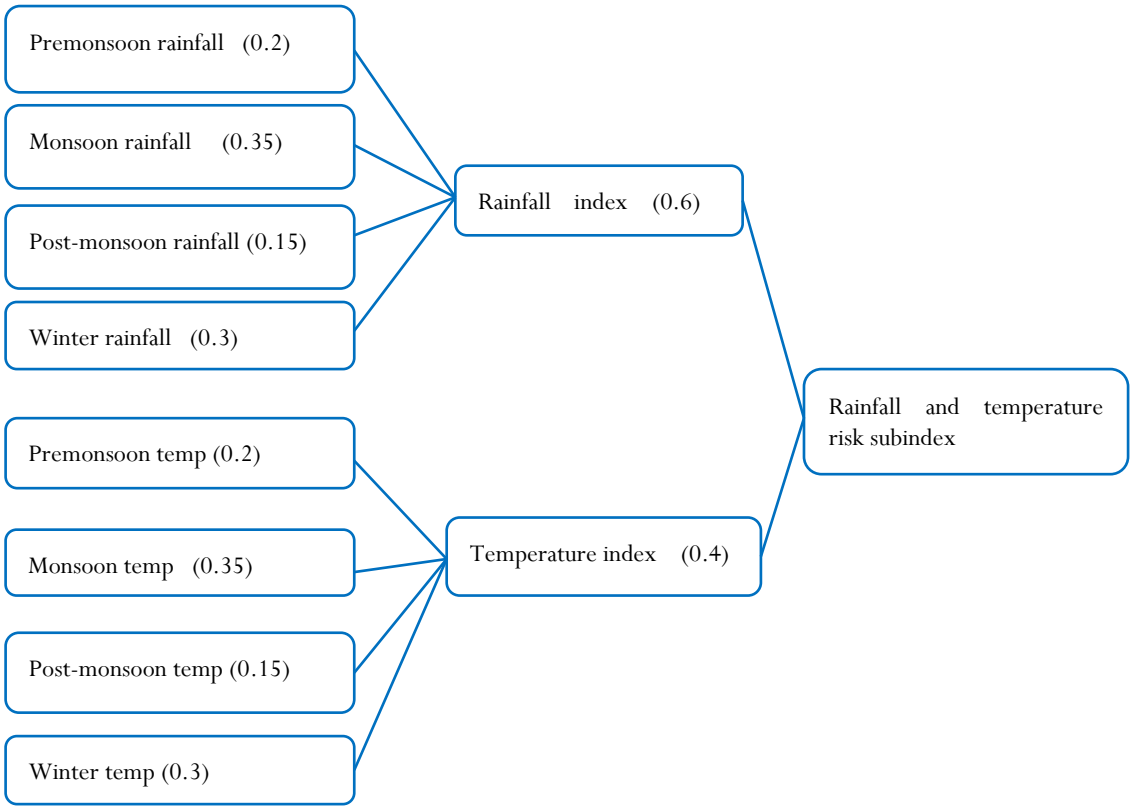
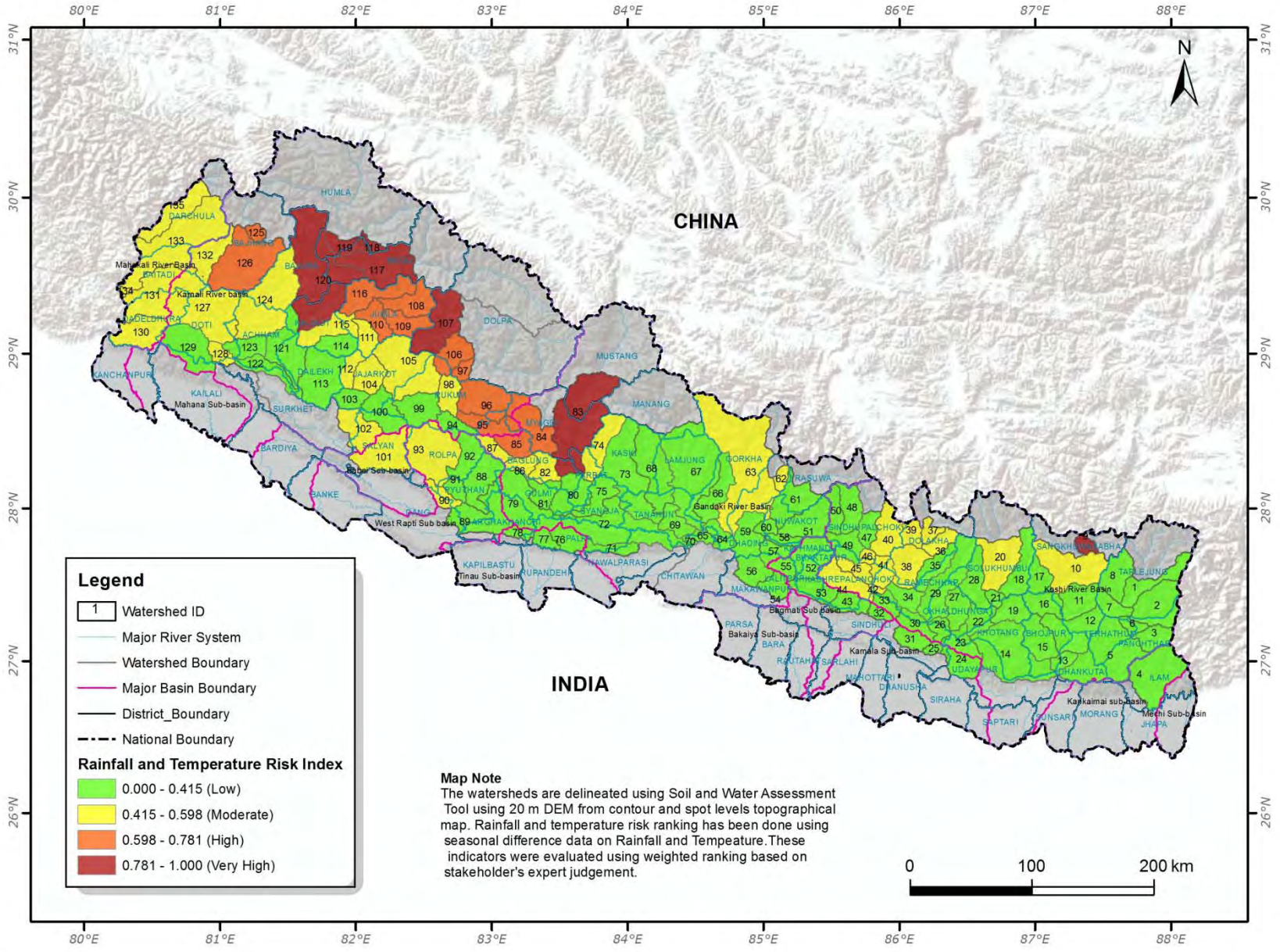


Figure 5. Rainfall and temperature risk subindices and their weightages (in parentheses).



Map 7. Rainfall and temperature risk map of watersheds in the Middle and High Mountain regions

From the perspective of rainfall and temperature risk/exposure, the watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 9. Accordingly, the Humla Karnali watershed in the Karnali River basin, Loti Karnali Watershed in the Karnali River Basin, Upper Kali Gandaki Watershed in the Gandaki River Basin, Mugu Karnali Watershed in the Karnali River Basin, Upper Karnali Watershed in the Karnali River Basin, Upper Arun Watershed in the Koshi River Basin and Bheri Watershed in the Karnali River Basin showed high exposure potential in terms of rainfall and temperature trends.

Table 9. Watersheds ranked by rainfall and temperature risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.781-1.000)	Karnali	Humla Karnali	Humla Karnali	119	1
	Karnali	Humla Karnali	Loti Karnali	118	2
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	3
	Karnali	Mugu Karnali	Mugu Karnali	117	4
	Karnali	-	Upper Karnali	120	5
	Koshi	Arun	Upper Arun	9	6
	Karnali	Thuli Bheri	Bheri	107	7
High (0.598-0.781)	Gandaki	Kali Gandaki	Myagdi Khola	84	8
	Karnali	Tila	Chaudhabis Khola	108	9
	Karnali	Thuli Bheri	Thuli Bheri	106	10
	Karnali	Tila	Daine Khola	116	11
	Karnali	Tila	Juliodar Khola	109	12
	Karnali	West Seti	Upper West Seti	125	13
	Karnali	Thuli Bheri	Sai Kumari Khola	97	14
	Karnali	Thuli Bheri	Pelma Khola	96	15
	Karnali	Tila	Upper Tila	110	16
	Gandaki	Kali Gandaki	Taman Khola	85	17
	Karnali	Thuli Bheri	Ganga	95	18
	Karnali	West Seti	Middle West Seti	126	19
Moderate (0.415-0.598)	Gandaki	Kali Gandaki	Daram Khola	82	20
	Gandaki	Budhi Gandaki	Bhabil Khola	62	21
	Mahakali	-	Surnaya Gad	131	22
	Koshi	Tamakoshi	Upper Tamakoshi	37	23
	Koshi	Tamakoshi	Sagu Khola	39	24
	Mahakali	-	Gairad Khola	134	25
	Gandaki	Kali Gandaki	Modi Khola	74	26
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	27
	Mahakali	-	Mahakali	135	28
	Karnali	Tila	Bheri Khola	111	29
	Mahakali	-	Ragun Khola	130	30
	Karnali	West Seti	Lower West Seti	127	31
	Gandaki	Kali Gandaki	Nisi Khola	87	32
	Koshi	Sun Koshi	Bhote Koshi	40	33
	Koshi	Sun Koshi	Chauri Khola	41	34
	Karnali	Thuli Bheri	Upper Bheri	105	35
	Karnali	Thuli Bheri	Sani Bheri	98	36
	Koshi	Sun Koshi	Kalunje Khola	42	37
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	38
	Karnali	West Seti	Budhi Ganga	124	39

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Sun Koshi	Jhikhu Khola	45	40
	Karnali	West Seti	Kalanga Gad	132	41
	Karnali	Tila	Lower Tila	115	42
	Karnali	Thuli Bheri	Mujkot Khola	112	43
	-	West Rapti	Siban Khola	93	44
	Mahakali	-	Chamaliya	133	45
	Koshi	Sun Koshi	Rosi Khola	44	46
	Karnali	-	Banda Gad	128	47
	Karnali	Thuli Bheri	Saru Khola	104	48
	Koshi	Tamakoshi	Middle Tamakoshi	38	49
	Koshi	Sun Koshi	Bhushe Khola	46	50
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	51
	Karnali	Thuli Bheri	Lower Bheri	102	52
	Koshi	Arun	Middle Arun	10	53
	-	Babai	Sarada	101	54
	Koshi	Tamakoshi	Khare Khola	36	55
	-	West Rapti	Arun Khola	90	56
Low (0.000-0.415)	Karnali	Thuli Bheri	Middle Bheri	100	57
	-	Bagmati	Kokhajor Khola	43	58
	Karnali	-	Sera Gad	129	59
	-	Tinau	Banganga	78	60
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	61
	Gandaki	East Seti	Madi	68	62
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	63
	-	West Rapti	Jhimruk Khola	88	64
	Karnali	West Seti	Chaira Khola	123	65
	Koshi	Dudh Koshi	Hongu Khola	18	66
	Karnali	Tila	Ruru Khola	114	67
	-	West Rapti	Rapti	89	68
	Gandaki	East Rapti	East Rapti	54	69
	Gandaki	East Seti	Upper East Seti	73	70
	-	West Rapti	Madi Khola	91	71
	-	Kamala	Chandaha Khola	31	72
	Gandaki	East Rapti	Gorandhi Khola	56	73
	Gandaki	Kali Gandaki	Ridi Khola	79	74
	-	West Rapti	Lindri Khola	92	75
	Koshi	Sun Koshi	Gangeti Khola	33	76
	Karnali	Thuli Bheri	Lukum Khola	94	77
	-	Bagmati	Lower Bagmati	53	78
	-	Tinau	West Tinau	77	79
	Koshi	Indrawati	Lower Indrawati	49	80
	Karnali	Thuli Bheri	Chhera Khola	103	81
	Koshi	Tamakoshi	Lower Tamakoshi	34	82
	Karnali	Thuli Bheri	Sano Bheri	99	83
	Koshi	Indrawati	Upper Indrawati	48	84
	-	Kamala	Thakur Khola	25	85
	Koshi	Sun Koshi	Balephi Khola	47	86
	-	Bagmati	Palun Khola	55	87

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	-	Tinau	East Tinau	76	88
	Koshi	Sun Koshi	Bandijor Khola	30	89
	Koshi	Indrawati	Melamchi	50	90
	Gandaki	Trishuli	Upper Trishuli	61	91
	Gandaki	Trishuli	Mahesh Khola	57	92
	-	Bagmati	Marin Khola	32	93
	Koshi	Sun Koshi	Khansan Khola	26	94
	-	Bagmati	Upper Bagmati	52	95
	Karnali	-	Lower Karnali	122	96
	Koshi	Arun	Sankhuwa Khola	17	97
	-	Kankai	Mai Khola	4	98
	Gandaki	Kali Gandaki	Aandi Khola	75	99
	Koshi	Tamakoshi	Khimti Khola	35	100
	Koshi	Arun	Lower Arun	16	101
	Koshi	Arun	Pikhuwa Khola	15	102
	Karnali	-	Lohare Khola	113	103
	Gandaki	Trishuli	Tadi Khola	51	104
	Gandaki	Trishuli	Kolpu Khola	58	105
	Koshi	Sun Koshi	Yari Khola	23	106
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	107
	Koshi	Tamor	Mewa Khola	8	108
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	109
	Koshi	Arun	Sabha Khola	11	110
	Koshi	Dudh Koshi	Solu Khola	28	111
	Koshi	Arun	Piluwa Khola	12	112
	Karnali	-	Middle Karnali	121	113
	Koshi	Tamor	Ghunsa Khola	1	114
	Gandaki	East Rapti	Arun Khola	71	115
	-	Kamala	Baidyanath Khola	24	116
	Koshi	Likhu	Likhu Khola	29	117
	Gandaki	Trishuli	Middle Trishuli	59	118
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	119
	Gandaki	Trishuli	Trishuli, Seti	70	120
	Koshi	Tamor	Tamor	5	121
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	122
	Koshi	Sun Koshi	Jagarpur Khola	27	123
	Gandaki	Trishuli	Lower Trishuli	64	124
	Gandaki	Marsyangdi	Marsyangdi	67	125
	Gandaki	East Seti	Lower East Seti	69	126
	Koshi	Dudh Koshi	Rawa Khola	19	127
	Koshi	Tamor	Shuban Khola	6	128
	Koshi	Sun Koshi	Sun Koshi	14	129
	Koshi	Tamor	Hewa Khola	3	130
	Koshi	Tamor	Nenwa Khola	7	131
	Gandaki	Trishuli	Bhyaure Khola	60	132
	Koshi	Tamor	Kabeli Khola	2	133
	Koshi	Arun	Lower Piluwa Khola	13	134
	Gandaki	Marsyangdi	Daraudi Khola	66	135

4.2.2. Ecological Risk/Exposure

The ecological risk/exposure index was derived from the human ecological index and physical ecology index. To construct the human ecology index, population per unit of forest area, human poverty and accessibility in terms of road density were considered. Among three indicators, more weightage was given to human poverty followed by accessibility and forest dependency and aggregated to derive the human ecology index. The measurable data on risk/exposure regarding the human ecology are rarely available. Therefore, published documents (MoFSC 2002) that disclose the risk to the natural ecological resources as a function of population were used for this study. MoFSC (2002) mentioned that the higher the number of population over the given natural ecological system, the higher the risk to such a system. Similarly, the natural ecological system of a particular area is also affected by the human poverty and dependency of people on it. Thus, the higher the level of poverty, the greater the pressure to the ecological resources. In addition, motorable roads could play a negative role to the ecological system. Roads could stimulate the rapid illegal extraction of the forest resources. To construct the physical ecological index, two direct factors/indicators were included which could act as hazardous for the natural ecological system. Surface soil erosion and mass wasting were taken as influencing factors for ecological risk/exposure analysis. Soil erosion and mass wasting maps were prepared based on the land system/unit map of LRMP. Land system units are delineated based on geological, geomorphological and climatic factors.

Though surface soil erosion and mass wasting are equally important and vulnerable, however the more weightage was assigned to the surface erosion due to the degree of impact and adverse effect made to the landslide and other hazards. Same procedure was applied to derive the physical index. Finally, both human ecology and physical ecology index were aggregated to get combined ecological risk index after giving equal weightage for standardization (Figure 6).

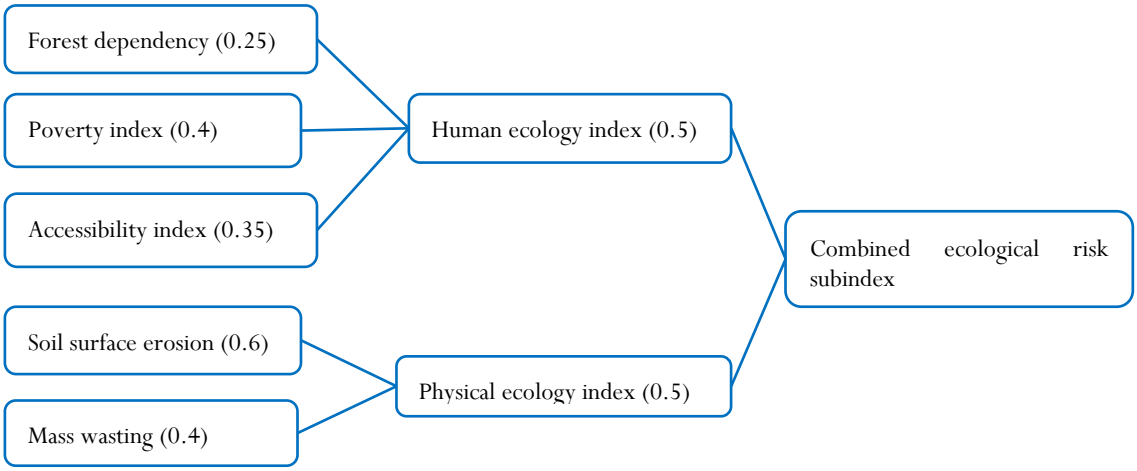
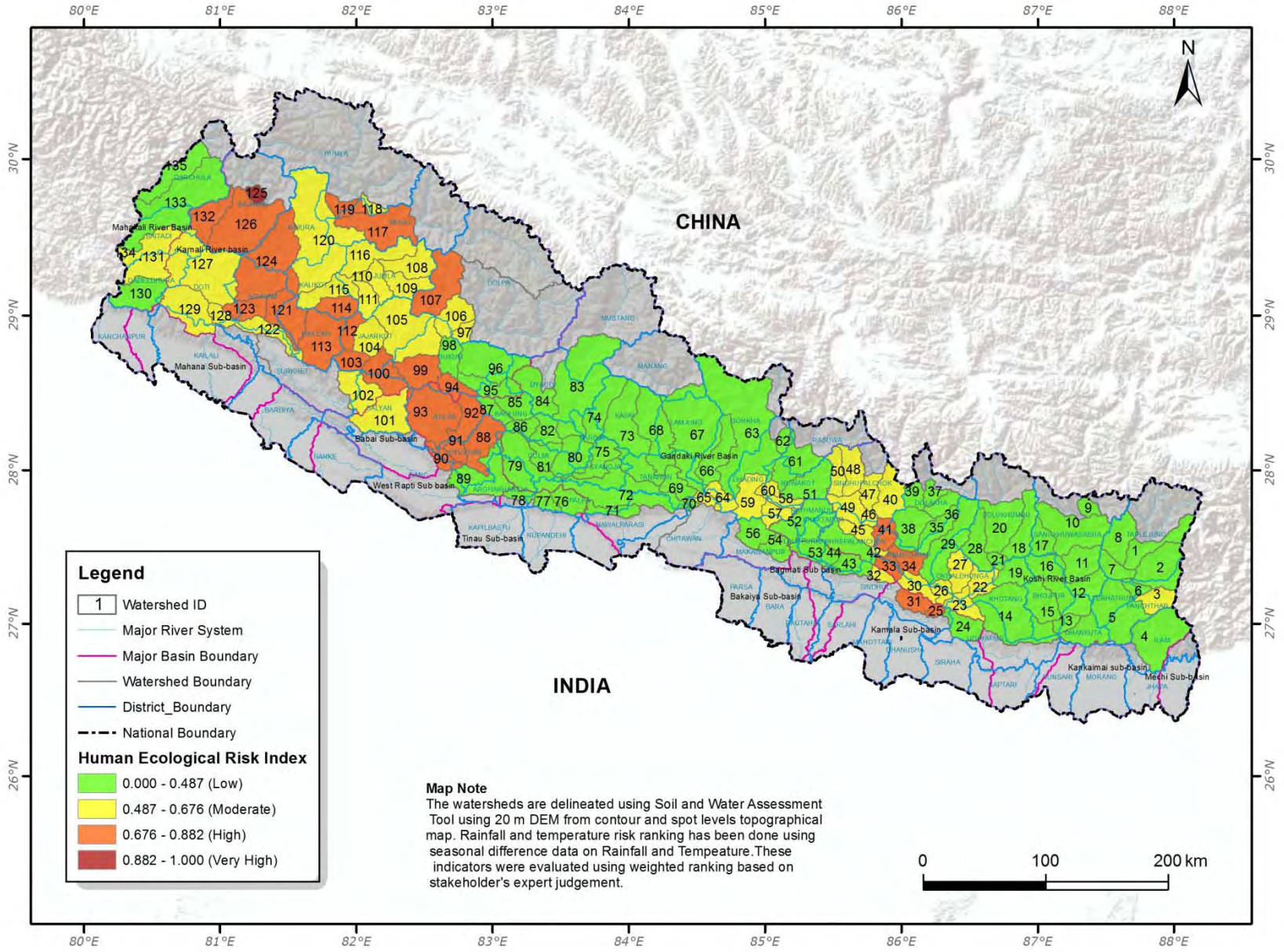


Figure 6. Ecological risk subindices and their weightages (in parentheses).

The watersheds of Middle and High Mountain regions of Nepal were ranked for human and physical ecological risk as presented in Table 10 and 11. Ecological risk/exposure was developed from human ecology (Map 8) and physical ecology risk indices (Map 9). The Upper West Seti Watershed in the Karnali River Basin showed a higher degree of ecological risk. Similarly, the Lower West Seti Watershed in Karnali River Basin, Sun Koshi Watershed and Tamor Watershed in Koshi River Basin, and Budhi Gandaki Watershed in Gandaki River Basin and so on also showed a higher degree of ecological risk.



Map 8. Human ecological risk map of watersheds in Middle and High Mountain regions

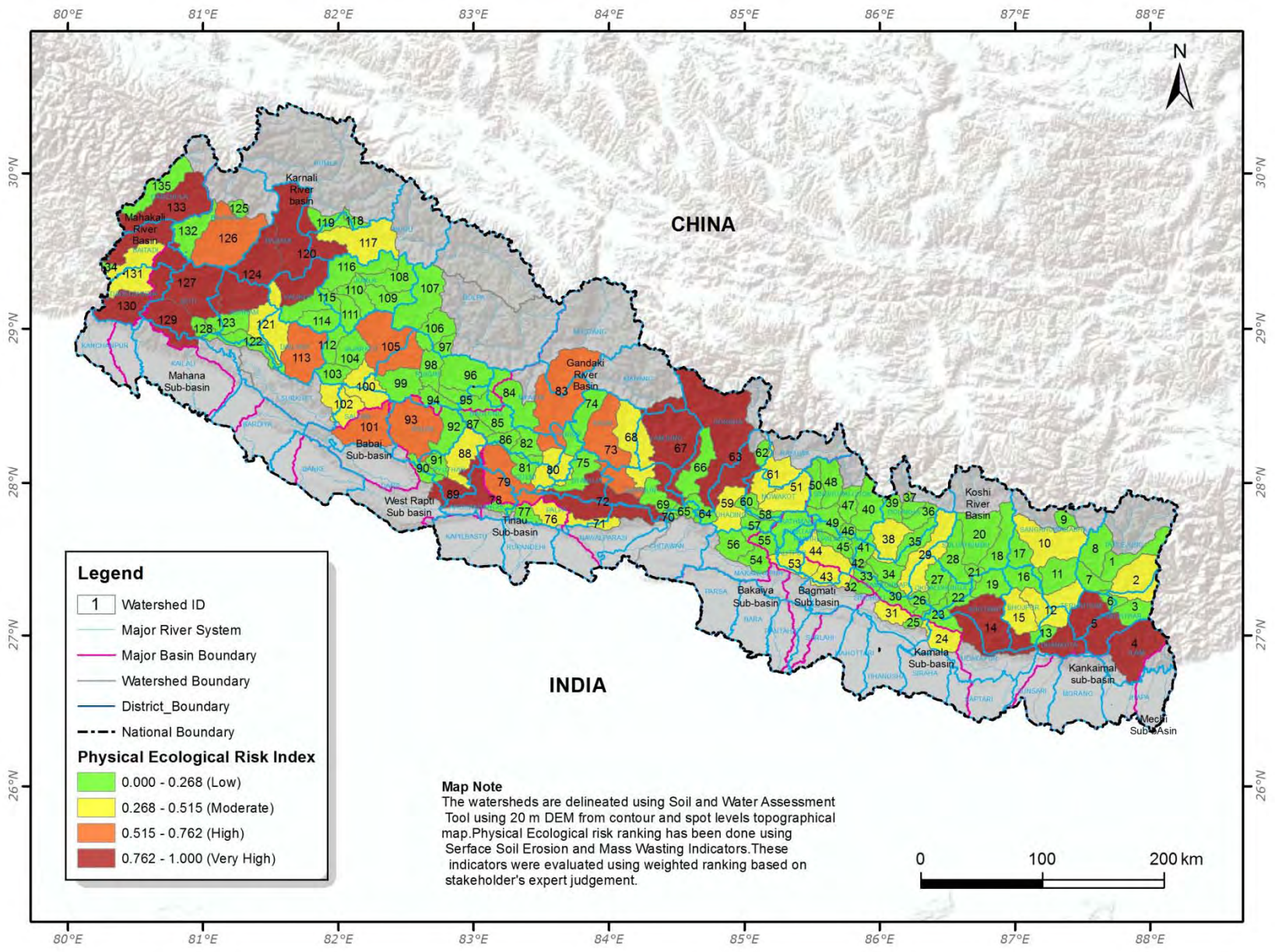
Similarly, watersheds were ranked based on combined/multiple ecological risk indices and presented in Table 12 and Map 10. The Lower West Seti Watershed and Sera Gad Watershed in Karnali River Basin, Upper Karnali Watershed and Budhi Ganga Watershed in Karnali River Basin, Siban Khola Watershed in West Rapti Sub-basin, and so on showed a higher degree of ecological risk/exposure.

Table 10. Watersheds ranked by human ecological risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.882-1.000)	Karnali	West Seti	Upper West Seti	125	1
High (0.676-0.882)	-	Kamala	Thakur Khola	25	2
	Koshi	Tamakoshi	Lower Tamakoshi	34	3
	Karnali	West Seti	Chaira Khola	123	4
	-	West Rapti	Siban Khola	93	5
	Karnali	Thuli Bheri	Chhera Khola	103	6
	Karnali	Thuli Bheri	Lukum Khola	94	7
	-	West Rapti	Arun Khola	90	8
	Karnali	-	Middle Karnali	121	9
	Karnali	Thuli Bheri	Middle Bheri	100	10
	-	West Rapti	Lindri Khola	92	11
	Karnali	Thuli Bheri	Mujkot Khola	112	12
	Koshi	Sun Koshi	Gangeti Khola	33	13
	Karnali	West Seti	Kalanga Gad	132	14
	Karnali	Tila	Ruru Khola	114	15
	Karnali	Thuli Bheri	Bheri	107	16
	Karnali	West Seti	Budhi Ganga	124	17
	Karnali	West Seti	Middle West Seti	126	18
	-	Kamala	Chandaha Khola	31	19
	Karnali	Humla Karnali	Humla Karnali	119	20
	-	West Rapti	Madi Khola	91	21
	Koshi	Sun Koshi	Chauri Khola	41	22
	Karnali	Thuli Bheri	Sano Bheri	99	23
	-	West Rapti	Jhimruk Khola	88	24
	Karnali	-	Lohare Khola	113	25
Moderate (0.487-0.676)	Karnali	Mugu Karnali	Mugu Karnali	117	26
	Karnali	Tila	Lower Tila	115	27
	Koshi	Sun Koshi	Yari Khola	23	28
	Karnali	Tila	Bheri Khola	111	29
	Koshi	Sun Koshi	Kalunje Khola	42	30
	-	Babai	Sarada	101	31
	Karnali	-	Lower Karnali	122	32
	Karnali	Thuli Bheri	Thuli Bheri	106	33
	Karnali	-	Sera Gad	129	34
	Karnali	Thuli Bheri	Saru Khola	104	35
	Mahakali	-	Surnaya Gad	131	36
	Mahakali	-	Gairad Khola	134	37
	Karnali	-	Banda Gad	128	38
	Gandaki	Trishuli	Kolpu Khola	58	39
	Karnali	Humla Karnali	Loti Karnali	118	40

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	Thuli Bheri	Sai Kumari Khola	97	41
	Karnali	-	Upper Karnali	120	42
	Koshi	Indrawati	Lower Indrawati	49	43
	Koshi	Sun Koshi	Bandijor Khola	30	44
	Gandaki	Trishuli	Middle Trishuli	59	45
	Karnali	Tila	Daine Khola	116	46
	Karnali	Tila	Upper Tila	110	47
	Karnali	Tila	Juliodar Khola	109	48
	Karnali	West Seti	Lower West Seti	127	49
	Koshi	Sun Koshi	Jhikhu Khola	45	50
	Karnali	Thuli Bheri	Upper Bheri	105	51
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	52
	Koshi	Sun Koshi	Bhushe Khola	46	53
	Gandaki	Trishuli	Bhyaure Khola	60	54
	Koshi	Tamor	Hewa Khola	3	55
	Karnali	Thuli Bheri	Lower Bheri	102	56
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	57
	Koshi	Sun Koshi	Balephi Khola	47	58
	Karnali	Tila	Chaudhabis Khola	108	59
	Koshi	Indrawati	Melamchi	50	60
	Koshi	Sun Koshi	Jagarpur Khola	27	61
	Gandaki	Trishuli	Lower Trishuli	64	62
	Gandaki	Trishuli	Mahesh Khola	57	63
	Koshi	Sun Koshi	Bhotekoshi	40	64
	Koshi	Indrawati	Upper Indrawati	48	65
	-	Bagmati	Marin Khola	32	66
	Koshi	Sun Koshi	Khansan Khola	26	67
Low (0.000-0.487)	Koshi	Tamakoshi	Middle Tamakoshi	38	68
	Karnali	Thuli Bheri	Sani Bheri	98	69
	Koshi	Tamakoshi	Khimti Khola	35	70
	Gandaki	Trishuli	Upper Trishuli	61	71
	Koshi	Tamor	Shuban Khola	6	72
	-	Kamala	Baidyanath Khola	24	73
	Koshi	Arun	Pikhuwa Khola	15	74
	Gandaki	East Seti	Lower East Seti	69	75
	-	West Rapti	Rapti	89	76
	Koshi	Likhu	Likhu Khola	29	77
	Gandaki	Trishuli	Tadi Khola	51	78
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	79
	Mahakali	-	Chamaliya	133	80
	Karnali	Thuli Bheri	Ganga	95	81
	Koshi	Sun Koshi	Sun Koshi	14	82
	Mahakali	-	Ragun Khola	130	83
	Koshi	Sun Koshi	Rosi Khola	44	84
	Gandaki	Kali Gandaki	Aandi Khola	75	85
	Gandaki	Trishuli	Trishuli-Seti	70	86
	Koshi	Dudh Koshi	Solu Khola	28	87
	Koshi	Tamor	Tamor	5	88

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	89
	Koshi	Arun	Piluwa Khola	12	90
	Koshi	Dudh Koshi	Rawa Khola	19	91
	Koshi	Arun	Lower Arun	16	92
	-	Bagmati	Palun Khola	55	93
	Gandaki	Marsyangdi	Daraudi Khola	66	94
	Gandaki	Kali Gandaki	Daram Khola	82	95
	Gandaki	Budhi Gandaki	Bhabil Khola	62	96
	-	Bagmati	Kokhajor Khola	43	97
	Gandaki	Kali Gandaki	Nisi Khola	87	98
	Karnali	Thuli Bheri	Pelma Khola	96	99
	Koshi	Arun	Sankhuwa Khola	17	100
	Gandaki	Kali Gandaki	Taman Khola	85	101
	Koshi	Tamakoshi	Sagu Khola	39	102
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	103
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	104
	Gandaki	East Rapti	East Rapti	54	105
	Koshi	Arun	Upper Arun	9	106
	Koshi	Dudh Koshi	Hongu Khola	18	107
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	108
	-	Kankai	Mai Khola	4	109
	Gandaki	Marsyangdi	Marsyangdi	67	110
	Koshi	Arun	Lower Piluwa Khola	13	111
	Koshi	Arun	Sabha Khola	11	112
	Mahakali	-	Mahakali	135	113
	Gandaki	Kali Gandaki	Myagdi Khola	84	114
	-	Bagmati	Upper Bagmati	52	115
	Koshi	Arun	Middle Arun	10	116
	Koshi	Tamakoshi	Khare Khola	36	117
	Koshi	Tamakoshi	Upper Tamakoshi	37	118
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	119
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	120
	Gandaki	East Seti	Upper East Seti	73	121
	Koshi	Tamor	Kabeli Khola	2	122
	Gandaki	East Rapti	Gorandhi Khola	56	123
	Gandaki	East Seti	Madi	68	124
	-	Tinau	Banganga	78	125
	Gandaki	Kali Gandaki	Ridi Khola	79	126
	Koshi	Tamor	Nenwa Khola	7	127
	-	Bagmati	Lower Bagmati	53	128
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	129
	Koshi	Tamor	Mewa Khola	8	130
	Gandaki	East Rapti	Arun Khola	71	131
	-	Tinau	East Tinau	76	132
	Koshi	Tamor	Ghunsa Khola	1	133
	-	Tinau	West Tinau	77	134
	Gandaki	Kali Gandaki	Modi Khola	74	135



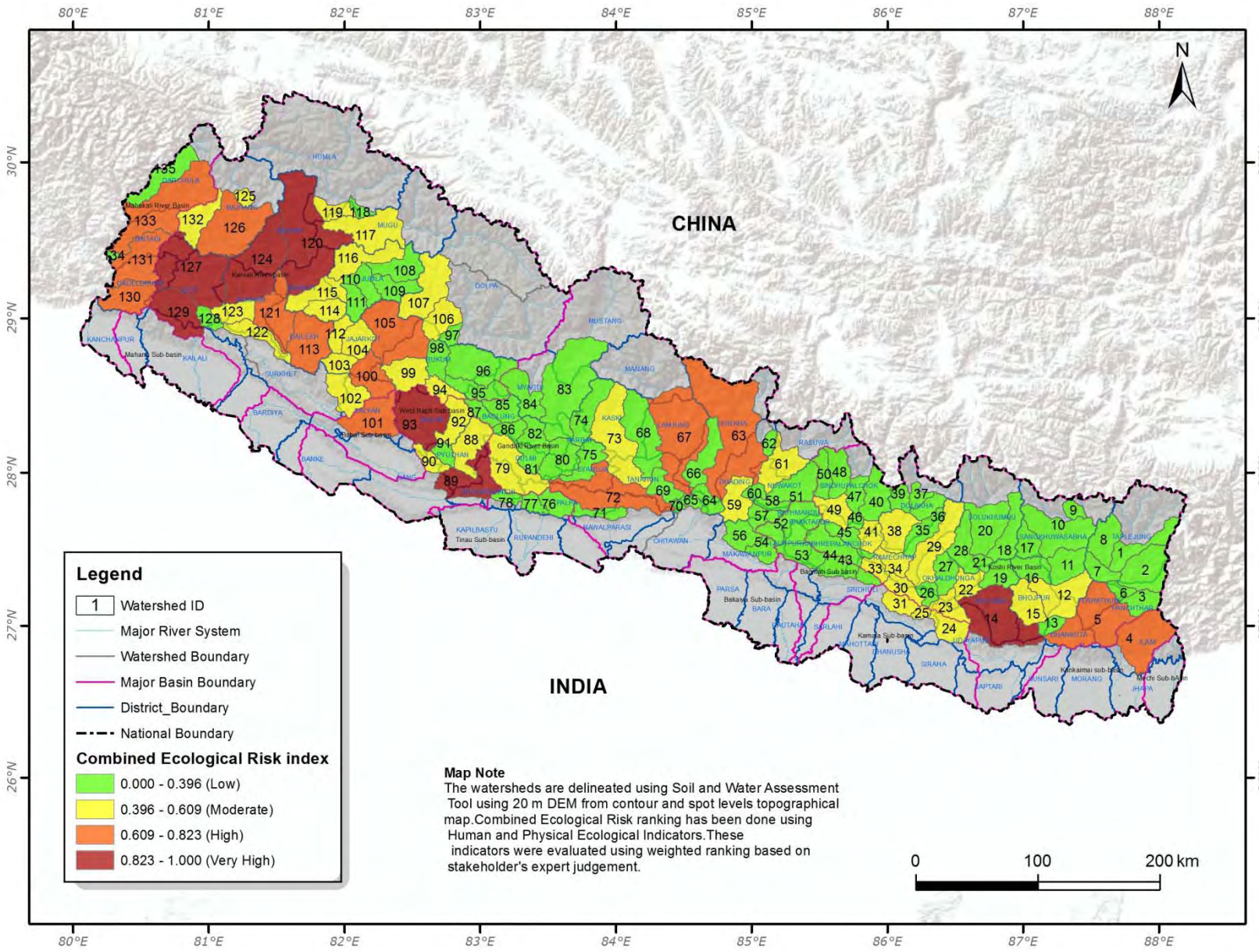
Map 9. Physical ecological risk map of watersheds in Middle and High Mountain regions.

Table 11. Watersheds ranked by physical ecological risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.762-1.000)	Karnali	West Seti	Lower West Seti	127	1
	Koshi	Sun Koshi	Sun Koshi	14	2
	Koshi	Tamor	Tamor	5	3
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	4
	Karnali	-	Upper Karnali	120	5
	-	Kankai	Mai Khola	4	6
	-	West Rapti	Rapti	89	7
	Karnali	-	Sera Gad	129	8
	Mahakali	-	Chamaliya	133	9
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	10
	Mahakali	-	Ragun Khola	130	11
	Karnali	West Seti	Budhi Ganga	124	12
	Gandaki	Marsyangdi	Marsyangdi	67	13
High (0.515-0.762)	-	West Rapti	Siban Khola	93	14
	Gandaki	East Seti	Upper East Seti	73	15
	Karnali	West Seti	Middle West Seti	126	16
	Gandaki	Kali Gandaki	Ridi Khola	79	17
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	18
	Karnali	Thuli Bheri	Upper Bheri	105	19
	Karnali	-	Lohare Khola	113	20
	-	Babai	Sarada	101	21
Moderate (0.268-0.515)	Mahakali	-	Surnaya Gad	131	22
	Koshi	Arun	Piluwa Khola	12	23
	-	Kamala	Baidyanath Khola	24	24
	Karnali	-	Middle Karnali	121	25
	Gandaki	East Seti	Madi	68	26
	Koshi	Likhu	Likhu Khola	29	27
	Koshi	Tamor	Kabeli Khola	2	28
	-	Bagmati	Kokhajor Khola	43	29
	-	Kamala	Chandaha Khola	31	30
	Koshi	Arun	Middle Arun	10	31
	-	West Rapti	Jhimruk Khola	88	32
	Karnali	Mugu Karnali	Mugu Karnali	117	33
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	34
	Karnali	Thuli Bheri	Middle Bheri	100	35
	Gandaki	Trishuli	Tadi Khola	51	36
	Karnali	Thuli Bheri	Lower Bheri	102	37
	Koshi	Arun	Pikhuwa Khola	15	38
	Koshi	Tamakoshi	Middle Tamakoshi	38	39
	Gandaki	East Rapti	Arun Khola	71	40
	Gandaki	Trishuli	Middle Trishuli	59	41
	-	Bagmati	Lower Bagmati	53	42
	Koshi	Sun Koshi	Rosi Khola	44	43
	Gandaki	Trishuli	Upper Trishuli	61	44
	-	Tinau	East Tinau	76	45
Low (0.000-0.268)	Gandaki	East Rapti	Gorandhi Khola	56	46
	Gandaki	Marsyangdi	Daraudi Khola	66	47

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	Thuli Bheri	Sano Bheri	99	48
	Koshi	Arun	Sabha Khola	11	49
	-	Bagmati	Upper Bagmati	52	50
	Gandaki	Kali Gandaki	Aandi Khola	75	51
	Koshi	Sun Koshi	Bhotekoshi	40	52
	-	West Rapti	Lindri Khola	92	53
	Koshi	Indrawati	Lower Indrawati	49	54
	-	Tinau	West Tinau	77	55
	Karnali	-	Lower Karnali	122	56
	Karnali	Tila	Daine Khola	116	57
	Karnali	West Seti	Kalanga Gad	132	58
	Karnali	Thuli Bheri	Pelma Khola	96	59
	-	Tinau	Banganga	78	60
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	61
	Karnali	Tila	Lower Tila	115	62
	Mahakali	-	Mahakali	135	63
	Karnali	Thuli Bheri	Saru Khola	104	64
	Gandaki	Kali Gandaki	Modi Khola	74	65
	Gandaki	Kali Gandaki	Myagdi Khola	84	66
	Koshi	Arun	Lower Arun	16	67
	Karnali	West Seti	Chaira Khola	123	68
	Karnali	Thuli Bheri	Bheri	107	69
	Koshi	Sun Koshi	Jagarpur Khola	27	70
	Koshi	Tamakoshi	Khimti Khola	35	71
	Koshi	Tamor	Hewa Khola	3	72
	Koshi	Dudh Koshi	Solu Khola	28	73
	Gandaki	East Rapti	East Rapti	54	74
	Koshi	Sun Koshi	Yari Khola	23	75
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	76
	Gandaki	East Seti	Lower East Seti	69	77
	Koshi	Dudh Koshi	Rawa Khola	19	78
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	79
	Koshi	Sun Koshi	Chauri Khola	41	80
	Koshi	Sun Koshi	Bandijor Khola	30	81
	Koshi	Tamakoshi	Lower Tamakoshi	34	82
	Gandaki	Kali Gandaki	Daram Khola	82	83
	Koshi	Tamor	Ghunsa Khola	1	84
	Karnali	Thuli Bheri	Thuli Bheri	106	85
	Koshi	Indrawati	Upper Indrawati	48	86
	Karnali	Thuli Bheri	Chhera Khola	103	87
	Koshi	Dudh Koshi	Hongu Khola	18	88
	-	Bagmati	Marin Khola	32	89
	Koshi	Tamor	Mewa Khola	8	90
	Gandaki	Trishuli	Mahesh Khola	57	91
	Gandaki	Trishuli	Lower Trishuli	64	92
	Koshi	Sun Koshi	Balephi Khola	47	93
	Gandaki	Kali Gandaki	Taman Khola	85	94
	-	West Rapti	Arun Khola	90	95

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Sun Koshi	Jhikhu Khola	45	96
	Koshi	Tamor	Nenwa Khola	7	97
	Karnali	Thuli Bheri	Ganga	95	98
	Karnali	Tila	Ruru Khola	114	99
	Karnali	-	Banda Gad	128	100
	Karnali	Thuli Bheri	Sani Bheri	98	101
	Karnali	Thuli Bheri	Lukum Khola	94	102
	Karnali	Tila	Chaudhabis Khola	108	103
	Karnali	Humla Karnali	Humla Karnali	119	104
	Koshi	Indrawati	Melamchi	50	105
	Koshi	Sun Koshi	Gangeti Khola	33	106
	Koshi	Arun	Sankhuwa Khola	17	107
	Karnali	Thuli Bheri	Mujkot Khola	112	108
	Karnali	Tila	Upper Tila	110	109
	-	Bagmati	Palun Khola	55	110
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	111
	Karnali	Tila	Juliodar Khola	109	112
	Koshi	Sun Koshi	Khansan Khola	26	113
	-	Kamala	Thakur Khola	25	114
	Karnali	Tila	Bheri Khola	111	115
	Koshi	Arun	Lower Piluwa Khola	13	116
	Gandaki	Kali Gandaki	Nisi Khola	87	117
	Koshi	Tamor	Shuban Khola	6	118
	-	West Rapti	Madi Khola	91	119
	Gandaki	Trishuli	Kolpu Khola	58	120
	Koshi	Tamakoshi	Sagu Khola	39	121
	Gandaki	Trishuli	Bhyaure Khola	60	122
	Koshi	Tamakoshi	Khare Khola	36	123
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	124
	Koshi	Tamakoshi	Upper Tamakoshi	37	125
	Koshi	Sun Koshi	Bhushe Khola	46	126
	Koshi	Arun	Upper Arun	9	127
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	128
	Gandaki	Budhi Gandaki	Bhabil Khola	62	129
	Karnali	Humla Karnali	Loti Karnali	118	130
	Gandaki	Trishuli	Trishuli, Seti	70	131
	Karnali	Thuli Bheri	Sai Kumari Khola	97	132
	Karnali	West Seti	Upper West Seti	125	133
	Mahakali	-	Gairad Khola	134	134
	Koshi	Sun Koshi	Kalunje Khola	42	135



Map 10. Combined ecological risk/exposure map of watersheds in Middle and High Mountain regions.

Table 12. Watersheds ranked by combined ecological risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.823-1.000)	Karnali	West Seti	Lower West Seti	127	1
	Karnali	-	Sera Gad	129	2
	Karnali	-	Upper Karnali	120	3
	Karnali	West Seti	Budhi Ganga	124	4
	-	West Rapti	Siban Khola	93	5
	Koshi	Sun Koshi	Sunkoshi	14	6
	-	West Rapti	Rapti	89	7
High (0.609-.823)	Koshi	Tamor	Tamor	5	8
	Mahakali	-	Chamaliya	133	9
	Karnali	West Seti	Middle West Seti	126	10
	Mahakali	-	Ragun Khola	130	11
	Karnali	-	Lohare Khola	113	12
	Karnali	-	Middle Karnali	121	13
	-	Kankai	Mai Khola	4	14
	-	Babai	Sarada	101	15
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	16
	Mahakali	-	Surnaya Gad	131	17
	Karnali	Thuli Bheri	Upper Bheri	105	18
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	19
	Gandaki	Marshyangdi	Marsyangdi	67	20
	Karnali	Thuli Bheri	Middle Bheri	100	21
Moderate (0.396-0.609)	-	Kamala	Chandaha Khola	31	22
	-	West Rapti	Jhimruk Khola	88	23
	Karnali	Mugu Karnali	Mugu Karnali	117	24
	Karnali	West Seti	Upper West Seti	125	25
	Karnali	West Seti	Chaira Khola	123	26
	Koshi	Tama Koshi	Lower Tamakoshi	34	27
	-	Kamala	Thakur Khola	25	28
	-	Kamala	Baidyanath Khola	24	29
	-	West Rapti	Lindri Khola	92	30
	Karnali	Thuli Bheri	Sano Bheri	99	31
	Karnali	West Seti	Kalanga Gad	132	32
	Karnali	Thuli Bheri	Chhera Khola	103	33
	Gandaki	Trishuli	Middle Trishuli	59	34
	Karnali	Thuli Bheri	Bheri	107	35
	Koshi	Arun	Piluwa Khola	12	36
	Karnali	Thuli Bheri	Lower Bheri	102	37
	Karnali	Tila	Lower Tila	115	38
	Karnali	-	Lower Karnali	122	39
	-	West Rapti	Arun Khola	90	40
	Koshi	Likhu	Likhu Khola	29	41
	Karnali	Thuli Bheri	Saru Khola	104	42
	Karnali	Thuli Bheri	Lukum Khola	94	43
	Gandaki	East Seti	Upper East Seti	73	44
	Koshi	Sun Koshi	Chauri Khola	41	45
	Koshi	Indrawati	Lower Indrawati	49	46
	Koshi	Sun Koshi	Yari Khola	23	47

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	Tila	Daine Khola	116	48
	Karnali	Tila	Ruru Khola	114	49
	Koshi	Sun Koshi	Gangeti Khola	33	50
	Karnali	Thuli Bheri	Mujkot Khola	112	51
	Karnali	Thuli Bheri	Thuli Bheri	106	52
	Karnali	Humla Karnali	Humla Karnali	119	53
	Koshi	Tama Koshi	Middle Tamakoshi	38	54
	Koshi	Arun	Pikhuwa Khola	15	55
	Gandaki	Trishuli	Upper Trishuli	61	56
	Gandaki	Kali Gandaki	Ridi Khola	79	57
	Koshi	Dudh Koshi	Lower Dudhkoshi	22	58
	Koshi	Sun Koshi	Bandijor Khola	30	59
Low (0.000-0.396)	-	West Rapti	Madi Khola	91	60
	Gandaki	Trishuli	Tadi Khola	51	61
	Koshi	Tamor	Hewa Khola	3	62
	Karnali	-	Banda Gad	128	63
	Karnali	Tila	Bheri Khola	111	64
	Koshi	Sun Koshi	Bhote Koshi	40	65
	Koshi	Sun Koshi	Jagarpur Khola	27	66
	Koshi	Sun Koshi	Jhikhu Khola	45	67
	-	Bagmati	Kokhajor Khola	43	68
	Koshi	Sun Koshi	Rosi Khola	44	69
	Karnali	Tila	Upper Tila	110	70
	Gandaki	Trishuli	Kolpu Khola	58	71
	Karnali	Tila	Juliodar Khola	109	72
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	73
	Koshi	Sun Koshi	Balephi Khola	47	74
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	75
	Koshi	Sun Koshi	Kalunje Khola	42	76
	Gandaki	East Seti	Madi	68	77
	Koshi	Tamakoshi	Khimti Khola	35	78
	Gandaki	Trishuli	Lower Trishuli	64	79
	Mahakali	-	Gairad Khola	134	80
	Gandaki	Trishuli	Mahesh Khola	57	81
	Gandaki	Marshyangdi	Daraudi Khola	66	82
	Karnali	Tila	Chaudhabis Khola	108	83
	Gandaki	Kali Gandaki	Aandi Khola	75	84
	Koshi	Indrawati	Melamchi	50	85
	Karnali	Humla Karnali	Loti Karnali	118	86
	Koshi	Indrawati	Upper Indrawati	48	87
	Gandaki	Trishuli	Bhyaure Khola	60	88
	Karnali	Thuli Bheri	Sai Kumari Khola	97	89
	-	Bagmati	Marin Khola	32	90
	Koshi	Sun Koshi	Bhushe Khola	46	91
	Gandaki	East Seti	Lower East Seti	69	92
	Koshi	Tamor	Kabeli Khola	2	93
	Gandaki	Trishuli	Trishuli, Marshyangdi	65	94
	Koshi	Arun	Middle Arun	10	95

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	Thuli Bheri	Sani Bheri	98	96
	Koshi	Arun	Lower Arun	16	97
	Koshi	Sun Koshi	Khansan Khola	26	98
	Koshi	Dudh Koshi	Solu Khola	28	99
	Koshi	Dudh Koshi	Rawa Khola	19	100
	Karnali	Thuli Bheri	Pelma Khola	96	101
	Karnali	Thuli Bheri	Ganga	95	102
	Koshi	Tamor	Shuban Khola	6	103
	Koshi	Arun	Sabha Khola	11	104
	Gandaki	Kali Gandaki	Daram Khola	82	105
	Koshi	Dudh Koshi	Upper Dudhkoshi	20	106
	-	Bagmati	Upper Bagmati	52	107
	Gandaki	East Rapti	Gorandhi Khola	56	108
	Gandaki	East Rapti	East Rapti	54	109
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	110
	-	Bagmati	Palun Khola	55	111
	Mahakali	-	Mahakali	135	112
	Koshi	Dudh Koshi	Middle Dudhkoshi	21	113
	Gandaki	Kali Gandaki	Taman Khola	85	114
	-	Bagmati	Lower Bagmati	53	115
	Gandaki	Kali Gandaki	Myagdi Khola	84	116
	Koshi	Dudh Koshi	Hongu Khola	18	117
	Koshi	Arun	Sankhuwa Khola	17	118
	Gandaki	Kali Gandaki	Nisi Khola	87	119
	Gandaki	Trishuli	Trishuli, Seti	70	120
	-	Tinau	Banganga	78	121
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	122
	Koshi	Tamakoshi	Sagu Khola	39	123
	Gandaki	East Rapti	Arun Khola	71	124
	Gandaki	Budhi Gandaki	Bhabil Khola	62	125
	Koshi	Arun	Lower Piluwa Khola	13	126
	Koshi	Arun	Upper Arun	9	127
	-	Tinau	East Tinau	76	128
	Koshi	Tamakoshi	Khare Khola	36	129
	Koshi	Tamor	Nenwa Khola	7	130
	Koshi	Tamakoshi	Upper Tamakoshi	37	131
	-	Tinau	West Tinau	77	132
	Koshi	Tamor	Mewa Khola	8	133
	Koshi	Tamor	Ghunsa Khola	1	134
	Gandaki	Kali Gandaki	Modi Khola	74	135

4.2.3. Landslide/Flood Risk Exposure

Historical index and positive rainfall trend index were used to construct the landslide/flood risk subindex. Historical index was constructed using the compatible format of recent 9 years' database and 1 year's most recent data of the Ministry of Home Affair (MoHA 2012) regarding landslide/flood occurrence, deaths, injured persons and loss of property. These data were separately weighted, standardized and combined to make the historical index. Similarly, the average annual positive and negative rainfall data for 30 years (1976-2005) of 161 meteorological stations were gathered from the publication of Practical Action, Nepal (Practical Action 2009). The station-wise rainfall trend data were integrated at watersheds using spatial analysis, i.e., Inverse Distance Weightage (IDW) interpolation method to obtain watersheds-wise rainfall trends. The watersheds-wise rainfall trends were then assigned weightage and standardized.

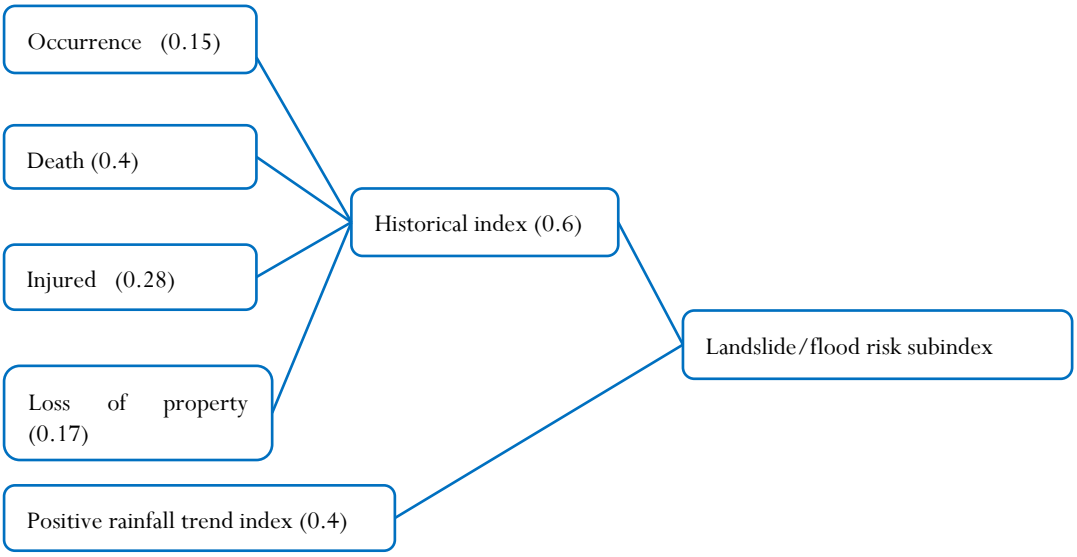
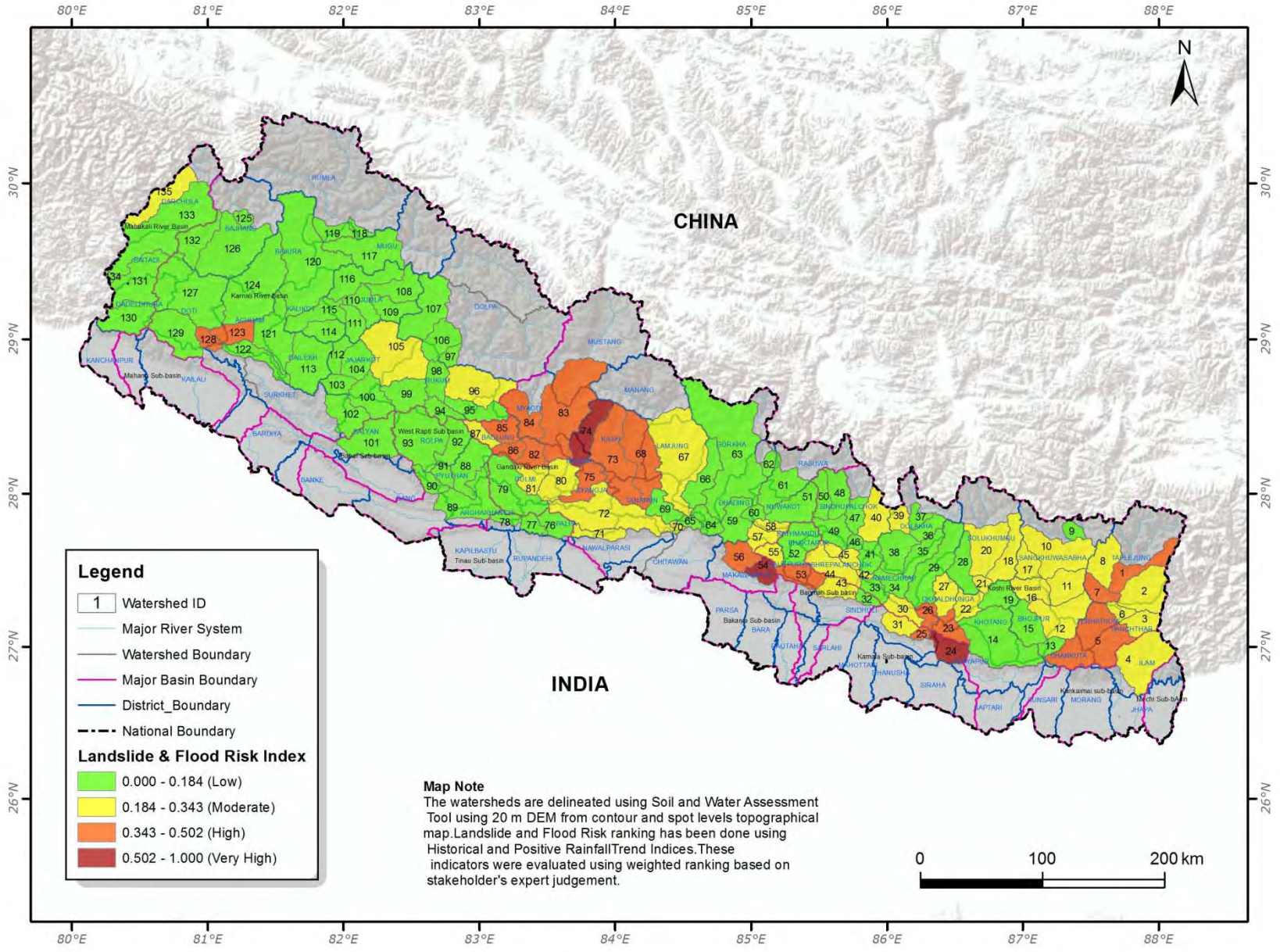


Figure 7. Landslide/flood risk subindices and their weightages (in parentheses)

To construct the historical index, more weightage was given to death followed by injured, property loss of property and weightage to the occurrence. Both historical and positive rainfall trend indices were standardized by giving more weightage to the historical index. Finally, standardized historical and positive rainfall trend indices were combined to construct the landslide/flood risk subindex (Figure 7) and values were normalized between 0 and 1. The subindex was then used to produce the landslide/flood risk map (Map 11).



Map 11. Landslide/flood risk map of watersheds in Middle and High Mountain regions.

Based on the landslide/flood risk exposure index, watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 13. It shows that Baidyanath Khola Watershed in Kamala Sub-basin, East Rapti Watershed and Modi Khola Watershed in Gandaki River Basin are highly landslide-/flood-risk prone compared to other basins and their watersheds.

Table 13. Watersheds ranked by landslides and flood risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.502-1.000)	-	Kamala	Baidyanath Khola	24	1
	Gandaki	East Rapti	East Rapti	54	2
	Gandaki	Kali Gandaki	Modi Khola	74	3
High (0.343-0.502)	Koshi	Sun Koshi	Yari Khola	23	4
	Gandaki	Kali Gandaki	Daram Khola	82	5
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	6
	Gandaki	East Seti	Upper East Seti	73	7
	Koshi	Tamor	Tamor	5	8
	Gandaki	East Rapti	Gorandhi Khola	56	9
	-	Bagmati	Lower Bagmati	53	10
	Karnali	West Seti	Chaira Khola	123	11
	Gandaki	East Seti	Madi	68	12
	Gandaki	Kali Gandaki	Taman Khola	85	13
	Koshi	Sun Koshi	Khansan Khola	26	14
	Koshi	Tamor	Ghunsa Khola	1	15
	Karnali	-	Banda Gad	128	16
	Gandaki	Kali Gandaki	Myagdi Khola	84	17
	Gandaki	Kali Gandaki	Aandi Khola	75	18
	Koshi	Tamor	Nenwa Khola	7	19
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	20
	-	Kamala	Thakur Khola	25	21
Moderate (0.184-0.343)	Koshi	Tamor	Mewa Khola	8	22
	Koshi	Arun	Middle Arun	10	23
	-	Kamala	Chandaha Khola	31	24
	Gandaki	Marsyangdi	Marsyangdi	67	25
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	26
	Koshi	Tamor	Kabeli Khola	2	27
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	28
	Koshi	Sun Koshi	Jagarpur Khola	27	29
	Gandaki	Trishuli	Trishuli-Seti	70	30
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	31
	Koshi	Tamakoshi	Sagu Khola	39	32
	-	Bagmati	Palun Khola	55	33
	Gandaki	East Rapti	Arun Khola	71	34
	-	Kankai	Mai Khola	4	35
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	36
	-	Bagmati	Kokhajor Khola	43	37
	Gandaki	Trishuli	Kolpu Khola	58	38
	Koshi	Sun Koshi	Rosi Khola	44	39
	Koshi	Tamor	Hewa Khola	3	40

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	41
	Koshi	Arun	Lower Arun	16	42
	Koshi	Sun Koshi	Bandijor Khola	30	43
	Gandaki	Kali Gandaki	Nisi Khola	87	44
	Koshi	Tamor	Shuban Khola	6	45
	Karnali	Thuli Bheri	Pelma Khola	96	46
	Koshi	Sun Koshi	Kalunje Khola	42	47
	Koshi	Arun	Sabha Khola	11	48
	Koshi	Sun Koshi	Jhikhu Khola	45	49
	Koshi	Arun	Piluwa Khola	12	50
	Koshi	Dudh Koshi	Hongu Khola	18	51
	Koshi	Sun Koshi	Bhote Koshi	40	52
	Gandaki	Trishuli	Mahesh Khola	57	53
	Mahakali	-	Mahakali	135	54
	Koshi	Arun	Sankhuwa Khola	17	55
	Karnali	Thuli Bheri	Upper Bheri	105	56
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	57
Low (0.000-0.184)	Mahakali	-	Chamaliya	133	58
	Gandaki	Trishuli	Tadi Khola	51	59
	Karnali	-	Lower Karnali	122	60
	Karnali	West Seti	Middle West Seti	126	61
	Karnali	Thuli Bheri	Ganga	95	62
	Karnali	West Seti	Kalanga Gad	132	63
	Koshi	Sun Koshi	Balephi Khola	47	64
	Koshi	Indrawati	Lower Indrawati	49	65
	Koshi	Dudh Koshi	Solu Khola	28	66
	Koshi	Dudh Koshi	Rawa Khola	19	67
	Karnali	West Seti	Upper West Seti	125	68
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	69
	-	Bagmati	Marin Khola	32	70
	Koshi	Sun Koshi	Gangeti Khola	33	71
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	72
	Gandaki	Trishuli	Bhyaure Khola	60	73
	-	Tinau	East Tinau	76	74
	Gandaki	Marsyangdi	Daraudi Khola	66	75
	Gandaki	Trishuli	Middle Trishuli	59	76
	Gandaki	Budhi Gandaki	Bhabil Khola	62	77
	Gandaki	Trishuli	Lower Trishuli	64	78
	Koshi	Arun	Upper Arun	9	79
	Koshi	Likhu	Likhu Khola	29	80
	-	Babai	Sarada	101	81
	-	Bagmati	Upper Bagmati	52	82
	Gandaki	East Seti	Lower East Seti	69	83
	Koshi	Indrawati	Upper Indrawati	48	84
	Koshi	Sun Koshi	Bhushe Khola	46	85
	Karnali	West Seti	Budhi Ganga	124	86
	Koshi	Arun	Lower Piluwa Khola	13	87
	-	West Rapti	Lindri Khola	92	88

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Sun Koshi	Sun Koshi	14	89
	Karnali	West Seti	Lower West Seti	127	90
	-	Tinau	Banganga	78	91
	Mahakali	-	Gairad Khola	134	92
	Koshi	Sun Koshi	Chauri Khola	41	93
	Koshi	Tamakoshi	Khimti Khola	35	94
	Gandaki	Kali Gandaki	Ridi Khola	79	95
	-	West Rapti	Siban Khola	93	96
	Karnali	Thuli Bheri	Middle Bheri	100	97
	Karnali	Tila	Daine Khola	116	98
	Koshi	Indrawati	Melamchi	50	99
	-	West Rapti	Rapti	89	100
	Gandaki	Trishuli	Upper Trishuli	61	101
	Koshi	Arun	Pikhuwa Khola	15	102
	-	West Rapti	Arun Khola	90	103
	Karnali	Thuli Bheri	Saru Khola	104	104
	Karnali	Thuli Bheri	Chhera Khola	103	105
	Karnali	Thuli Bheri	Mujkot Khola	112	106
	Karnali	-	Sera Gad	129	107
	-	West Rapti	Jhimruk Khola	88	108
	Karnali	-	Middle Karnali	121	109
	-	West Rapti	Madi Khola	91	110
	Mahakali	-	Surnaya Gad	131	111
	Koshi	Tamakoshi	Lower Tamakoshi	34	112
	Koshi	Tamakoshi	Middle Tamakoshi	38	113
	Koshi	Tamakoshi	Upper Tamakoshi	37	114
	Koshi	Tamakoshi	Khare Khola	36	115
	Karnali	-	Lohare Khola	113	116
	Mahakali	-	Ragun Khola	130	117
	Karnali	Thuli Bheri	Sai Kumari Khola	97	118
	Karnali	Tila	Bheri Khola	111	119
	Karnali	Thuli Bheri	Thuli Bheri	106	120
	Karnali	Mugu Karnali	Mugu Karnali	117	121
	Karnali	Thuli Bheri	Lukum Khola	94	122
	Karnali	Thuli Bheri	Sano Bheri	99	123
	Karnali	Thuli Bheri	Sani Bheri	98	124
	Karnali	Thuli Bheri	Lower Bheri	102	125
	-	Tinau	West Tinau	77	126
	Karnali	Thuli Bheri	Bheri	107	127
	Karnali	Tila	Lower Tila	115	128
	Karnali	Tila	Ruru Khola	114	129
	Karnali	-	Upper Karnali	120	130
	Karnali	Tila	Upper Tila	110	131
	Karnali	Tila	Chaudhabis Khola	108	132
	Karnali	Tila	Juliodar Khola	109	133
	Karnali	Humla Karnali	Humla Karnali	119	134
	Karnali	Humla Karnali	Loti Karnali	118	135

4.2.4. Drought and Food Risk/Exposure

Drought is a long-term average feature of a dry climate, or with water scarcity, which reflects conditions of long-term imbalances between available water resources and demands (Tallaksen and van Lanen 2004). In this study, the drought index was assessed as an integrated index which shows the combined drought risk at any given location in terms of reliability and vulnerability of precipitation/river discharge. It ranges from 0 to 1. Higher DRI values imply that the area has less reliable precipitation/discharge. The DRI is calculated as follows:

——— —— ..... (Eq. 5)

where, — and ——

————..... (Eq. 6)

V= vulnerability; Imax = maximum drought intensity (maximum individual deficit per time step) in each drought run, ND = the number of drought runs; RV= relative vulnerability; MMP= mean monthly precipitation or mean monthly river discharge; Ns= number of intervals (months) that the target demand (mean monthly precipitation or mean monthly river discharge) was fully met; and N= total number of intervals (months). The DRI was mapped at 0.5^0 resolution.

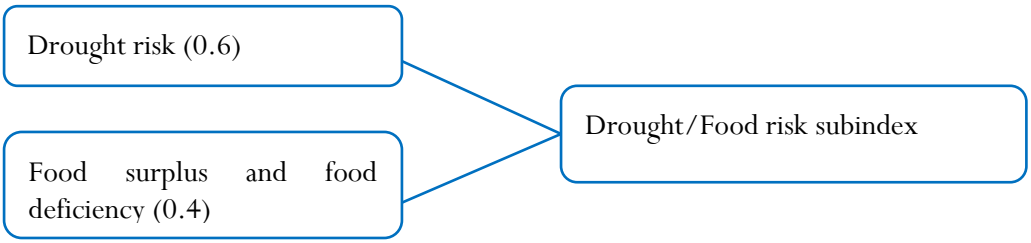
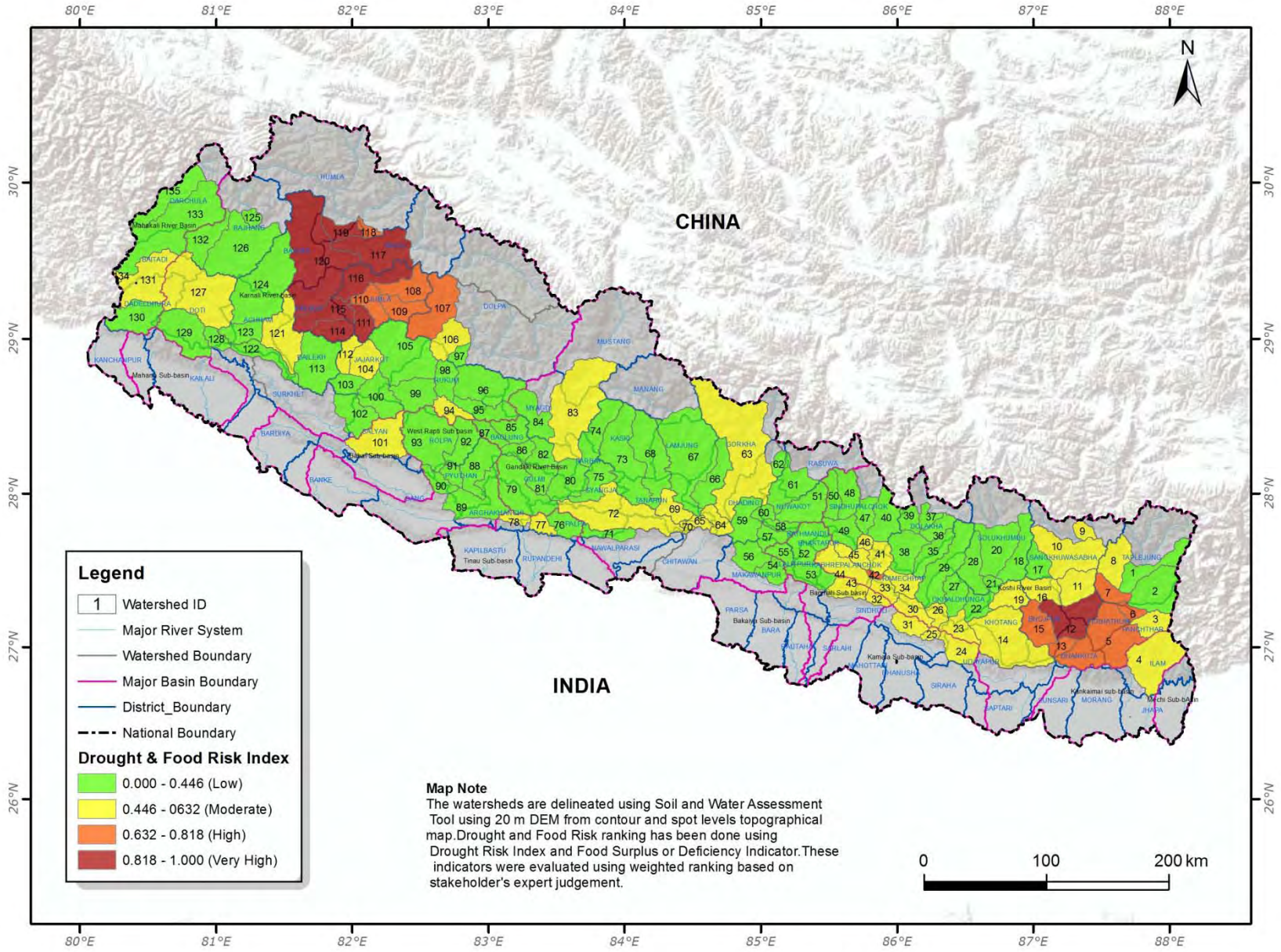


Figure 8. Drought/food risk subindices and their weightages (in parentheses).

Food surplus and deficiency (FSD) and precipitation/river discharge were considered as proxy indicators for this analysis. To calculate the FSD, district-level total food/grain production (cereals and potato) data for the period 2008-2011 were collected from the Ministry of Agriculture and Cooperatives. Food calories available at district level were estimated after subtracting the grains from seeds, losses after harvest and processing and food grains used for other purposes from the total grain production. The demand for food calories at district level was estimated by taking into account the total calories supplied by the food grains per person per day in the recommended total calories intake for an active and healthy life. Food surplus or deficiency at watershed level was estimated as a ratio of food demand to supply. More weightage was assigned to DRI than to FSD (Figure 8). The drought/food risk subindex was constructed by adopting the aggregation method. The combined drought/food risk subindex was normalized to the values between 0 and 1, and the drought/food risk subindex map was produced (Map 12).



Map 12. Drought and food-risk map of the watersheds in Middle and High Mountain regions.

From the drought/food risk consideration, the watersheds of Middle and High Mountain regions of Nepal were ranked as presented in Table 14. Watersheds of Karnali River Basin, i.e., Lower Tila Watershed, Upper Karnali Watershed, Daine Khola Watershed, Humla Karnali Watershed, Ruru Khola Watershed, Bheri Khola watershed and Mugu Karnali watershed; and Piluwa Khola Watershed in Koshi River Basin were highly prone to drought/food-risk exposure than other basins and their watersheds.

Table 14. Watersheds ranked by drought and food risk.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.818-1.000)	Karnali	Tila	Lower Tila	115	1
	Karnali	-	Upper Karnali	120	2
	Karnali	Tila	Daine Khola	116	3
	Karnali	Humla Karnali	Humla Karnali	119	4
	Karnali	Tila	Ruru Khola	114	5
	Karnali	Tila	Bheri Khola	111	6
	Koshi	Arun	Piluwa Khola	12	7
	Karnali	Mugu Karnali	Mugu Karnali	117	8
High (0.632-0.818)	Karnali	Tila	Upper Tila	110	9
	Karnali	Humla Karnali	Loti Karnali	118	10
	Koshi	Tamor	Tamor	5	11
	Koshi	Arun	Pikhuwa Khola	15	12
	Karnali	Tila	Chaudhabis Khola	108	13
	Koshi	Tamor	Nenwa Khola	7	14
	Karnali	Tila	Juliodar Khola	109	15
	Koshi	Tamor	Shuban Khola	6	16
	Koshi	Sun Koshi	Kalunje Khola	42	17
	Karnali	Thuli Bheri	Bheri	107	18
	Koshi	Arun	Lower Piluwa Khola	13	19
Moderate (0.446-0.632)	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	20
	-	Kamala	Chandaha Khola	31	21
	-	Bagmati	Marin Khola	32	22
	Koshi	Sun Koshi	Gangeti Khola	33	23
	-	Kamala	Baidyanath Khola	24	24
	-	Kamala	Thakur Khola	25	25
	Koshi	Arun	Sabha Khola	11	26
	Koshi	Sun Koshi	Bandijor Khola	30	27
	Koshi	Tamakoshi	Lower Tamakoshi	34	28
	Koshi	Sun Koshi	Sun Koshi	14	29
	Gandaki	East Seti	Lower East Seti	69	30
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	31
	-	Kankai	Mai Khola	4	32
	Koshi	Sun Koshi	Yari Khola	23	33
	Koshi	Sun Koshi	Rosi Khola	44	34
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	35
	Mahakali	-	Surnaya Gad	131	36
	Koshi	Arun	Lower Arun	16	37
	Karnali	Thuli Bheri	Mujkot Khola	112	38
	-	Babai	Sarada	101	39
	Koshi	Sun Koshi	Jhikhu Khola	45	40

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	-	Middle Karnali	121	41
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	42
	Koshi	Sun Koshi	Khansan Khola	26	43
	Gandaki	Trishuli	Trishuli-Seti	70	44
	-	Bagmati	Kokhajor Khola	43	45
	-	Tinau	Banganga	78	46
	Mahakali	-	Gairad Khola	134	47
	Gandaki	Trishuli	Lower Trishuli	64	48
	Karnali	West Seti	Lower West Seti	127	49
	Koshi	Tamor	Mewa Khola	8	50
	Koshi	Arun	Middle Arun	10	51
	Koshi	Sun Koshi	Bhushe Khola	46	52
	Koshi	Sun Koshi	Chauri Khola	41	53
	Koshi	Dudh Koshi	Rawa Khola	19	54
	Koshi	Arun	Upper Arun	9	55
	Karnali	Thuli Bheri	Lukum Khola	94	56
	-	Tinau	West Tinau	77	57
	Koshi	Tamor	Hewa Khola	3	58
	Karnali	Thuli Bheri	Saru Khola	104	59
	Karnali	Thuli Bheri	Thuli Bheri	106	60
Low (0.000-0.446)	-	Tinau	East Tinau	76	61
	Gandaki	Marsyangdi	Daraudi Khola	66	62
	-	West Rapti	Siban Khola	93	63
	Gandaki	Kali Gandaki	Aandi Khola	75	64
	Karnali	-	Lower Karnali	122	65
	Karnali	-	Banda Gad	128	66
	Karnali	-	Lohare Khola	113	67
	Karnali	Thuli Bheri	Sani Bheri	98	68
	-	West Rapti	Arun Khola	90	69
	Gandaki	Trishuli	Kolpu Khola	58	70
	Karnali	Thuli Bheri	Middle Bheri	100	71
	Karnali	Thuli Bheri	Lower Bheri	102	72
	Koshi	Tamor	Kabeli Khola	2	73
	Karnali	West Seti	Chaira Khola	123	74
	Karnali	Thuli Bheri	Upper Bheri	105	75
	Karnali	Thuli Bheri	Sai Kumari Khola	97	76
	Gandaki	Kali Gandaki	Daram Khola	82	77
	Koshi	Tamor	Ghunsa Khola	1	78
	Koshi	Indrawati	Lower Indrawati	49	79
	Gandaki	East Rapti	Arun Khola	71	80
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	81
	Karnali	Thuli Bheri	Chhera Khola	103	82
	Gandaki	Marsyangdi	Marsyangdi	67	83
	Koshi	Arun	Sankhuwa Khola	17	84
	Gandaki	East Rapti	Gorandhi Khola	56	85
	Koshi	Sun Koshi	Jagarpur Khola	27	86
	Karnali	-	Sera Gad	129	87
	-	West Rapti	Madi Khola	91	88

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	-	West Rapti	Rapti	89	89
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	90
	Gandaki	Trishuli	Upper Trishuli	61	91
	Karnali	West Seti	Budhi Ganga	124	92
	Koshi	Likhu	Likhu Khola	29	93
	Koshi	Dudh Koshi	Solu Khola	28	94
	Mahakali	-	Chamaliya	133	95
	Gandaki	Kali Gandaki	Ridi Khola	79	96
	Gandaki	Trishuli	Mahesh Khola	57	97
	Gandaki	Trishuli	Bhyaure Khola	60	98
	Karnali	Thuli Bheri	Sano Bheri	99	99
	Koshi	Sun Koshi	Bhote Koshi	40	100
	-	West Rapti	Lindri Khola	92	101
	Karnali	Thuli Bheri	Pelma Khola	96	102
	Gandaki	Trishuli	Tadi Khola	51	103
	Gandaki	Trishuli	Middle Trishuli	59	104
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	105
	Mahakali	-	Mahakali	135	106
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	107
	Gandaki	East Seti	Madi	68	108
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	109
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	110
	-	Bagmati	Palun Khola	55	111
	-	West Rapti	Jhimruk Khola	88	112
	-	Bagmati	Lower Bagmati	53	113
	Mahakali	-	Ragun Khola	130	114
	Koshi	Sun Koshi	Balephi Khola	47	115
	Koshi	Dudh Koshi	Hongu Khola	18	116
	Gandaki	Budhi Gandaki	Bhabil Khola	62	117
	Gandaki	East Rapti	East Rapti	54	118
	Koshi	Tamakoshi	Khimti Khola	35	119
	Karnali	Thuli Bheri	Ganga	95	120
	Gandaki	Kali Gandaki	Nisi Khola	87	121
	Karnali	West Seti	Middle West Seti	126	122
	Gandaki	East Seti	Upper East Seti	73	123
	Karnali	West Seti	Kalanga Gad	132	124
	Gandaki	Kali Gandaki	Myagdi Khola	84	125
	Karnali	West Seti	Upper West Seti	125	126
	Koshi	Tamakoshi	Middle Tamakoshi	38	127
	Gandaki	Kali Gandaki	Taman Khola	85	128
	Koshi	Tamakoshi	Khare Khola	36	129
	Koshi	Indrawati	Melamchi	50	130
	Koshi	Indrawati	Upper Indrawati	48	131
	Gandaki	Kali Gandaki	Modi Khola	74	132
	Koshi	Tamakoshi	Upper Tamakoshi	37	133
	Koshi	Tamakoshi	Sagu Khola	39	134
	-	Bagmati	Upper Bagmati	52	135

4.2.5. Combined /Multiple Risk Exposure

A combined/multiple risk exposure index was constructed based on landslide/flood risk, drought and food risk, ecological risk and rainfall and temperature risk indices. Each of the indices was assigned weightage, standardized and aggregated to get the combined index (Figure 9). The combined index was then normalized to get values in the range of 0-1 and the combined risk/exposure map was produced (Map 13).

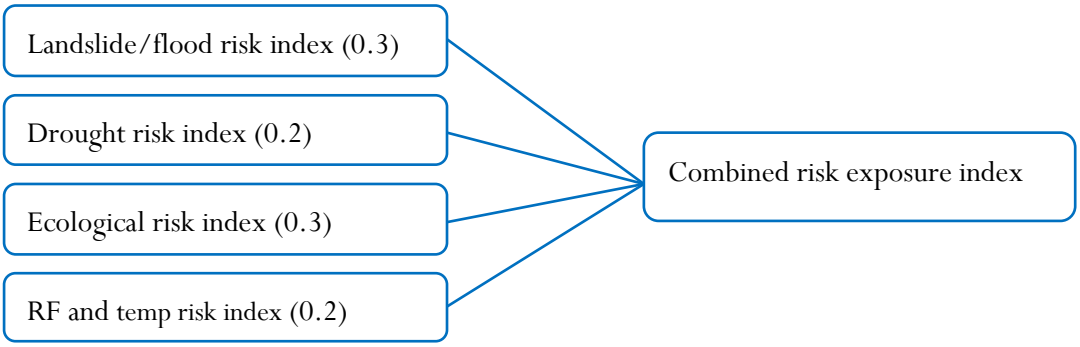
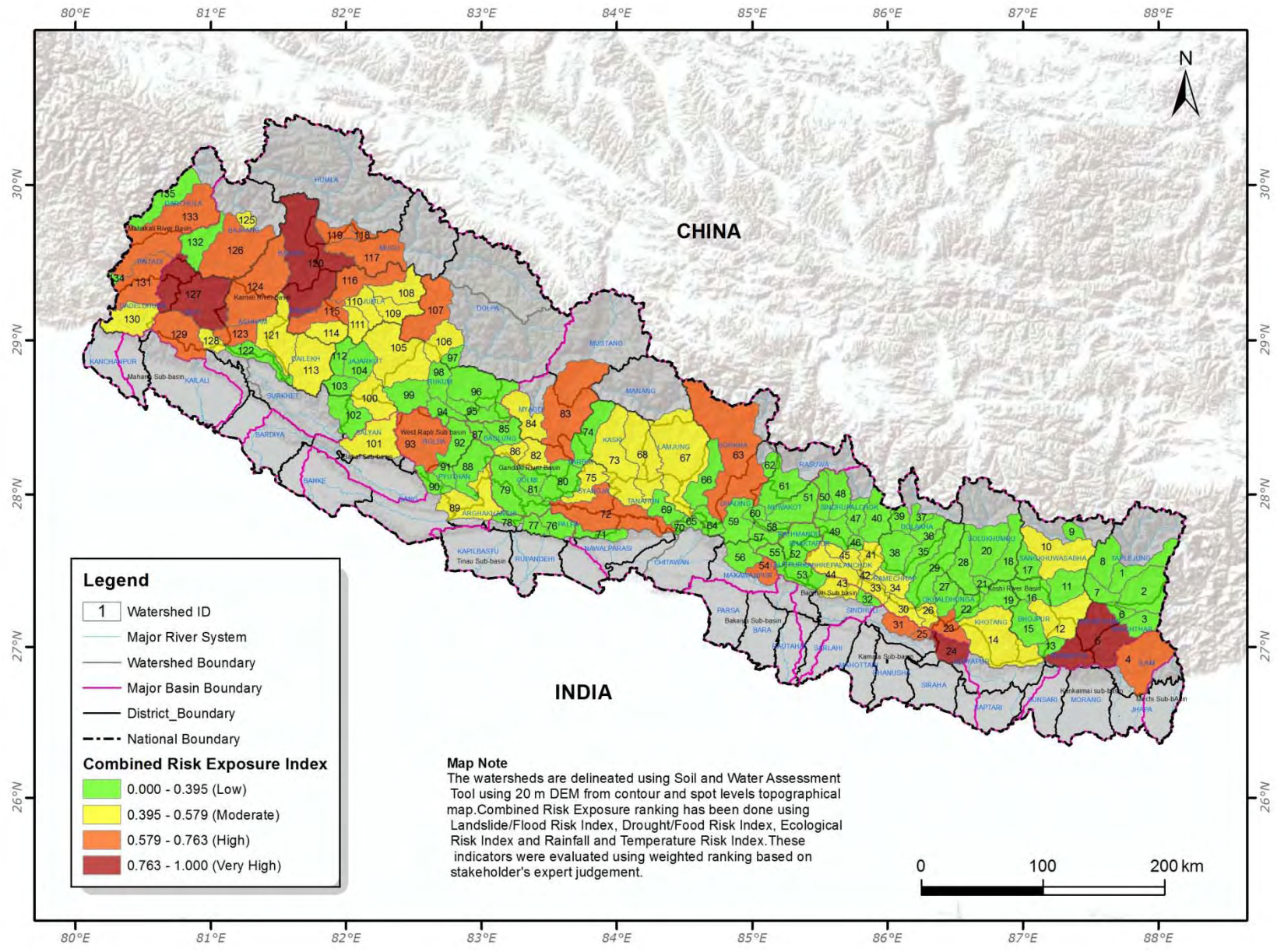


Figure 9. Combined risk/exposure index with subindices and their weightages (in parentheses).



Map 13. Combined risk/exposure map of watersheds in Middle and High Mountain regions

Table 15. Watersheds ranked by combined/multiple risk exposure.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.763-1.000)	Karnali	-	Upper Karnali	120	1
	-	Kamala	Baidyanath Khola	24	2
	Koshi	Tamor	Tamor	5	3
	Karnali	West Seti	Lower West Seti	127	4
High (0.579-0763)	Karnali	Mugu Karnali	Mugu Karnali	117	5
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	6
	Karnali	Humla Karnali	Humla Karnali	119	7
	Karnali	Tila	Daine Khola	116	8
	-	Kamala	Chandaha Khola	31	9
	-	West Rapti	Siban Khola	93	10
	Karnali	West Seti	Budhi Ganga	124	11
	-	Kankai	Mai Khola	4	12
	Karnali	-	Sera Gad	129	13
	Karnali	West Seti	Chaira Khola	123	14
	-	Kamala	Thakur Khola	25	15
	Gandaki	East Rapti	East Rapti	54	16
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	17
	Karnali	West Seti	Middle West Seti	126	18
	Karnali	Thuli Bheri	Bheri	107	19
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	20
	Koshi	Sun Koshi	Yari Khola	23	21
	Karnali	Humla Karnali	Loti Karnali	118	22
	Mahakali	-	Surnaya Gad	131	23
	Karnali	Tila	Lower Tila	115	24
	Mahakali	-	Chamaliya	133	25
Moderate (0.395-0.579)	-	Babai	Sarada	101	26
	Karnali	Thuli Bheri	Upper Bheri	105	27
	Koshi	Sun Koshi	Sun Koshi	14	28
	Koshi	Arun	Piluwa Khola	12	29
	-	West Rapti	Rapti	89	30
	Gandaki	Kali Gandaki	Daram Khola	82	31
	Karnali	West Seti	Upper West Seti	125	32
	Karnali	Tila	Bheri Khola	111	33
	Karnali	-	Banda Gad	128	34
	Gandaki	East Seti	Upper East Seti	73	35
	Karnali	Tila	Juliodar Khola	109	36
	Karnali	Tila	Upper Tila	110	37
	Karnali	Tila	Ruru Khola	114	38
	Gandaki	Marsyangdi	Marsyangdi	67	39
	Karnali	Tila	Chaudhabis Khola	108	40
	Koshi	Sun Koshi	Kalunje Khola	42	41
	Mahakali	-	Ragun Khola	130	42
	Koshi	Sun Koshi	Rosi Khola	44	43
	Karnali	Thuli Bheri	Thuli Bheri	106	44
	Karnali	-	Middle Karnali	121	45
	Koshi	Sun Koshi	Bandijor Khola	30	46

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	47
	Koshi	Sun Koshi	Gangeti Khola	33	48
	Karnali	Thuli Bheri	Middle Bheri	100	49
	Koshi	Sun Koshi	Jhikhu Khola	45	50
	Karnali	-	Lohare Khola	113	51
	-	Bagmati	Kokhajor Khola	43	52
	Koshi	Tamakoshi	Lower Tamakoshi	34	53
	Koshi	Arun	Middle Arun	10	54
	Gandaki	Kali Gandaki	Myagdi Khola	84	55
	Koshi	Sun Koshi	Khansan Khola	26	56
	Gandaki	East Seti	Madi	68	57
	Koshi	Sun Koshi	Chauri Khola	41	58
	Gandaki	Kali Gandaki	Aandi Khola	75	59
Low (0.000-0.395)	Koshi	Arun	Pikhuwa Khola	15	60
	Gandaki	East Rapti	Gorandhi Khola	56	61
	Karnali	Thuli Bheri	Mujkot Khola	112	62
	Karnali	-	Lower Karnali	122	63
	Karnali	Thuli Bheri	Pelma Khola	96	64
	Koshi	Sun Koshi	Bhote Koshi	40	65
	Gandaki	Kali Gandaki	Taman Khola	85	66
	Karnali	West Seti	Kalanga Gad	132	67
	Karnali	Thuli Bheri	Saru Khola	104	68
	Koshi	Indrawati	Lower Indrawati	49	69
	Mahakali	-	Gairad Khola	134	70
	-	West Rapti	Lindri Khola	92	71
	Koshi	Arun	Upper Arun	9	72
	-	West Rapti	Jhimruk Khola	88	73
	-	West Rapti	Arun Khola	90	74
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	75
	Gandaki	Trishuli	Kolpu Khola	58	76
	Koshi	Tamor	Hewa Khola	3	77
	Koshi	Tamor	Shuban Khola	6	78
	-	Bagmati	Marin Khola	32	79
	Karnali	Thuli Bheri	Lower Bheri	102	80
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	81
	Koshi	Arun	Lower Arun	16	82
	Karnali	Thuli Bheri	Chhera Khola	103	83
	Koshi	Sun Koshi	Jagarpur Khola	27	84
	Karnali	Thuli Bheri	Sai Kumari Khola	97	85
	Karnali	Thuli Bheri	Lukum Khola	94	86
	-	Bagmati	Lower Bagmati	53	87
	Koshi	Sun Koshi	Bhushe Khola	46	88
	Koshi	Tamor	Nenwa Khola	7	89
	Karnali	Thuli Bheri	Sano Bheri	99	90
	Gandaki	Kali Gandaki	Modi Khola	74	91
	Koshi	Arun	Sabha Khola	11	92
	Karnali	Thuli Bheri	Ganga	95	93
	Gandaki	Trishuli	Middle Trishuli	59	94

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Likhu	Likhu Khola	29	95
	Gandaki	Trishuli	Mahesh Khola	57	96
	Koshi	Tamor	Kabeli Khola	2	97
	Mahakali	-	Mahakali	135	98
	Gandaki	Trishuli	Tadi Khola	51	99
	Gandaki	Kali Gandaki	Ridi Khola	79	100
	-	West Rapti	Madi Khola	91	101
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	102
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	103
	Gandaki	Trishuli	Upper Trishuli	61	104
	Gandaki	Trishuli	Lower Trishuli	64	105
	Gandaki	Trishuli	Trishuli, Seti	70	106
	Koshi	Sun Koshi	Balephi Khola	47	107
	Gandaki	East Seti	Lower East Seti	69	108
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	109
	Gandaki	Kali Gandaki	Nisi Khola	87	110
	Karnali	Thuli Bheri	Sani Bheri	98	111
	-	Bagmati	Palun Khola	55	112
	Koshi	Tamakoshi	Middle Tamakoshi	38	113
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	114
	Koshi	Tamor	Mewa Khola	8	115
	Koshi	Tamakoshi	Sagu Khola	39	116
	-	Tinau	Banganga	78	117
	Koshi	Dudh Koshi	Rawa Khola	19	118
	Koshi	Dudh Koshi	Hongu Khola	18	119
	Gandaki	Budhi Gandaki	Bhabil Khola	62	120
	Koshi	Arun	Sankhuwa Khola	17	121
	Koshi	Dudh Koshi	Solu Khola	28	122
	Gandaki	East Rapti	Arun Khola	71	123
	Koshi	Tamor	Ghunsa Khola	1	124
	Koshi	Tamakoshi	Khimti Khola	35	125
	Gandaki	Trishuli	Bhyaure Khola	60	126
	-	Tinau	East Tinau	76	127
	Koshi	Indrawati	Upper Indrawati	48	128
	Gandaki	Marsyangdi	Daraudi Khola	66	129
	Koshi	Arun	Lower Piluwa Khola	13	130
	Koshi	Indrawati	Melamchi	50	131
	-	Tinau	West Tinau	77	132
	Koshi	Tamakoshi	Upper Tamakoshi	37	133
	-	Bagmati	Upper Bagmati	52	134
	Koshi	Tamakoshi	Khare Khola	36	135

4.3. Adaptation Capacity Indices

Adaptive capacity is defined as the ability of a system to adjust to/cope with climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences (IPCC 2001). As the Intergovernmental Panel on Climate Change (IPCC) has defined, adaptive capacity is a function of socioeconomic factors, infrastructure and technology and it can be summarized as:

$$Adaptive\ Capacity = f(socioeconomic,\ technology,\ infrastructure\ factors) \quad \text{.....(Eq. 7)}$$

Lacking in the watershed-level information, district-level information about socioeconomic factors, infrastructure and technology were gathered from concerned institutions and were integrated at watersheds level to construct an adaptive capacity index. Each socioeconomic adaptive capacity, infrastructure adaptive capacity and technological adaptive capacity index was derived and aggregated to construct the combined/multiple adaptation map.

4.3.1. Socioeconomic Adaptation Capability

The socioeconomic adaptation capability subindex was prepared by using the district- level data set published by UNDP (United Nation Development Programme) in Nepal Human Development Report 2004. The data set used for this study comprised Human Development Index (HDI), Gender Development Index (GDI), Human Poverty Index (HPI) and Human Empowerment Index (HEI). These district-level data were aggregated at watersheds. To standardize the indices, the highest weight was assigned to HPI followed by HDI, GDI and HEI and added to derive the socioeconomic adaptation capability subindex (Figure 10). In addition, there was a direct/inverse relationship between socioeconomic factors, i.e., the higher the HDI and HEI, the lower the HPI. Likewise, HPI was treated negatively, and hence, HPI values were inversed for the correct interpretation. Then, from the derived subindex, called the socioeconomic capability index, was used for mapping (Map 14).

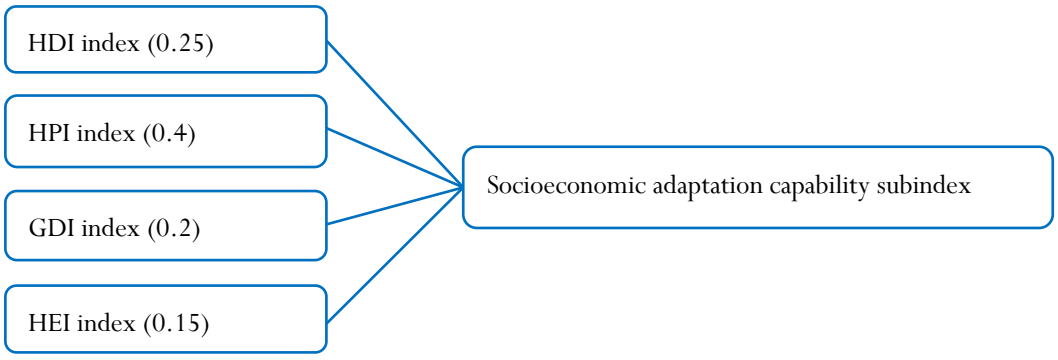
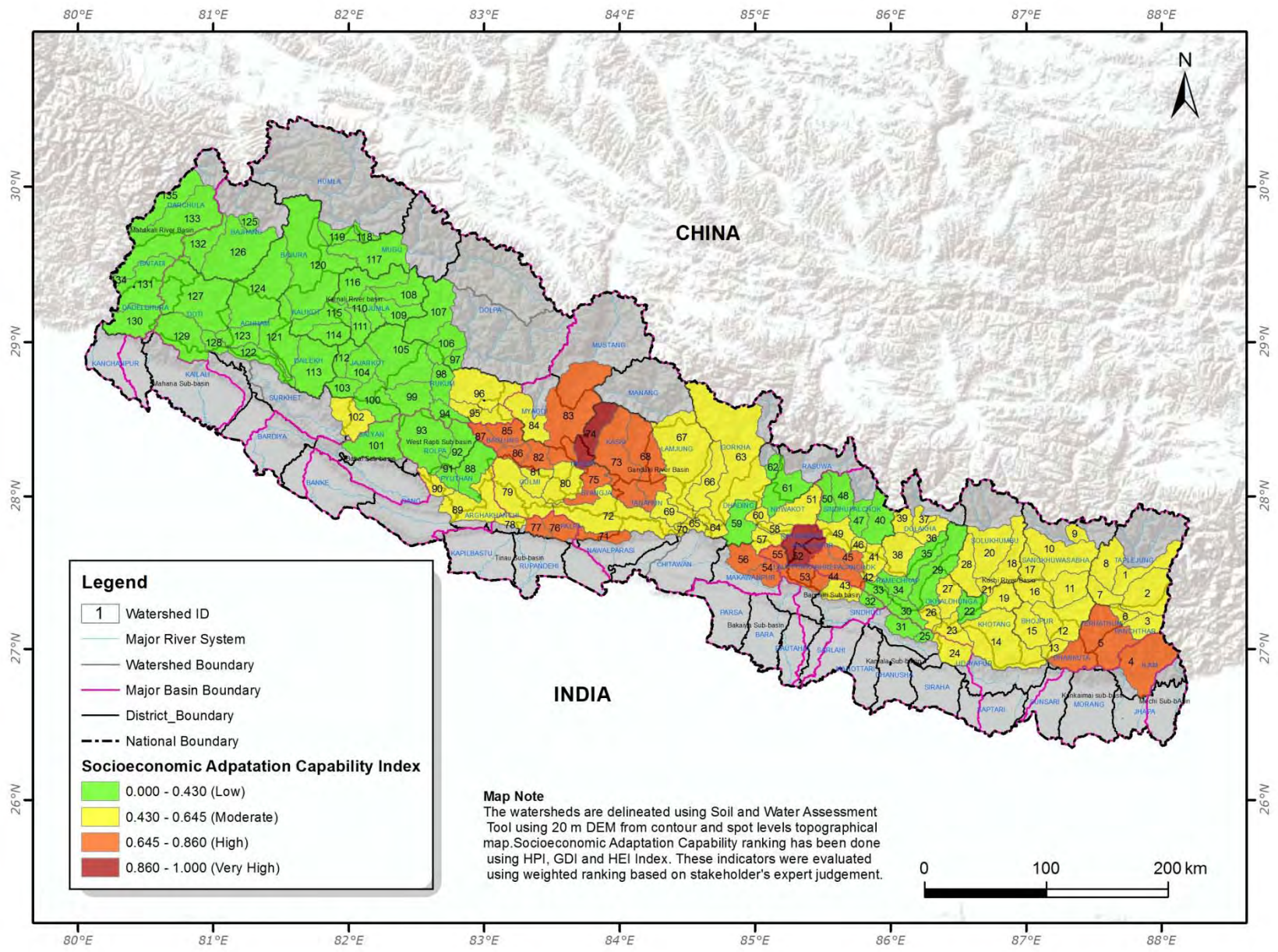


Figure 10. Socioeconomic adaptation capability subindices and their weightages (in parentheses).



Map 14. Socioeconomic adaptation capability map of watersheds in Middle and High Mountain regions

Based on the socioeconomic adaptation capability subindices, the watersheds of Middle and High Mountains were ranked as presented in Table 16.

Table 16. Watersheds ranked by socioeconomic adaptation capability index.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.860-1.000)	-	Bagmati	Upper Bagmati	52	1
	Gandaki	Kali Gandaki	Modi Khola	74	2
High (0.645-0.860)	-	Bagmati	Lower Bagmati	53	3
	Gandaki	East Seti	Upper East Seti	73	4
	Koshi	Sun Koshi	Rosi Khola	44	5
	Koshi	Sun Koshi	Jhikhu Khola	45	6
	Gandaki	East Seti	Madi	68	7
	-	Kankai	Mai Khola	4	8
	Gandaki	Kali Gandaki	Aandi Khola	75	9
	-	Tinau	East Tinau	76	10
	Gandaki	East Rapti	Arun Khola	71	11
	-	Tinau	West Tinau	77	12
	Gandaki	East Rapti	Gorandhi Khola	56	13
	-	Bagmati	Palun Khola	55	14
	Gandaki	East Rapti	East Rapti	54	15
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	16
	Gandaki	Kali Gandaki	Taman Khola	85	17
	Gandaki	Kali Gandaki	Daram Khola	82	18
	Gandaki	Kali Gandaki	Nisi Khola	87	19
	Koshi	Tamor	Tamor	5	20
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	21
Moderate (0.430-0.645)	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	22
	Gandaki	East Seti	Lower East Seti	69	23
	Gandaki	Trishuli	Trishuli, Seti	70	24
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	25
	Gandaki	Kali Gandaki	Ridi Khola	79	26
	Koshi	Arun	Lower Piluwa Khola	13	27
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	28
	-	West Rapti	Arun Khola	90	29
	Koshi	Tamor	Shuban Khola	6	30
	-	Kamala	Baidyanath Khola	24	31
	Koshi	Arun	Piluwa Khola	12	32
	-	Bagmati	Kokhajor Khola	43	33
	-	Tinau	Banganga	78	34
	Gandaki	Marsyangdi	Marsyangdi	67	35
	Gandaki	Kali Gandaki	Myagdi Khola	84	36
	Koshi	Tamor	Kabeli Khola	2	37
	Koshi	Tamor	Ghunsa Khola	1	38
	Koshi	Tamor	Mewa Khola	8	39
	Koshi	Tamor	Nenwa Khola	7	40
	Koshi	Indrawati	Lower Indrawati	49	41
	Koshi	Sun Koshi	Bhushe Khola	46	42

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Tamor	Hewa Khola	3	43
	Koshi	Arun	Middle Arun	10	44
	Koshi	Arun	Sabha Khola	11	45
	Koshi	Arun	Sankhuwa Khola	17	46
	Koshi	Arun	Upper Arun	9	47
	Koshi	Sun Koshi	Kalunje Khola	42	48
	Gandaki	Trishuli	Tadi Khola	51	49
	Koshi	Sun Koshi	Yari Khola	23	50
	Gandaki	Trishuli	Mahesh Khola	57	51
	Koshi	Sun Koshi	Sun Koshi	14	52
	Gandaki	Marsyangdi	Daraudi Khola	66	53
	Koshi	Tamakoshi	Middle Tamakoshi	38	54
	Koshi	Tamakoshi	Sagu Khola	39	55
	Koshi	Tamakoshi	Khare Khola	36	56
	Koshi	Tamakoshi	Upper Tamakoshi	37	57
	-	West Rapti	Rapti	89	58
	Koshi	Arun	Pikhuwa Khola	15	59
	Koshi	Arun	Lower Arun	16	60
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	61
	Koshi	Dudh Koshi	Solu Khola	28	62
	Koshi	Dudh Koshi	Hongu Khola	18	63
	Koshi	Sun Koshi	Chauri Khola	41	64
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	65
	Koshi	Dudh Koshi	Rawa Khola	19	66
	Karnali	Thuli Bheri	Ganga	95	67
	Karnali	Thuli Bheri	Pelma Khola	96	68
	Gandaki	Trishuli	Bhyaure Khola	60	69
	Gandaki	Trishuli	Kolpu Khola	58	70
	Koshi	Sun Koshi	Jagarpur Khola	27	71
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	72
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	73
	Gandaki	Trishuli	Lower Trishuli	64	74
	Koshi	Sun Koshi	Khansan Khola	26	75
	Karnali	Thuli Bheri	Lower Bheri	102	76
Low (0.000-0.430)	Koshi	Likhu	Likhu Khola	29	77
	Mahakali	-	Ragun Khola	130	78
	Gandaki	Trishuli	Upper Trishuli	61	79
	-	Kamala	Chandaha Khola	31	80
	-	Bagmati	Marin Khola	32	81
	-	Kamala	Thakur Khola	25	82
	Gandaki	Trishuli	Middle Trishuli	59	83
	Gandaki	Budhi Gandaki	Bhabil Khola	62	84
	Mahakali	-	Mahakali	135	85
	Koshi	Tamakoshi	Khimti Khola	35	86
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	87
	-	West Rapti	Jhimruk Khola	88	88
	-	West Rapti	Madi Khola	91	89
	Koshi	Indrawati	Upper Indrawati	48	90

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Sun Koshi	Bhote Koshi	40	91
	Koshi	Indrawati	Melamchi	50	92
	Koshi	Sun Koshi	Balephi Khola	47	93
	Karnali	-	Banda Gad	128	94
	Mahakali	-	Surnaya Gad	131	95
	Mahakali	-	Chamaliya	133	96
	Koshi	Sun Koshi	Bandijor Khola	30	97
	Koshi	Sun Koshi	Gangeti Khola	33	98
	-	Babai	Sarada	101	99
	Karnali	-	Lower Karnali	122	100
	Karnali	West Seti	Lower West Seti	127	101
	Mahakali	-	Gairad Khola	134	102
	Koshi	Tamakoshi	Lower Tamakoshi	34	103
	Karnali	-	Lohare Khola	113	104
	Karnali	-	Sera Gad	129	105
	Karnali	Thuli Bheri	Middle Bheri	100	106
	Karnali	Thuli Bheri	Sano Bheri	99	107
	Karnali	Thuli Bheri	Sani Bheri	98	108
	Karnali	Thuli Bheri	Lukum Khola	94	109
	-	West Rapti	Siban Khola	93	110
	-	West Rapti	Lindri Khola	92	111
	Karnali	West Seti	Chaira Khola	123	112
	Karnali	Tila	Daine Khola	116	113
	Karnali	Tila	Chaudhabis Khola	108	114
	Karnali	Tila	Juliodar Khola	109	115
	Karnali	Tila	Upper Tila	110	116
	Karnali	Tila	Bheri Khola	111	117
	Karnali	-	Middle Karnali	121	118
	Karnali	Thuli Bheri	Upper Bheri	105	119
	Karnali	Thuli Bheri	Saru Khola	104	120
	Karnali	Thuli Bheri	Chhera Khola	103	121
	Karnali	Thuli Bheri	Mujkot Khola	112	122
	Karnali	West Seti	Budhi Ganga	124	123
	Karnali	Tila	Lower Tila	115	124
	Karnali	Thuli Bheri	Bheri	107	125
	Karnali	Thuli Bheri	Thuli Bheri	106	126
	Karnali	Thuli Bheri	Sai Kumari Khola	97	127
	Karnali	Tila	Ruru Khola	114	128
	Karnali	West Seti	Middle West Seti	126	129
	Karnali	West Seti	Kalanga Gad	132	130
	Karnali	West Seti	Upper West Seti	125	131
	Karnali	-	Upper Karnali	120	132
	Karnali	Mugu Karnali	Mugu Karnali	117	133
	Karnali	Humla Karnali	Loti Karnali	118	134
	Karnali	Humla Karnali	Humla Karnali	119	135

4.3.2. Infrastructure Adaptation Capability

Road networks (transportation infrastructure), communication (telephone lines) and households with access to electricity are the main infrastructure facilities related to communities' adaptation capacity. It is assumed that the higher the infrastructure facilities residing in any spatial unit the lower the vulnerability in that unit. In addition, roads were categorized in six different categories: airport, highways, district road, feeder road, trails, tracks and foot path. Highways and district roads were prioritized by assigning higher weightage with the assumption that the longer the highway and district roads the higher the adaptive capability in the communities.

In this regard, road length, landline telephone and number of consumers using electricity were considered as indicators of infrastructure-related adaptation capacity (Figure 11). Road networks and length of roads were derived from the data of the Topographic Map and Department of Roads using spatial analysis. The total number of consumers using updated landline telephones (PSTN) and electricity were obtained from Nepal Telecommunication and other available secondary information. Due to nonavailability of the above data at the watershed level, the district-level data were integrated at watersheds to derive the infrastructure-adaptation capability subindex. The district-level ratio of the number of landline telephones to the total population of the district and number consumers using electricity to the total population of the district were calculated. The districts and watersheds were then regrouped in development regions and the average ratio of each region was calculated. The average ratio of the region was then multiplied with the watershed's population and the number of consumers using watershed-wise landline telephones and electricity were obtained and normalized. Weightage for each derived indicator was assigned for standardization. Then, these indices were aggregated and normalized to the produce infrastructure-adaptation capability map (Map 15).

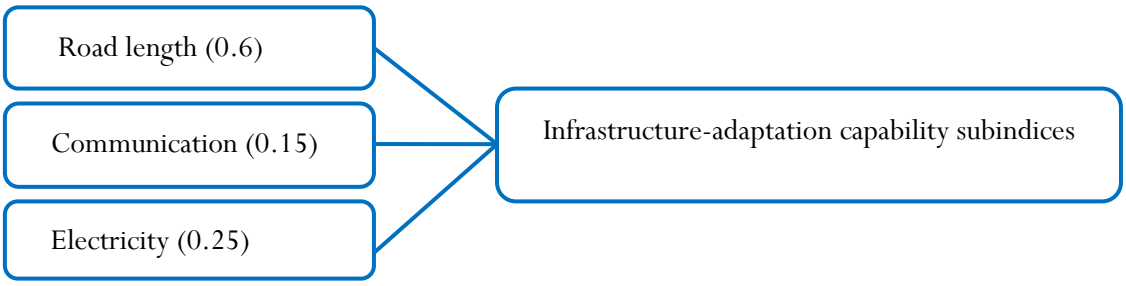
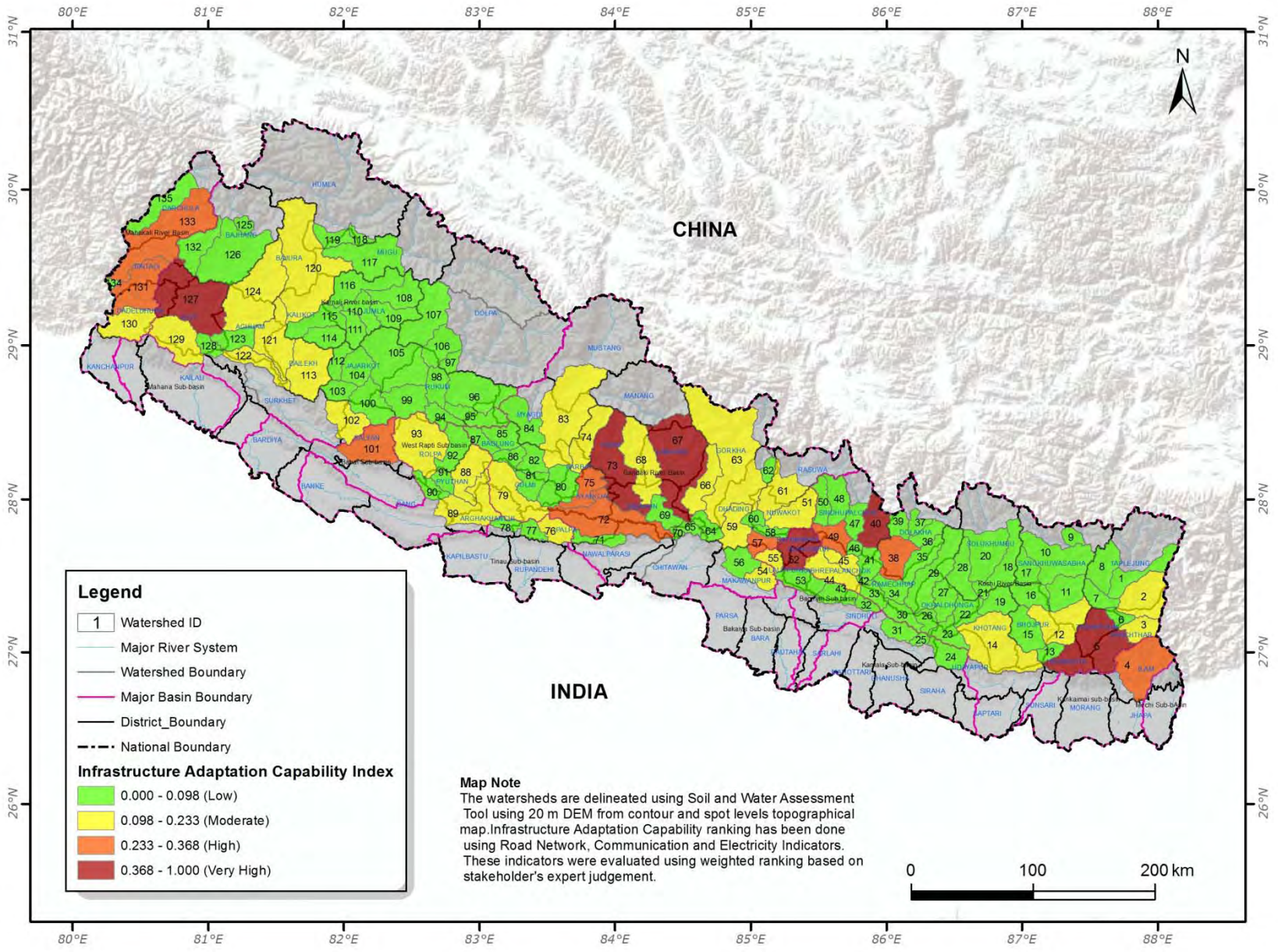


Figure 11. Infrastructure adaptation capability subindices and their weightages (in parentheses).



Map 15. Infrastructure adaptation capability map of watersheds in Middle and High Mountain regions.

Based on the Infrastructure-adaptation capability subindices, the watersheds of Middle and High Mountains were ranked as presented in Table 17. It indicates that Upper Bagmati Watershed in Bagmati Sub-basin, Upper East Seti Watershed in Gandaki River Basin and Lower West Seti Watershed in Karnali River Basin have a well infrastructure-adaptation capability.

Table 17. Watersheds ranked by infrastructure adaptation capability index.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.368- 1.000)	-	Bagmati	Upper Bagmati	52	1
	Gandaki	East Seti	Upper East Seti	73	2
	Karnali	West Seti	Lower West Seti	127	3
	Koshi	Tamor	Tamor	5	4
	Gandaki	Marsyangdi	Marsyangdi	67	5
	Koshi	Sun Koshi	Bhote Koshi	40	6
High (0.233-0.368)	-	Kankai	Mai Khola	4	7
	Koshi	Tamakoshi	Middle Tamakoshi	38	8
	Mahakali	-	Surnaya Gad	131	9
	Mahakali	-	Chamaliya	133	10
	Gandaki	Trishuli	Mahesh Khola	57	11
	-	Babai	Sarada	101	12
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	13
	Gandaki	Kali Gandaki	Aandi Khola	75	14
	Koshi	Indrawati	Lower Indrawati	49	15
Moderate (0.098-0.233)	Karnali	West Seti	Budhi Ganga	124	16
	Gandaki	Trishuli	Tadi Khola	51	17
	-	West Rapti	Rapti	89	18
	Gandaki	Kali Gandaki	Ridi Khola	79	19
	-	West Rapti	Siban Khola	93	20
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	21
	Gandaki	Trishuli	Upper Trishuli	61	22
	Gandaki	Trishuli	Middle Trishuli	59	23
	Karnali	-	Sera Gad	129	24
	Karnali	-	Lohare Khola	113	25
	Koshi	Tamor	Hewa Khola	3	26
	Gandaki	East Seti	Madi	68	27
	Koshi	Sun Koshi	Rosi Khola	44	28
	-	Tinau	East Tinau	76	29
	Gandaki	Kali Gandaki	Modi Khola	74	30
	Koshi	Sun Koshi	Sun Koshi	14	31
	Karnali	-	Middle Karnali	121	32
	Mahakali	-	Ragun Khola	130	33
	Koshi	Arun	Piluwa Khola	12	34
	Gandaki	East Rapti	East Rapti	54	35
	Koshi	Tamor	Kabeli Khola	2	36
	Karnali	Thuli Bheri	Lower Bheri	102	37
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	38
	Gandaki	Marsyangdi	Daraudi Khola	66	39
	Karnali	-	Lower Karnali	122	40
	-	Bagmati	Palun Khola	55	41

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	-	West Rapti	Jhimruk Khola	88	42
	Karnali	-	Upper Karnali	120	43
	Koshi	Sun Koshi	Jhikhu Khola	45	44
Low (0.000-0.098)	Karnali	West Seti	Middle West Seti	126	45
	Gandaki	East Rapti	Gorandhi Khola	56	46
	Gandaki	Trishuli	Kolpu Khola	58	47
	Koshi	Sun Koshi	Bhushe Khola	46	48
	-	West Rapti	Madi Khola	91	49
	-	West Rapti	Lindri Khola	92	50
	Karnali	Thuli Bheri	Middle Bheri	100	51
	Gandaki	East Seti	Lower East Seti	69	52
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	53
	Koshi	Likhu	Likhu Khola	29	54
	Koshi	Tamakoshi	Khimti Khola	35	55
	Koshi	Arun	Pikhuwa Khola	15	56
	Karnali	Thuli Bheri	Upper Bheri	105	57
	-	Bagmati	Lower Bagmati	53	58
	Karnali	Thuli Bheri	Sano Bheri	99	59
	Koshi	Sun Koshi	Chauri Khola	41	60
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	61
	Koshi	Sun Koshi	Yari Khola	23	62
	-	Kamala	Baidyanath Khola	24	63
	Gandaki	Trishuli	Trishuli, Seti	70	64
	Karnali	West Seti	Chaira Khola	123	65
	Karnali	West Seti	Kalanga Gad	132	66
	Koshi	Tamor	Shuban Khola	6	67
	Koshi	Tamakoshi	Lower Tamakoshi	34	68
	Gandaki	Trishuli	Lower Trishuli	64	69
	Koshi	Dudh Koshi	Solu Khola	28	70
	Gandaki	Kali Gandaki	Daram Khola	82	71
	Koshi	Sun Koshi	Balephi Khola	47	72
	-	Kamala	Chandaha Khola	31	73
	-	Bagmati	Kokhajor Khola	43	74
	Koshi	Sun Koshi	Jagarpur Khola	27	75
	-	West Rapti	Arun Khola	90	76
	Gandaki	Kali Gandaki	Myagdi Khola	84	77
	Karnali	-	Banda Gad	128	78
	Gandaki	Kali Gandaki	Taman Khola	85	79
	Karnali	Thuli Bheri	Lukum Khola	94	80
	Koshi	Sun Koshi	Bandijor Khola	30	81
	Koshi	Arun	Lower Arun	16	82
	Koshi	Indrawati	Upper Indrawati	48	83
	Karnali	Thuli Bheri	Ganga	95	84
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	85
	Koshi	Arun	Sabha Khola	11	86
	Koshi	Indrawati	Melamchi	50	87
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	88
	Karnali	Thuli Bheri	Saru Khola	104	89

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Dudh Koshi	Rawa Khola	19	90
	Mahakali	-	Mahakali	135	91
	Koshi	Sun Koshi	Gangeti Khola	33	92
	Karnali	Thuli Bheri	Chhera Khola	103	93
	Koshi	Tamakoshi	Sagu Khola	39	94
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	95
	Koshi	Sun Koshi	Khansan Khola	26	96
	Karnali	Thuli Bheri	Pelma Khola	96	97
	Karnali	Tila	Lower Tila	115	98
	Koshi	Tamor	Nenwa Khola	7	99
	Koshi	Arun	Middle Arun	10	100
	Gandaki	Trishuli	Bhyaure Khola	60	101
	Koshi	Dudh Koshi	Hongu Khola	18	102
	Karnali	Tila	Daine Khola	116	103
	Karnali	Thuli Bheri	Bheri	107	104
	Koshi	Tamor	Ghunsa Khola	1	105
	Koshi	Arun	Lower Piluwa Khola	13	106
	Karnali	Mugu Karnali	Mugu Karnali	117	107
	-	Tinau	West Tinau	77	108
	Gandaki	Kali Gandaki	Nisi Khola	87	109
	Koshi	Tamor	Mewa Khola	8	110
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	111
	Koshi	Arun	Sankhuwa Khola	17	112
	Karnali	Thuli Bheri	Mujkot Khola	112	113
	Karnali	Thuli Bheri	Thuli Bheri	106	114
	Karnali	Tila	Juliodar Khola	109	115
	Karnali	Thuli Bheri	Sani Bheri	98	116
	-	Kamala	Thakur Khola	25	117
	Koshi	Tamakoshi	Khare Khola	36	118
	-	Bagmati	Marin Khola	32	119
	Karnali	Tila	Upper Tila	110	120
	Karnali	Tila	Bheri Khola	111	121
	Koshi	Tamakoshi	Upper Tamakoshi	37	122
	Karnali	Tila	Chaudhabis Khola	108	123
	Karnali	Thuli Bheri	Sai Kumari Khola	97	124
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	125
	Gandaki	Budhi Gandaki	Bhabil Khola	62	126
	Koshi	Sun Koshi	Kalunje Khola	42	127
	Karnali	Humla Karnali	Humla Karnali	119	128
	-	Tinau	Banganga	78	129
	Koshi	Arun	Upper Arun	9	130
	Karnali	Humla Karnali	Loti Karnali	118	131
	Gandaki	East Rapti	Arun Khola	71	132
	Karnali	Tila	Ruru Khola	114	133
	Mahakali	-	Gairad Khola	134	134
	Karnali	West Seti	Upper West Seti	125	135

4.3.3. Technological Adaptation Capability

More than one-third of the national GDP is dependent on natural-resources-based industries, especially from agriculture, fisheries and forestry. However, the productivity of such resources in the mountains of Nepal is limited also due to high slopes and the fragile nature of the landscape. Terracing is the dominant technology adopted and promoted in hills and mountains farming systems that have played a vital role in agricultural production as well as soil stability in the fragile and fragmented landscape. Undeniably, irrigation facilities are also indispensable to increase the productivity of food crops. In addition to the programs and interventions made by government institutions, NGOs/INGOs also play a significant role to increase the community's capability for technological adaptation. This is especially true in remote areas. Therefore, irrigated land, terracing and existence of interventions were selected as proxy indicators to derive the technological adaptation capability subindices (Figure 12).

The district-level irrigated land area and existence of interventions were integrated at watersheds by adopting the same approach used for the integration of communication and electricity data layer at watersheds. The use of terracing technology was calculated by using spatial analysis. In the case of interventions, 1 and 0 values were assigned to watersheds to indicate presence of external interventions. To construct the technology adaptation capability subindex, each of three indicators was standardized by assigning weightage recommended by the experts and then aggregated. The aggregated value was normalized and the technology adaptation capability map was produced (Map 16).

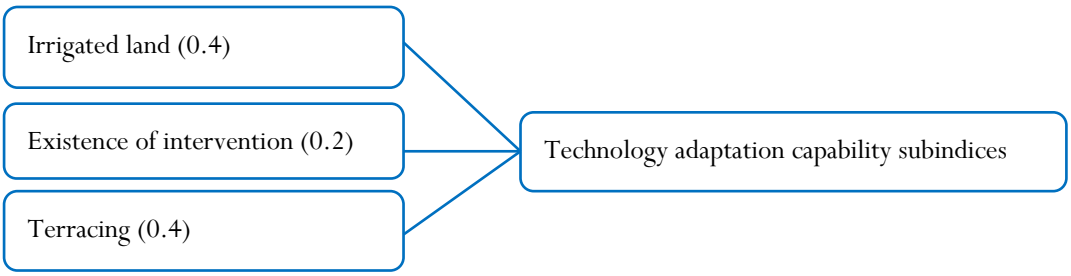
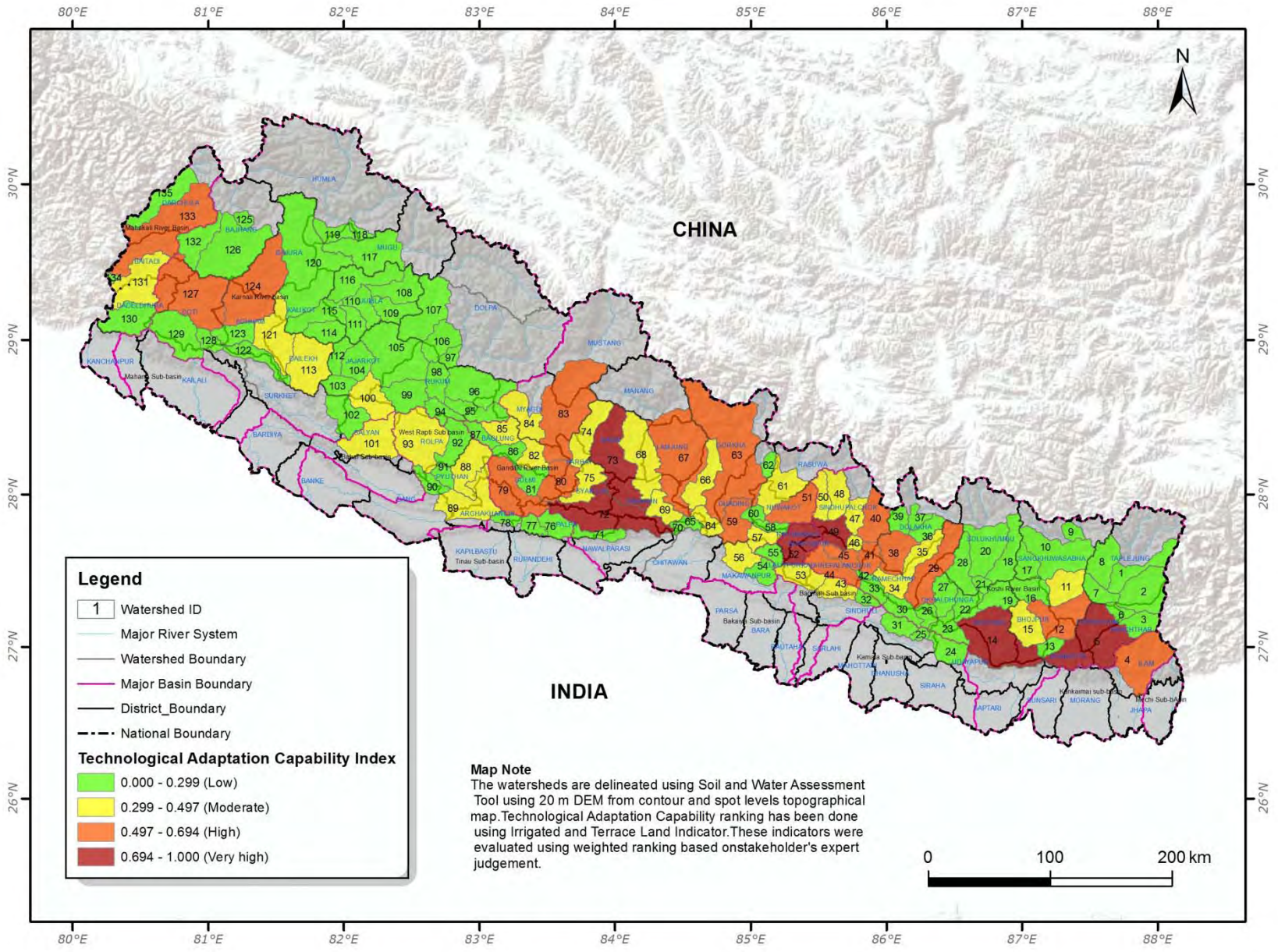


Figure 12. Technology-adaptation capability subindices and their weightages (in parentheses).



Map 16. Technological adaptation capability map of watersheds in Middle and High Mountain regions.

Based on technological adaptation subindices, the watersheds of Middle and High Mountains were ranked as presented in Table 18. It shows that Tamor Watershed in Khosi River Basin, Lower Kali Gandaki Watershed in Gandaki River Basin and Sun Koshi Watershed in Koshi River Basin are highly adaptive in terms of technology.

Table 18. Watersheds ranked by technological adaptation capability index.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.694-1.000)	Koshi	Tamor	Tamor	5	1
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	2
	Koshi	Sun Koshi	Sun Koshi	14	3
	Gandaki	East Seti	Upper East Seti	73	4
	Koshi	Indrawati	Lower Indrawati	49	5
	-	Bagmati	Upper Bagmati	52	6
High (0.497-0.694)	Gandaki	Budhi Gandaki	Budhi Gandaki	63	7
	Gandaki	Trishuli	Tadi Khola	51	8
	Koshi	Likhu	Likhu Khola	29	9
	Karnali	West Seti	Lower West Seti	127	10
	Koshi	Sun Koshi	Rosi Khola	44	11
	Gandaki	Marsyangdi	Marsyangdi	67	12
	Koshi	Tamakoshi	Middle Tamakoshi	38	13
	-	Kankai	Mai Khola	4	14
	Koshi	Arun	Piluwa Khola	12	15
	Gandaki	Trishuli	Middle Trishuli	59	16
	Gandaki	Kali Gandaki	Ridi Khola	79	17
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	18
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	19
	Koshi	Sun Koshi	Bhote Koshi	40	20
	Karnali	West Seti	Budhi Ganga	124	21
	Koshi	Sun Koshi	Chauri Khola	41	22
	Mahakali	-	Chamaliya	133	23
	Koshi	Sun Koshi	Jhikhu Khola	45	24
Moderate (0.299-0.497)	Gandaki	Kali Gandaki	Aandi Khola	75	25
	Gandaki	East Seti	Madi	68	26
	Gandaki	Trishuli	Upper Trishuli	61	27
	-	West Rapti	Siban Khola	93	28
	Koshi	Sun Koshi	Balephi Khola	47	29
	-	Bagmati	Lower Bagmati	53	30
	Karnali	-	Lohare Khola	113	31
	Koshi	Arun	Pikhuwa Khola	15	32
	Koshi	Indrawati	Melamchi	50	33
	-	Babai	Sarada	101	34
	Gandaki	Trishuli	Mahesh Khola	57	35
	Koshi	Indrawati	Upper Indrawati	48	36
	Mahakali	-	Surnaya Gad	131	37
	Koshi	Tamakoshi	Khimti Khola	35	38
	Gandaki	East Seti	Lower East Seti	69	39
	Koshi	Tamakoshi	Lower Tamakoshi	34	40
	Gandaki	Kali Gandaki	Modi Khola	74	41

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Karnali	-	Middle Karnali	121	42
	Gandaki	Marsyangdi	Daraudi Khola	66	43
	-	Bagmati	Kokhajor Khola	43	44
	Gandaki	Kali Gandaki	Myagdi Khola	84	45
	Koshi	Sun Koshi	Bhushe Khola	46	46
	Gandaki	Kali Gandaki	Daram Khola	82	47
	Koshi	Arun	Sabha Khola	11	48
	Gandaki	East Rapti	Gorandhi Khola	56	49
	Gandaki	Trishuli	Lower Trishuli	64	50
	Gandaki	Kali Gandaki	Taman Khola	85	51
	-	West Rapti	Rapti	89	52
	-	West Rapti	Jhimruk Khola	88	53
	Karnali	Thuli Bheri	Middle Bheri	100	54
Low (0.000-0.299)	Koshi	Arun	Lower Arun	16	55
	Gandaki	Trishuli	Kolpu Khola	58	56
	Gandaki	Kali Gandaki	Nisi Khola	87	57
	Koshi	Tamor	Kabeli Khola	2	58
	Karnali	Thuli Bheri	Lower Bheri	102	59
	Koshi	Sun Koshi	Jagarpur Khola	27	60
	Koshi	Tamor	Hewa Khola	3	61
	Koshi	Sun Koshi	Bandijor Khola	30	62
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	63
	Karnali	Thuli Bheri	Ganga	95	64
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	65
	-	Bagmati	Palun Khola	55	66
	Karnali	West Seti	Middle West Seti	126	67
	Gandaki	Trishuli	Bhyaure Khola	60	68
	Koshi	Dudh Koshi	Rawa Khola	19	69
	-	West Rapti	Lindri Khola	92	70
	-	Kamala	Chandaha Khola	31	71
	Gandaki	East Rapti	East Rapti	54	72
	-	Tinau	East Tinau	76	73
	Koshi	Arun	Middle Arun	10	74
	Karnali	Thuli Bheri	Sano Bheri	99	75
	Karnali	-	Sera Gad	129	76
	Koshi	Arun	Lower Piluwa Khola	13	77
	Koshi	Tamor	Nenwa Khola	7	78
	Karnali	-	Upper Karnali	120	79
	Koshi	Sun Koshi	Gangeti Khola	33	80
	Koshi	Tamor	Shuban Khola	6	81
	Koshi	Sun Koshi	Khansan Khola	26	82
	Koshi	Tamakoshi	Sagu Khola	39	83
	Koshi	Sun Koshi	Yari Khola	23	84
	Mahakali	-	Mahakali	135	85
	Karnali	Tila	Daine Khola	116	86
	-	Kamala	Baidyanath Khola	24	87
	Koshi	Tamor	Ghunsa Khola	1	88
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	89

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	-	West Rapti	Arun Khola	90	90
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	91
	Mahakali	-	Ragun Khola	130	92
	Koshi	Tamakoshi	Khare Khola	36	93
	Karnali	Thuli Bheri	Lukum Khola	94	94
	Koshi	Tamor	Mewa Khola	8	95
	-	Kamala	Thakur Khola	25	96
	Karnali	Tila	Upper Tila	110	97
	Koshi	Tamakoshi	Upper Tamakoshi	37	98
	Koshi	Arun	Sankhuwa Khola	17	99
	Gandaki	East Rapti	Arun Khola	71	100
	Koshi	Sun Koshi	Kalunje Khola	42	101
	-	Tinau	West Tinau	77	102
	Karnali	-	Banda Gad	128	103
	-	West Rapti	Madi Khola	91	104
	-	Bagmati	Marin Khola	32	105
	-	Tinau	Banganga	78	106
	Karnali	Thuli Bheri	Pelma Khola	96	107
	Karnali	Tila	Bheri Khola	111	108
	Karnali	Thuli Bheri	Upper Bheri	105	109
	Gandaki	Budhi Gandaki	Bhabil Khola	62	110
	Karnali	Tila	Chaudhabis Khola	108	111
	Karnali	Thuli Bheri	Sani Bheri	98	112
	Karnali	Tila	Juliodar Khola	109	113
	Koshi	Arun	Upper Arun	9	114
	Koshi	Dudh Koshi	Solu Khola	28	115
	Mahakali	-	Gairad Khola	134	116
	Gandaki	Trishuli	Trishuli-Seti	70	117
	Karnali	Tila	Lower Tila	115	118
	Karnali	West Seti	Chaira Khola	123	119
	Karnali	Thuli Bheri	Chhera Khola	103	120
	Karnali	West Seti	Kalanga Gad	132	121
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	122
	Karnali	Thuli Bheri	Saru Khola	104	123
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	124
	Karnali	-	Lower Karnali	122	125
	Karnali	Mugu Karnali	Mugu Karnali	117	126
	Koshi	Dudh Koshi	Hongu Khola	18	127
	Karnali	Humla Karnali	Humla Karnali	119	128
	Karnali	Thuli Bheri	Mujkot Khola	112	129
	Karnali	Thuli Bheri	Thuli Bheri	106	130
	Karnali	Thuli Bheri	Bheri	107	131
	Karnali	Tila	Ruru Khola	114	132
	Karnali	Thuli Bheri	Sai Kumari Khola	97	133
	Karnali	Humla Karnali	Loti Karnali	118	134
	Karnali	West Seti	Upper West Seti	125	135

4.3.4. Combined/Multiple Adaptation Capability Index

To construct the Combined/Multiple Adaptation Capability Index, all three subindices were assigned weightage and combined assuming that the higher the socioeconomic status (education, income/employment, health and sanitation, human development and empowerment, gender empowerment, etc.), infrastructure and technological development in the communities residing in a specific spatial location, the higher the adaptive capability of that community. In this regard, higher weightage was assigned to socioeconomic factors as they play a significant role for the communities' adaptation capability (Figure 13).

Decisively, the higher the index value, the higher the adaptive capability and the lower the vulnerability. Conversely, the lower the value, the higher the vulnerability. The combined weighted value was then aggregated and normalized to produce the combined adaptive capability map (Map 17).

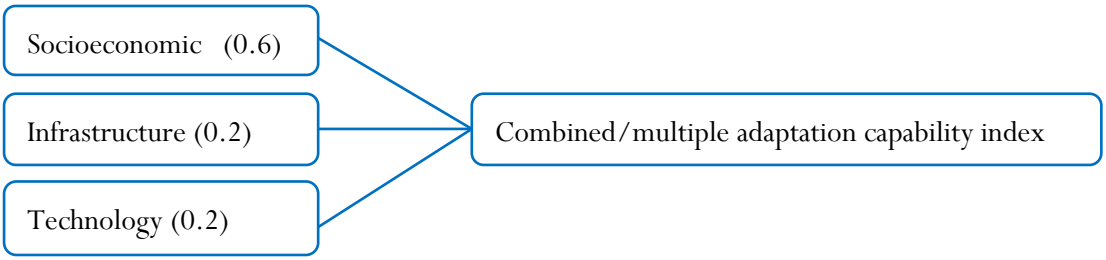
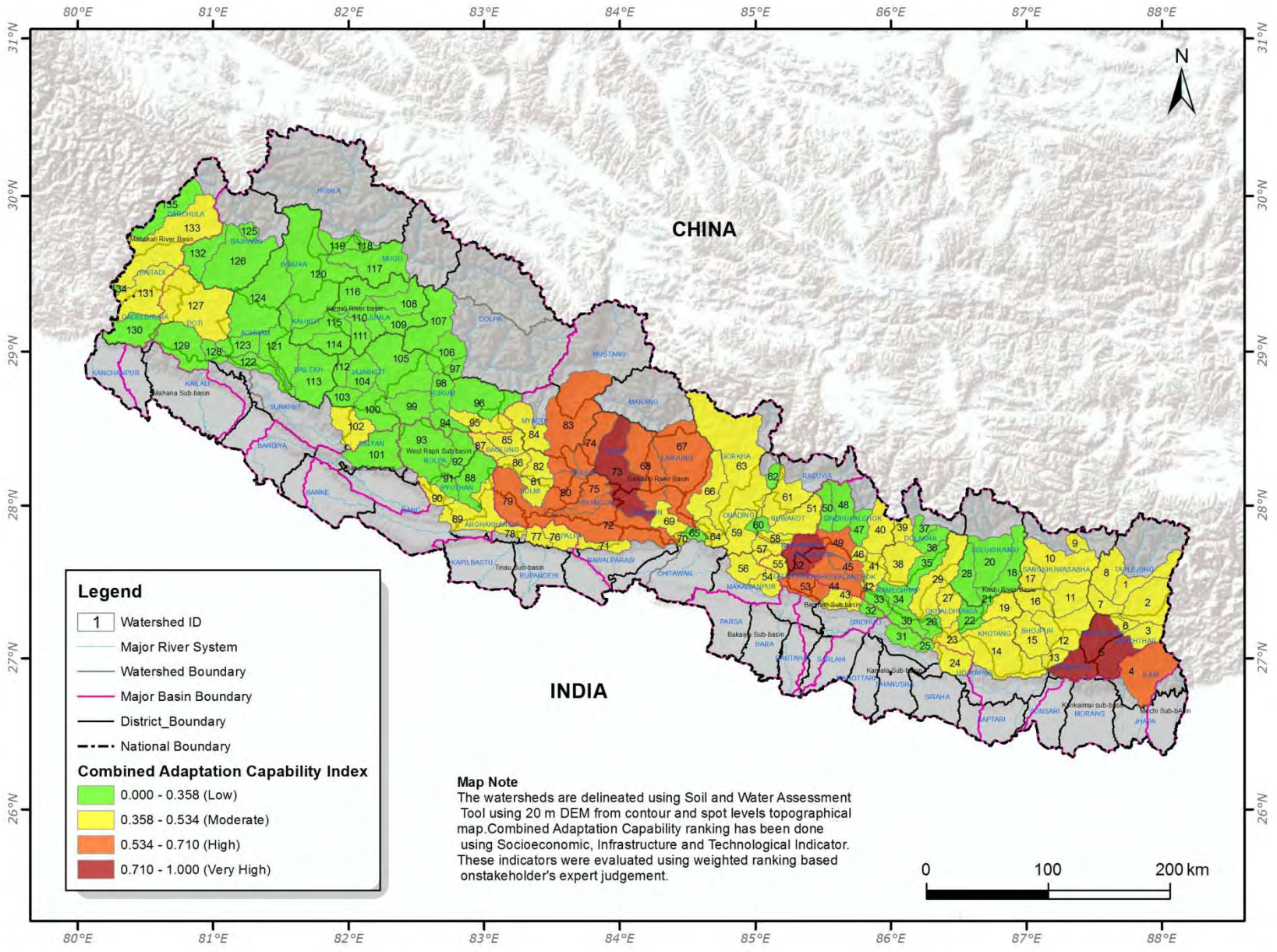


Figure 13. Combined adaptation capability index, subindices and their weightages (in parentheses).



Map 17. Combined/Multiple adaptation capability map of watersheds in Middle and High Mountain regions.

Based on combined/multiple adaptation capability subindices, the watersheds of Middle and High Mountains were ranked as presented in Table 19. According to this, the Upper Bagmati Watershed in Bagmati Sub-basin, Upper East Seti Watershed in Gandaki River Basin and Tamor Watershed in Koshi River Basin have high adaptive capability.

Table 19. Watersheds ranked by the combined/multiple adaptation capability index.

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
Very high (0.710-1.000)	-	Bagmati	Upper Bagmati	52	1
	Gandaki	East Seti	Upper East Seti	73	2
	Koshi	Tamor	Tamor	5	3
High (0.534-0.710)	-	Kankai	Mai Khola	4	4
	Koshi	Sun Koshi	Rosi Khola	44	5
	Gandaki	Kali Gandaki	Modi Khola	74	6
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	7
	Koshi	Sun Koshi	Jhikhu Khola	45	8
	-	Bagmati	Lower Bagmati	53	9
	Gandaki	East Seti	Madi	68	10
	Gandaki	Kali Gandaki	Aandi Khola	75	11
	Gandaki	Marsyangdi	Marsyangdi	67	12
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	13
	Koshi	Indrawati	Lower Indrawati	49	14
	Gandaki	Kali Gandaki	Ridi Khola	79	15
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	16
Moderate (0.358-0.534)	Koshi	Arun	Piluwa Khola	12	17
	-	Tinau	East Tinau	76	18
	Gandaki	Trishuli	Tadi Khola	51	19
	Koshi	Tamakoshi	Middle Tamakoshi	38	20
	Gandaki	East Rapti	Gorandhi Khola	56	21
	Koshi	Sun Koshi	Sun Koshi	14	22
	-	Bagmati	Palun Khola	55	23
	Gandaki	East Rapti	East Rapti	54	24
	Gandaki	Kali Gandaki	Daram Khola	82	25
	Gandaki	Kali Gandaki	Taman Khola	85	26
	Gandaki	East Seti	Lower East Seti	69	27
	Gandaki	Kali Gandaki	Nisi Khola	87	28
	-	Tinau	West Tinau	77	29
	Gandaki	East Rapti	Arun Khola	71	30
	Gandaki	Trishuli	Mahesh Khola	57	31
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	32
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	33
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	34
	Koshi	Tamor	Kabeli Khola	2	35
	-	Bagmati	Kokhajor Khola	43	36
	Koshi	Sun Koshi	Bhushe Khola	46	37
	Karnali	West Seti	Lower West Seti	127	38
	Koshi	Tamor	Hewa Khola	3	39
	Gandaki	Kali Gandaki	Myagdi Khola	84	40
	Koshi	Arun	Lower Piluwa Khola	13	41

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Tamor	Shuban Khola	6	42
	-	Kamala	Baidyanath Khola	24	43
	Gandaki	Trishuli	Trishuli, Seti	70	44
	-	West Rapti	Arun Khola	90	45
	Koshi	Sun Koshi	Chauri Khola	41	46
	Koshi	Sun Koshi	Bhote Koshi	40	47
	-	West Rapti	Rapti	89	48
	Koshi	Likhu	Likhu Khola	29	49
	Koshi	Tamor	Nenwa Khola	7	50
	Gandaki	Marsyangdi	Daraudi Khola	66	51
	Koshi	Arun	Sabha Khola	11	52
	Gandaki	Trishuli	Middle Trishuli	59	53
	Koshi	Tamor	Ghunsa Khola	1	54
	Koshi	Arun	Pikhuwa Khola	15	55
	Koshi	Tamor	Mewa Khola	8	56
	-	Tinau	Banganga	78	57
	Koshi	Arun	Middle Arun	10	58
	Gandaki	Trishuli	Upper Trishuli	61	59
	Mahakali	-	Chamaliya	133	60
	Koshi	Sun Koshi	Yari Khola	23	61
	Koshi	Arun	Lower Arun	16	62
	Koshi	Arun	Sankhuwa Khola	17	63
	Gandaki	Trishuli	Kolpu Khola	58	64
	Koshi	Arun	Upper Arun	9	65
	Mahakali	-	Surnaya Gad	131	66
	Koshi	Sun Koshi	Kalunje Khola	42	67
	Koshi	Tamakoshi	Sagu Khola	39	68
	Karnali	Thuli Bheri	Lower Bheri	102	69
	Koshi	Dudh Koshi	Rawa Khola	19	70
	Karnali	Thuli Bheri	Ganga	95	71
	Koshi	Sun Koshi	Jagarpur Khola	27	72
	Gandaki	Trishuli	Lower Trishuli	64	73
Low (0.000-0.358)	-	Babai	Sarada	101	74
	Gandaki	Trishuli	Bhyaure Khola	60	75
	Koshi	Tamakoshi	Khare Khola	36	76
	Koshi	Tamakoshi	Upper Tamakoshi	37	77
	Koshi	Tamakoshi	Khimti Khola	35	78
	Koshi	Dudh Koshi	Solu Khola	28	79
	-	West Rapti	Jhimruk Khola	88	80
	Koshi	Sun Koshi	Balephi Khola	47	81
	Koshi	Sun Koshi	Khansan Khola	26	82
	Karnali	Thuli Bheri	Pelma Khola	96	83
	Mahakali	-	Ragun Khola	130	84
	Koshi	Dudh Koshi	Upper Dudh Koshi	20	85
	Gandaki	Trishuli	Trishuli, Marsyangdi	65	86
	Koshi	Indrawati	Melamchi	50	87
	Koshi	Dudh Koshi	Hongu Khola	18	88
	Koshi	Indrawati	Upper Indrawati	48	89

Class	Major river basin	Subbasin	Watershed	WS ID	Rank
	Koshi	Dudh Koshi	Middle Dudh Koshi	21	90
	-	Kamala	Chandaha Khola	31	91
	Koshi	Dudh Koshi	Lower Dudh Koshi	22	92
	Mahakali	-	Mahakali	135	93
	-	West Rapti	Madi Khola	91	94
	-	Kamala	Thakur Khola	25	95
	-	Bagmati	Marin Khola	32	96
	Koshi	Sun Koshi	Bandijor Khola	30	97
	Gandaki	Budhi Gandaki	Bhabil Khola	62	98
	Karnali	-	Lohare Khola	113	99
	Koshi	Tamakoshi	Lower Tamakoshi	34	100
	Koshi	Sun Koshi	Gangeti Khola	33	101
	Karnali	-	Banda Gad	128	102
	-	West Rapti	Siban Khola	93	103
	Karnali	-	Lower Karnali	122	104
	Karnali	-	Sera Gad	129	105
	Mahakali	-	Gairad Khola	134	106
	Karnali	West Seti	Budhi Ganga	124	107
	Karnali	Thuli Bheri	Middle Bheri	100	108
	Karnali	-	Middle Karnali	121	109
	-	West Rapti	Lindri Khola	92	110
	Karnali	Thuli Bheri	Sano Bheri	99	111
	Karnali	Thuli Bheri	Lukum Khola	94	112
	Karnali	Thuli Bheri	Sani Bheri	98	113
	Karnali	Tila	Daine Khola	116	114
	Karnali	West Seti	Chaira Khola	123	115
	Karnali	Thuli Bheri	Upper Bheri	105	116
	Karnali	Tila	Upper Tila	110	117
	Karnali	Tila	Bheri Khola	111	118
	Karnali	Tila	Juliodar Khola	109	119
	Karnali	Tila	Chaudhabis Khola	108	120
	Karnali	West Seti	Middle West Seti	126	121
	Karnali	Thuli Bheri	Chhera Khola	103	122
	Karnali	Thuli Bheri	Saru Khola	104	123
	Karnali	-	Upper Karnali	120	124
	Karnali	Thuli Bheri	Mujkot Khola	112	125
	Karnali	Tila	Lower Tila	115	126
	Karnali	West Seti	Kalanga Gad	132	127
	Karnali	Thuli Bheri	Thuli Bheri	106	128
	Karnali	Thuli Bheri	Bheri	107	129
	Karnali	Thuli Bheri	Sai Kumari Khola	97	130
	Karnali	Tila	Ruru Khola	114	131
	Karnali	West Seti	Upper West Seti	125	132
	Karnali	Mugu Karnali	Mugu Karnali	117	133
	Karnali	Humla Karnali	Humla Karnali	119	134
	Karnali	Humla Karnali	Loti Karnali	118	135

4.4. Vulnerability Assessment at Watersheds

Vulnerability is a function of exposure, sensitivity and adaptive capacity. Thus, to construct a combined vulnerability index, three subindices, i.e., sensitivity, exposure and adaptive capacity were assigned weightage and aggregated (Figure 14). Prior to the aggregation process, the combined adaptive capability index was inversed, since adaptation capability indices were treated inversely for vulnerability. The assumption has been made that the higher the value, the lower the adaptive capability and vice-versa. In this regard, index values were inversed for the correct representation and results. Therefore, combined adaptation capability index values were inversed and standardized by assigning weightages and by giving higher weight for adaptive capability. Then standardized values of each index (sensitivity, exposure and adaptive capability) were aggregated and normalized to produce the combined vulnerability map (Map 18).

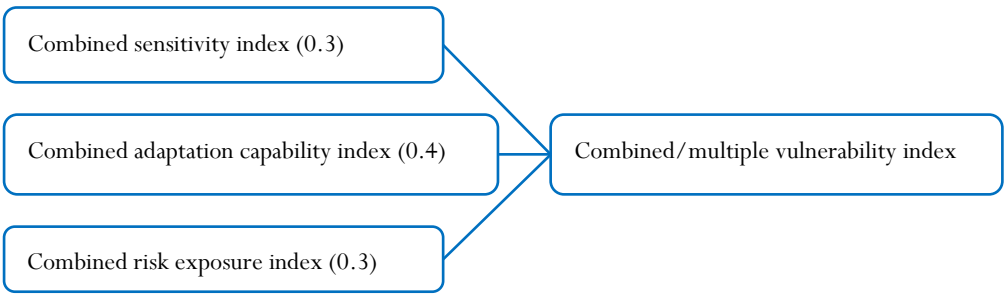
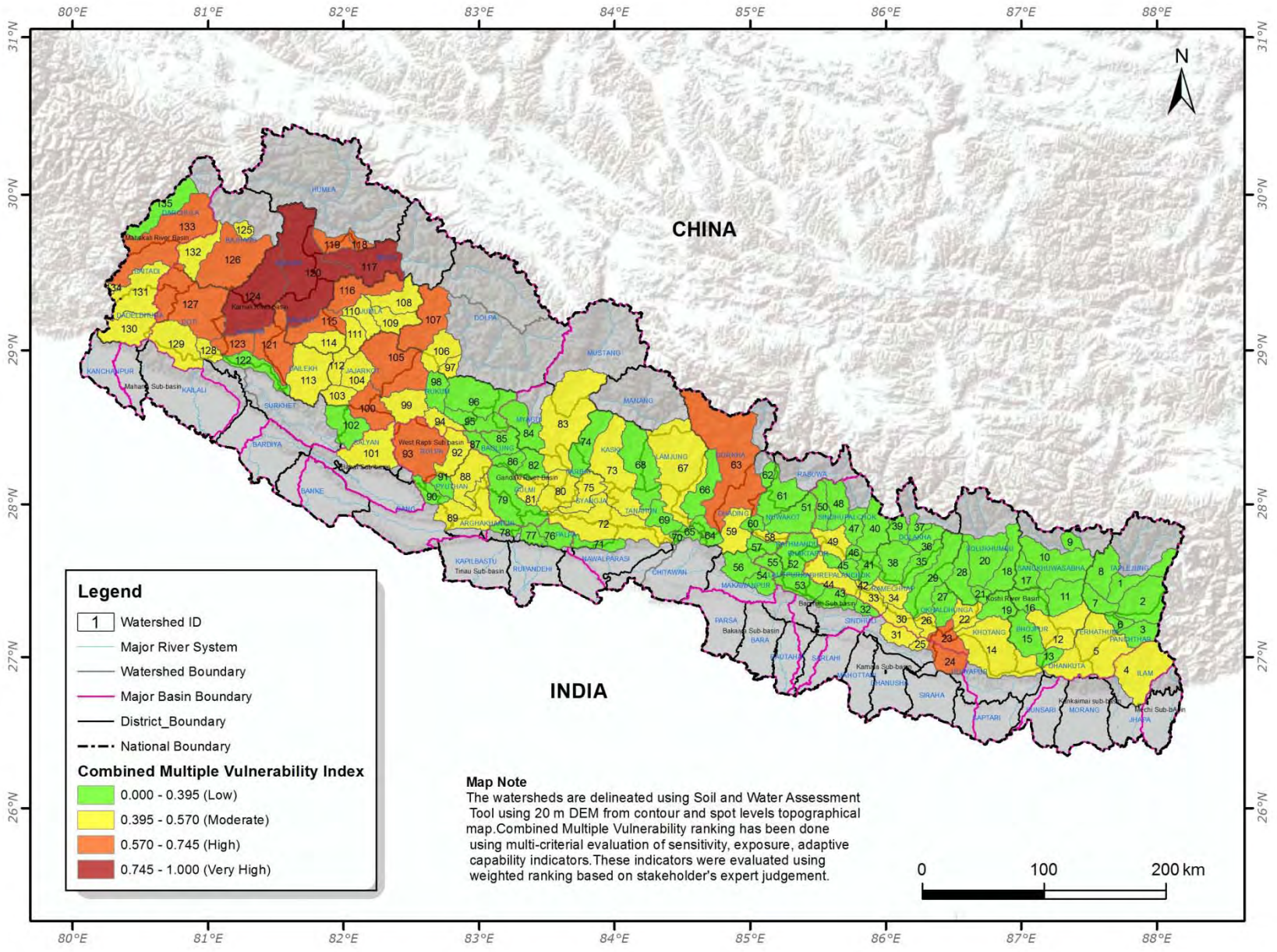


Figure 14. Combined/multiple vulnerability index, and combined sensitivity, adaptation capability and risk exposure indices with their weightages (in parentheses).



Map 18. Combined/multiple vulnerability map of watershed in Middle and High Mountain regions.

Based on combined/multiple vulnerability indices, the watersheds of Middle and High Mountains were ranked as presented in Table 20. In terms of vulnerability, the Upper Karnali Watershed, Mugu Karnali Watershed, and Budhi Ganga Watershed in Karnali River Basin are the most vulnerable among 135 watersheds in Middle and High Mountain regions of Nepal.

Table 20. Watersheds ranked by combined/multiple vulnerability index.

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
Very High (0.745-1.000)	Karnali	-	Upper Karnali	120	2557.76	Bajura, Humla, Kalikot, Mugu	1
	Karnali	Mugu Karnali	Mugu Karnali	117	1049.18	Mugu	2
	Karnali	West Seti	Budhi Ganga	124	1744.53	Achham, Bajura	3
High (0.570-0.745)	Karnali	West Seti	Middle West Seti	126	1487.56	Bajhang	4
	Karnali	Humla Karnali	Humla Karnali	119	297.04	Humla, Mugu	5
	-	West Rapti	Siban Khola	93	1281.69	Pyuthan, Rolpa, Rukum, Salyan	6
	Karnali	West Seti	Lower West Seti	127	1827.91	Achham, Baitadi, Bajhang, Dadeldhura, Doti	7
	Karnali	Tila	Lower Tila	115	545.12	Jumla, Kalikot	8
	Karnali	Tila	Daine Khola	116	738.82	Jumla	9
	Karnali	-	Middle Karnali	121	903.7	Achham, Dailekh, Kalikot	10
	Karnali	Thuli Bheri	Bheri	107	1014.37	Dolpa	11
	-	Kamala	Baidyanath Khola	24	428.15	Sindhuli, Udayapur	12
	Karnali	Thuli Bheri	Upper Bheri	105	1457.55	Jajarkot, Rukum	13
	Karnali	West Seti	Chaira Khola	123	380.75	Achham, Doti	14
	Gandaki	Budhi Gandaki	Budhi Gandaki	63	2960.15	Dhading, Gorkha, Nuwakot	15
	Karnali	Humla Karnali	Loti Karnali	118	120.06	Humla, Mugu	16
	Koshi	Sun Koshi	Yari Khola	23	359.71	Khotang, Okhaldhunga, Sindhuli,	17

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
						Udayapur	
	Mahakali	-	Chamaliya	133	1953.57	Baitadi, Darchula	18
	Karnali	Thuli Bheri	Middle Bheri	100	649.22	Jajarkot, Rukum, Salyan	19
Moderate (0.395-0.570)	Karnali	-	Sera Gad	129	885.98	Doti, Kailali	20
	Koshi	Sun Koshi	Gangeti Khola	33	234.65	Ramechhap, Sindhuli	21
	-	Babai	Sarada	101	872.51	Salyan	22
	Karnali	West Seti	Kalanga Gad	132	560.43	Bajhang	23
	Karnali	Tila	Upper Tila	110	375.03	Jumla	24
	Karnali	-	Lohare Khola	113	1023.66	Dailekh	25
	Karnali	Tila	Ruru Khola	114	382.68	Kalikot	26
	Mahakali	-	Surnaya Gad	131	960.22	Baitadi, Dadeldhura	27
	Koshi	Tamor	Tamor	5	1681.84	Dhankuta, Panchthar, Terhathum	28
	Gandaki	Kali Gandaki	Upper Kali Gandaki	83	2084.59	Baglung, Mustang, Myagdi, Parbat	29
	Koshi	Tama Koshi	Lower Tamakoshi	34	325.58	Ramechhap	30
	Karnali	Thuli Bheri	Thuli Bheri	106	523.07	Dolpa, Rukum	31
	Koshi	Sun Koshi	Sunkoshi	14	1622.98	Bhojpur, Khotang, Udayapur	32
	Gandaki	East Seti	Upper East Seti	73	1470.65	Kaski, Syangja, Tanahun	33
	-	Kamala	Chandaha Khola	31	304.82	Sindhuli	34
	Koshi	Sun Koshi	Bandijor Khola	30	318.43	Ramechhap, Sindhuli	35
	Karnali	West Seti	Upper West Seti	125	134.11	Bajhang	36
	Karnali	Tila	Chaudhabis Khola	108	552.08	Jumla	37
	-	West Rapti	Lindri Khola	92	503.18	Pyuthan, Rolpa	38
	Karnali	Thuli Bheri	Sano Bheri	99	586.52	Rukum	39
	Karnali	Tila	Juliodar Khola	109	422.85	Jumla	40
	Karnali	Thuli Bheri	Saru Khola	104	477.23	Jajarkot	41
	Karnali	Tila	Bheri Khola	111	310.03	Jumla	42
	-	West Rapti	Rapti	89	942.86	Arghakhanchi, Dang, Gulmi,	43

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
						Pyuthan	
	Karnali	Thuli Bheri	Chhera Khola	103	283.27	Jajarkot	44
	Gandaki	Kali Gandaki	Lower Kali Gandaki	72	1547.58	Nawalparasi, Palpa, Syangja, Tanahun	45
	-	West Rapti	Jhimruk Khola	88	679.85	Arghakhanchi, Gulmi, Pyuthan	46
	-	Kamala	Thakur Khola	25	98.96	Sindhuli	47
	Koshi	Sun Koshi	Khansan Khola	26	205.16	Okhaldhunga, Sindhuli	48
	Karnali	Thuli Bheri	Mujkot Khola	112	257.79	Jajarkot	49
	Gandaki	Trishuli	Kolpu Khola	58	170.28	Dhading, Nuwakot	50
	Karnali	Thuli Bheri	Sai Kumari Khola	97	162.87	Dolpa	51
	Koshi	Sun Koshi	Kalunje Khola	42	53.7	Kabhrepalanchok, Ramechhap	52
	Koshi	Indrawati	Lower Indrawati	49	432.14	Kabhrepalanchok, Sindhupalchok	53
	Koshi	Sun Koshi	Rosi Khola	44	564.81	Kabhrepalanchok, Sindhuli	54
	Mahakali	-	Gairad Khola	134	46.38	Baitadi	55
	Gandaki	Marshyangdi	Marsyangdi	67	2054.6	Gorkha, Lamjung, Manang, Tanahun, Kaski	56
	-	Kankai	Mai Khola	4	1172.11	Ilam	57
	Gandaki	Kali Gandaki	Lower Badigad Khola	81	339.03	Baglung, Gulmi	58
	Gandaki	Trishuli	Middle Trishuli	59	557.96	Dhading	59
	Gandaki	Kali Gandaki	Middle Kali Gandaki	80	648.07	Baglung, Gulmi, Parbat, Syangja	60
	Gandaki	Kali Gandaki	Aandi Khola	75	479.63	Parbat, Syangja	61
	Karnali	-	Banda Gad	128	205.64	Doti, Surkhet	62
	Mahakali	-	Ragun Khola	130	690.14	Dadeldhura, Doti	63
	Koshi	Arun	Piluwa Khola	12	902.29	Bhojpur, Dhankuta, Sangkhuwasabha	64
	Karnali	Thuli Bheri	Lukum Khola	94	290.77	Rolpa, Rukum	65
	Koshi	Dudh Koshi	Lower	22	342.53	Khotang,	66

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
			Dudhkoshi			Okhaldhunga	
Low (0.000-0.395)	Karnali	-	Lower Karnali	122	434.92	Achham, Dailekh, Surkhet	67
	Gandaki	Kali Gandaki	Ridi Khola	79	1075.69	Arghakhanchi, Gulmi, Palpa, Syangja	68
	Koshi	Sun Koshi	Chauri Khola	41	327.86	Dolakha, Kabhrepalanchok, Ramechhap, Sindhupalchok	69
	Koshi	Sun Koshi	Jhikhu Khola	45	266.55	Kabhrepalanchok	70
	Gandaki	East Rapti	East Rapti	54	293.17	Makawanpur	71
	Gandaki	Trishuli	Mahesh Khola	57	278.95	Dhading, Makawanpur	72
	Koshi	Sun Koshi	Bhushe Khola	46	108.61	Kabhrepalanchok, Sindhupalchok	73
	Koshi	Arun	Pikhuwa Khola	15	585.11	Bhojpur	74
	-	West Rapti	Madi Khola	91	187.73	Pyuthan	75
	Koshi	Dudh Koshi	Middle Dudhkoshi	21	128.28	Khotang, Solukhumbu	76
	Gandaki	Kali Gandaki	Daram Khola	82	335.6	Baglung, Gulmi	77
	Koshi	Sun Koshi	Jagarpur Khola	27	410.61	Okhaldhunga	78
	Gandaki	Trishuli	Bhyaure Khola	60	153.82	Dhading, Nuwakot	79
	Karnali	Thuli Bheri	Sani Bheri	98	372.1	Rukum	80
	Karnali	Thuli Bheri	Lower Bheri	102	601.23	Salyan, Surkhet	81
	Gandaki	Kali Gandaki	Upper Badigad Khola	86	239.08	Baglung, Gulmi	82
	Koshi	Sun Koshi	Bhotekoshi	40	589.86	Sindhupalchok	83
	-	West Rapti	Arun Khola	90	258.82	Dang, Pyuthan, Rolpa	84
	Koshi	Tamor	Hewa Khola	3	371.49	Panchthar	85
	Gandaki	Trishuli	Lower Trishuli	64	281.66	Chitawan, Dhading, Gorkha	86
	Karnali	Thuli Bheri	Pelma Khola	96	1002.59	Baglung, Rukum, Myagdi	87
	Gandaki	Trishuli	Tadi Khola	51	664.04	Nuwakot	88
	Gandaki	Trishuli	Trishuli-Marshyangdi	65	127.64	Chitawan, Tanahun	89
	Gandaki	Trishuli	Upper Trishuli	61	707.22	Dhading, Rasuwa,	90

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
						Nuwakot	
	Koshi	Arun	Middle Arun	10	1126.99	Sangkhuwasabha	91
	-	Bagmati	Kokhajor Khola	43	354.75	Kabhrepalanchok, Sindhuli	92
	-	Bagmati	Marin Khola	32	138.7	Sindhuli	93
	Koshi	Sun Koshi	Balephi Khola	47	300.23	Sindhupalchok	94
	Koshi	Likhu	Likhu Khola	29	1049.69	Okhaldhunga, Ramechhap, Solukhumbu	95
	Koshi	Arun	Lower Arun	16	424.86	Bhojpur, Sangkhuwasabha	96
	Koshi	Arun	Sabha Khola	11	553.63	Sangkhuwasabha	97
	Mahakali	-	Mahakali	135	646.55	Darchula	98
	Gandaki	Marshyangdi	Daraudi Khola	66	610.18	Gorkha	99
	Koshi	Tama Koshi	Middle Tamakoshi	38	616.74	Dolakha, Ramechhap	100
	Koshi	Tamor	Shuban Khola	6	166.24	Panchthar, Taplejung, Terhathum	101
	-	Tinau	Banganga	78	155.48	Arghakhanchi, Palpa	102
	Koshi	Dudh Koshi	Upper Dudhkoshi	20	863.59	Solukhumbu	103
	Gandaki	Kali Gandaki	Myagdi Khola	84	614.94	Myagdi	104
	Gandaki	East Rapti	Gorandhi Khola	56	425.84	Makawanpur	105
	Gandaki	East Seti	Madi	68	1121.97	Kaski, Lamjung, Tanahun	106
	Koshi	Dudh Koshi	Rawa Khola	19	404.63	Khotang	107
	Gandaki	East Seti	Lower East Seti	69	354.45	Tanahun	108
	Koshi	Tamor	Nenwa Khola	7	310.6	Taplejung	109
	-	Tinau	East Tinau	76	359.07	Palpa	110
	-	Bagmati	Palun Khola	55	219.55	Makawanpur	111
	Koshi	Indrawati	Upper Indrawati	48	472.76	Sindhupalchok	112
	Koshi	Tamor	Kabeli Khola	2	892.29	Panchthar, Taplejung	113
	Koshi	Tama Koshi	Khimti Khola	35	445.83	Dolakha, Ramechhap	114
	Koshi	Dudh Koshi	Solu Khola	28	532.21	Solukhumbu	115
	Koshi	Dudh Koshi	Hongu Khola	18	604.22	Solukhumbu	116
	Karnali	Thuli Bheri	Ganga	95	487.24	Baglung, Myagdi, Rukum	117
	Koshi	Arun	Upper Arun	9	163.33	Sangkhuwasabha	118
	Koshi	Tama Koshi	Sagu Khola	39	248.03	Dolakha, Sindhupalchok	119
	Koshi	Arun	Lower Piluwa Khola	13	192.22	Bhojpur, Dhankuta	120

Class	Major River Basin	Sub-Basin	Watershed	WS ID	Area (Sq. km)	Included District	Rank
	Gandaki	Kali Gandaki	Taman Khola	85	373.98	Baglung	121
	Gandaki	Trishuli	Trishuli-Seti	70	59.24	Chitawan, Tanahun	122
	Koshi	Indrawati	Melamchi	50	324.18	Sindhupalchok	123
	Gandaki	Kali Gandaki	Modi Khola	74	674.74	Kaski, Parbat	124
	Gandaki	Budhi Gandaki	Bhabil Khola	62	144.09	Dhading	125
	Koshi	Tamor	Ghunsa Khola	1	550.95	Taplejung	126
	Koshi	Tamor	Mewa Khola	8	582.46	Taplejung	127
	-	Bagmati	Lower Bagmati	53	439.87	Kabhrepalanchok, Lalitpur, Makawanpur	128
	Koshi	Arun	Sankhuwa Khola	17	352.96	Sangkhuwasabha	129
	Gandaki	Kali Gandaki	Nisi Khola	87	233.6	Baglung	130
	Koshi	Tama Koshi	Upper Tamakoshi	37	180.07	Dolakha	131
	Gandaki	East Rapti	Arun Khola	71	270.86	Nawalparasi, Palpa	132
	Koshi	Tama Koshi	Khare Khola	36	265.65	Dolakha	133
	-	Tinau	West Tinau	77	196.15	Palpa	134
	-	Bagmati	Upper Bagmati	52	677.58	Bhaktapur, Kathmandu, Lalitpur	135

Table 21 presents the number of watersheds at different vulnerability classes in the major river basins of Nepal.

Table 21. Watersheds ranked by state of vulnerability in each river basin.

Major river Basin	Subbasin	Low (0.000-0.395)	Moderate (0.395-0.570)	High (0.570-0.745)	Very high (0.745-1.000)	No. of watersheds
Koshi	-	31	12	1	-	44
Gandaki	-	21	9	1	-	31
Karnali	-	5	17	11	3	36
Mahakali	-	1	3	1	-	5
-	Kankai	-	1	-	-	1
-	Kamala	-	2	1	-	3
-	Bagmati	5	-	-	-	5
-	Tinau	3	-	-	-	3
-	West Rapti	2	3	1	-	6
-	Babai	-	1	-	-	1
Total		68	48	16	3	135

Chapter 5

Conclusion

5.1. Conclusion

This study adopted the method proposed by Yusuf and Francisco (2009) for the vulnerability assessment. Altogether, 135 watersheds were assessed based on three parameters, i.e., sensitivity, exposure and adaptive capacity. The associated vulnerability map was then developed by constructing a combined index.

The 135 watersheds were distributed in 4 major river basins and 6 sub-basins of the country. The degree and extent of vulnerability differed according to the main vulnerability parameters, i.e., sensitivity, exposure/risk and adaptive capacity. Based on the sensitivity analysis, it was found that the Upper Seti Watershed in Gandaki River Basin is highly sensitive to climate change followed by the Upper Bagmati Watershed in Bagmati Sub-basin and Rosi Khola Watershed in the Koshi River Basin. Based on the exposure/risk analysis, it was found that the Upper Karnali Watershed in Karnali River Basin is highly exposed to significant climate changes followed by the Baidyanath Khola Watershed in Kamala Sub-basin, Tamor Watershed in Koshi River Basin and Lower West Seti Watershed in Karnali River Basin. Therefore, these watersheds are at a higher risk from various hazardous conditions such as landslides/flood, more frequent droughts, food insecurity and more frequent intensive rainstorms. As the ability of a community to respond and adjust to climate-induced risks also affects the level of vulnerability, the study assessed the adaptive capacity of the communities by looking at socioeconomic indices, presence of infrastructure as well as existing technologies. Based on the adaptive capacity analysis, it was found that the Upper Bagmati Watershed in Bagmati Sub-basin has the highest adaptive capacity followed by Upper East Seti Watershed in Gandaki River Basin and Tamor Watershed in Koshi River Basin.

The final vulnerability ranking identified the Upper Karnali Watershed, Mugu Karnali Watershed and Budhi Ganga Watershed in Karnali River Basin as the most vulnerable to climate change. These are followed by watersheds in the Koshi River Basin. The watersheds under Upper Bagmati and West Tinau are the least vulnerable.

The quantification of local climate change impacts and vulnerability assessments are imperative for the design of adaptation measures. The use of such assessments will allow the various adaptation intervention programs to be targeted to areas where the risks of catastrophic climate-induced impacts are highest. Therefore, the final vulnerability map and various other assessments in the study are expected to provide necessary information to the Government of Nepal for developing a scientifically justified road map for the planning of effective watershed management interventions to build climate resilience in the mountain watersheds of Nepal.

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