

Geospatial approach to the risk assessment of climate-induced disasters (drought and erosion) and impacts on out-migration in Nepal

Sakar Nepal^a, Shankar Tripathi^a, Hari Adhikari^{b,c,*}

^a Faculty of Forestry, Agriculture and Forestry University, Hetauda, P.O. Box 13712, Nepal

^b Department of Geosciences and Geography, P.O. Box 68, FI-00014, University of Helsinki, Finland

^c Institute for Atmospheric and Earth System Research, Faculty of Science, University of Helsinki, Finland

ARTICLE INFO

Keywords:

Disaster risk assessment
Drought index
Vulnerability map

ABSTRACT

Out-migration is one of the most recognized adaptation practices when dealing with scarce resources and disasters. With the general objective of exploring migration as an impact of climate-induced disasters, our study was conducted in Khaniyapani, in the Sunapati rural municipality of Ramechhap district, Nepal. Disaster prioritization was conducted using the pair-wise ranking method, with results suggesting that drought and soil erosion are the most severe disasters in the study area. The severity maps were prepared using remotely sensed data. A Normalized Difference Drought Index and the Revised Universal Soil Loss Equation were used to produce the drought and erosion severity maps, respectively. Approximately 46.2% of the total study area was found to experience severe droughts, and almost 10% of the area had high soil erosion rates. In total, 100 out of 794 households were interviewed for a semi-structured questionnaire. Drought severity was found to directly impact livelihoods due to a decline in agricultural productivity, a decline in livestock, and drying of water sources. Out of 100 families, 64 practiced seasonal migration. A decline in agricultural productivity and livestock, and water scarcity were identified as the most influencing push factors. Excessive seasonal migration has reduced the resilience of these families. Drought-resistant land, water, and crop management techniques and practices, and alternative income-generating activities should be promoted to curb the seasonal migration.

1. Introduction

The global climate has been changing continuously since the very beginning of the earth. It is considered a natural phenomenon, but the rate of change is accelerated due to various human activities [1]. The Intergovernmental Panel on Climate Change (IPCC) has defined climate change as one of the most critical factors affecting the disaster risk [2]. The frequency and severity caused by climate-induced hazards are increasing and vulnerable areas of under-developed countries face many challenges [3]. The increasing warming trend and fluctuating weather patterns have resulted in irregular precipitation, which has caused increased flooding and drought risks [4]. Other adverse effects of rapidly increasing warming trends have been seen concerning the sustainable management of our planet's resources, such as those relating to biodiversity, water, forest, land, along with various sectorial activities e.g. agriculture and tourism [5].

Nepal is one of these highly vulnerable countries due to its physiological condition. Young mountains and a fragile ecosystem are

enormously impacted by climate change [6]. In 2017, Nepal was ranked 4th on the list of countries most affected by climate change [7]. The risks for disasters, such as floods, drought, fire, erosion, mudslides, landslides, and a glacial lake outburst flood have increased as the impact of climate change increases [8]. More than 16 climate-induced events were documented from 1972 to 2016, and most of these were documented from the eastern region of Nepal, which massively affects agricultural crops and livelihoods [9]. Bhatt et al. [10] found decreases to agricultural crop production due to drought and associated climate-induced impacts in the Koshi River Basin. Winters are becoming drier and the monsoon summers wetter, which have been causing more frequent and intense summer floods and winter droughts [11]. Because a significant portion of the Nepalese economy relies on climate-sensitive industries, such as agriculture, forestry, and ecotourism, the vulnerability of the people is exceptionally high [12,13].

Human movement in response to extreme weather patterns as a means to escape danger and increase resilience is a typical behavior since pre-historic times [14]. Migration has a dual nature. It is both an

* Corresponding author. Department of Geosciences and Geography, P.O. Box 68, FI-00014, University of Helsinki, Finland.

E-mail address: hari.adhikari@helsinki.fi (H. Adhikari).

<https://doi.org/10.1016/j.ijdr.2021.102241>

Received 10 March 2021; Accepted 29 March 2021

Available online 6 April 2021

2212-4209/© 2021 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

impact of climate change and an adaptation to climate change [15]. Impacts of the unchecked increase in temperature remain understudied, especially those concerning social sciences. Any further increase in temperature may threaten the peoples very survival [16,17]. People face manifold impacts from climate change and natural disasters, which along with socio-economic vulnerabilities reinforce their decisions to migrate from one place to another [18]. The increased strength and frequency of storms and floods, droughts and desertification, and sea-level rise are prominent environmental factors responsible for migration, and they are further expected to aggravate in the future considering anthropogenic climate change [18,19]. The IPCC has defined migration as the most dangerous short-term effect of climate change [20]. Nepal is liable to an unplanned wave of climatic migration [21]. Soil erosion and drought played major roles in reducing soil fertility, resulting in low productivity leading to poverty, which was a major factor contributing to migrations in Nepal [22].

Satellite images are essential for hilly terrain, such as Nepal, and these images can be accurately used to measure and detect various climate-related events [23]. Satellite-derived drought indices use multispectral bands, each of which provides different information concerning surface conditions [24]. Certain satellite-derived drought indices include the Normalized Difference Vegetation Index (NDVI) as a drought exposure index, the Normalized Difference Water Index (NDWI) as a water stressor index, and the Normalized Difference Drought Index (NDDI) as a drought severity index [25].

Several predictive models have been developed to estimate soil loss, which can be grouped into three main categories: empirical, physical, and conceptual [26]. The Universal Soil Loss Equation (USLE) and its successors the Modified Universal Soil Loss Equation (MUSLE) and the Revised Universal Soil Loss Equation (RUSLE), are globally the most used empirical models in the quantitative estimation of soil loss [27]. Application of remote sensing together with RUSLE in soil loss estimation makes it more reasonable in terms of costs and maintains significant accuracy considering its spatial coverage [28].

Our research focuses on climate-induced disaster severity using spatial and meteorological data in the GIS platform. We have attempted to explore the social data to resonate with the concept that climate-induced disasters, such as drought, soil erosion, flood etc., directly impact various essential factors contributing to the livelihoods of the rural population and to investigate the influence of these impacts on humans' decisions to out-migrate.

2. Materials and methods

2.1. Study area

Ramechhap district lies in the mid-hills of Nepal, in Province number 3. The altitude of the district ranges from 369 m (the mean sea level at Kolonjorghat) to 6959 m at Numbur Chuli. The climate ranges from subtropical to alpine. Five forest types, i.e. sub-tropical evergreen, deciduous, coniferous, high temperate, and cold desert, are found in the district. The major tree species include *Shorea robusta*, *Acacia catechu*, *Michelia champaca*, *Schima wallichii*, *Alnus nepalensis*, *Thuja occidentalis*, *Pinus roxburghii*, and *Pinus wallichiana*. The percentages of land use and land cover covered by cultivated lands, forestland, shrubland, grassland, abandoned/wastage land, and other land uses in Ramechhap district are 32.54%, 34.58%, 15.81%, 5.93%, 9.2%, and 1.94% respectively [29].

Climate change vulnerability mapping for Nepal, published by the Ministry of Environment [30], has stated that the overall climate change trend in the district is very high. This severe climate change has resulted in very high exposure to disasters such as drought, erosion, and landslides. Furthermore, despite the high vulnerability to disasters, local people have substantially low estimated socioeconomic capabilities for adaptation.

In this study, we focused on Khaniyapani, former Village Development Committee and presently ward 5 of Sunapati rural municipality in

the Ramechhap district. The average altitude is 1094 m (3589 feet) above the mean sea level. Khaniyapani is comprised of two Nepali words: "Khaniya" meaning "digging" and "Pani" meaning "water". This ancient name has been kept due to the area's characteristic scarcity of water, which caused local people to dig deeper in search of it. Geographically, Khaniyapani lies in the northern rain shadow area of the Mahabharat range, and therefore has faced more severe droughts than other parts of the district. The biodiversity in the area is on a decreasing trend, where even drought-resistant species e.g. *Acacia catechu* are concurrently being replaced by thorny shrub species.

2.2. Data collection

Landsat 8 Operational Land Imager (OLI) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) global digital elevation model version 2 (GDEM 002) image were downloaded from Earth explorer and The United States Geological Survey. Satellite data, a digital elevation model, soil, and precipitation data were used for the drought and erosion sensitivity analyses (Table 1).

Due to study area having no meteorological station, we obtained monthly precipitation data from the three nearest stations, i.e. Manthali, Panchkhal, Sindhuli, from the Department of Hydrology and Meteorology, and obtained continuous average precipitation data from Worldclim version 2.0. Monthly precipitation data for the study area (1988–2017) were estimated using the normal ratio method.

$$P = \frac{N}{n} \left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} \right) \quad (1)$$

where P is the estimated monthly precipitation data for Khaniyapani; P1, P2, and P3 are the monthly precipitation data from Manthali, Panchkhal, and Sindhuli stations, respectively; N, N1, N2, and N3 are the average precipitation data from the Worldclim database for Khaniyapani, Manthali, Panchkhal, and Sindhuli, respectively; n = total number of stations = 3.

2.3. Analysis

2.3.1. Drought severity map

The NDDI [25] was calculated from the Landsat 8 OLI/TIRS image for 2017. The NDDI map was reclassified to prepare the drought severity map [24] (see Fig. 1).

Table 1
Data sets used and different sources.

Data	Attributes	Type	Use
LANDSAT 8 OLI/TIRS ^a	Collection 1, Path: 141, Row: 041, Acquisition date: 3rd April, 2017	Raster	Normalized Difference Vegetation Index, Normalized Difference Water Index, Normalized Difference Drought Index
ASTER GDEM ^b	Version 2.0, Resolution: 1 Arc second	Raster	Topographic Factor, Support Practice factor
Soil Map ^c	HWSD version 1.2, Resolution: 30 Arc seconds	Raster	Soil erodibility factor
Precipitation data ^d	Archival data from DHM, Government of Nepal	Excel data	Precipitation trend analysis, Rainfall erosivity factor
	Worldclim version 2.0, Resolution: 30 Arc seconds	Raster	

^a www.earthexplorer.usgs.gov.

^b www.gdex.cr.usgs.gov.

^c <https://web.archive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/>.

^d www.worldclim.org/version2.

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{2}$$

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \tag{3}$$

$$NDDI = \frac{NDVI - NDWI}{NDVI + NDWI} \tag{4}$$

where the NDVI, NDWI, near-infrared band (NIR), red band (Red), and Short-wave infrared band (SWIR). The NDDI was used to estimate the drought severity of the study area. The map was prepared by reclassifying the NDDI value into five severity classes, as classified by Ref. [24], which is shown in Fig. 2.

2.3.2. Erosion severity map

The RUSLE model, which is updated from the USLE model, was used in the GIS platform to prepare the erosion map of the study area. The RUSLE model is expressed by equation $A = RKLSCP$, where A is soil loss ($t\ ha^{-1}\ yr^{-1}$) and R, K, LS, C, and P are RUSLE parameters (Table 2). The final map obtained for the annual soil loss by multiplying all these parameters using the raster calculator in ArcGIS was then reclassified into severity classes. We used the soil erodibility for various textural classes from Ref. [31] (Annex 1) and the P factor for different slope from Ref. [32] (Annex 2).

The following parameters were used for estimating the potential annual soil erosion rate and classifying the study area based on erosion severity:

1. Rainfall Erosivity Factor (R): 115.3 mm–136.717 mm
2. Soil Erodibility Factor (K): 0.25
3. Slope Length and Slope Steepness factor or Topographic Factor (LS): 0–847.024

4. Cover Management Factor (C): 0.212–1.245

5. Support practice Factor (P): 0.55–1

2.3.3. Focus group discussion (FGD)

Semi-structured questionnaire interviews were conducted with a hundred households and focus group discussions (FGD) with three groups to understand the impacts of drought and erosion on livelihoods. Household sample size for the survey was calculated with a confidence of no less than 90% and a confidence interval of 10 with a sampling intensity of more than 10%. A stratified random sampling method was used to identify sample households, so that the sample was representative of all groups and social divisions and was unbiased to the highest possible extent.

The social data analysis mainly used three approaches: the pairwise ranking method for disaster prioritization, the Likert scale to analyze the impacts of the disasters on livelihoods, and rank analysis for various push factors of seasonal migration. Moreover, the social data collected from the semi-structured household interviews were processed and analyzed using Microsoft Excel.

3. Results

3.1. Disaster prioritization and drought severity map

The list of disasters in the study area was prepared with deliberation in the FGDs. Furthermore, they were prioritized using the pairwise ranking (LAPA framework) method, as shown in Table 3.

The discussion for prioritizing the possible climatic disasters using the pairwise ranking method showed that drought is the most severe disaster in Khaniyapani, followed by soil erosion. Drought severity classes with their NDDI value ranges and the areas occupied by each class are shown in Table 4. The table also includes data from a similar

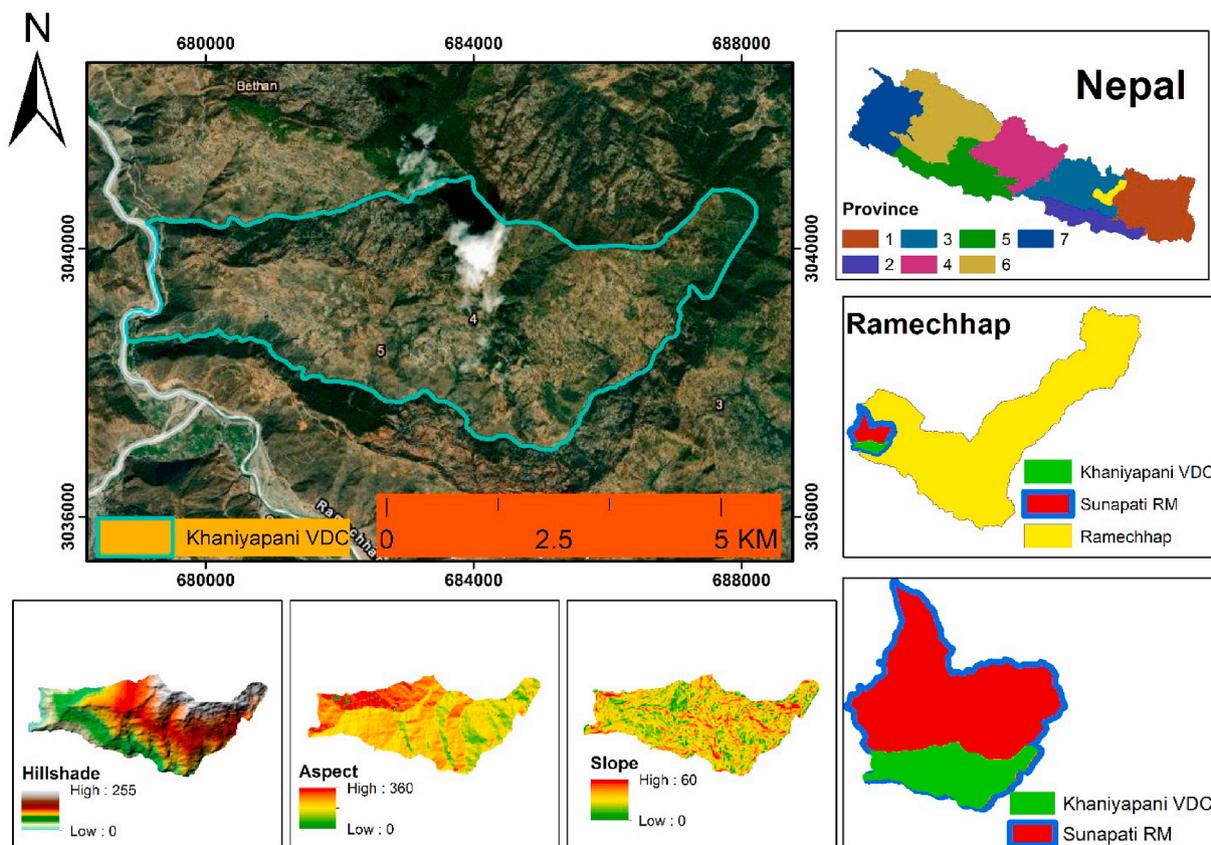


Fig. 1. Location map of study area.

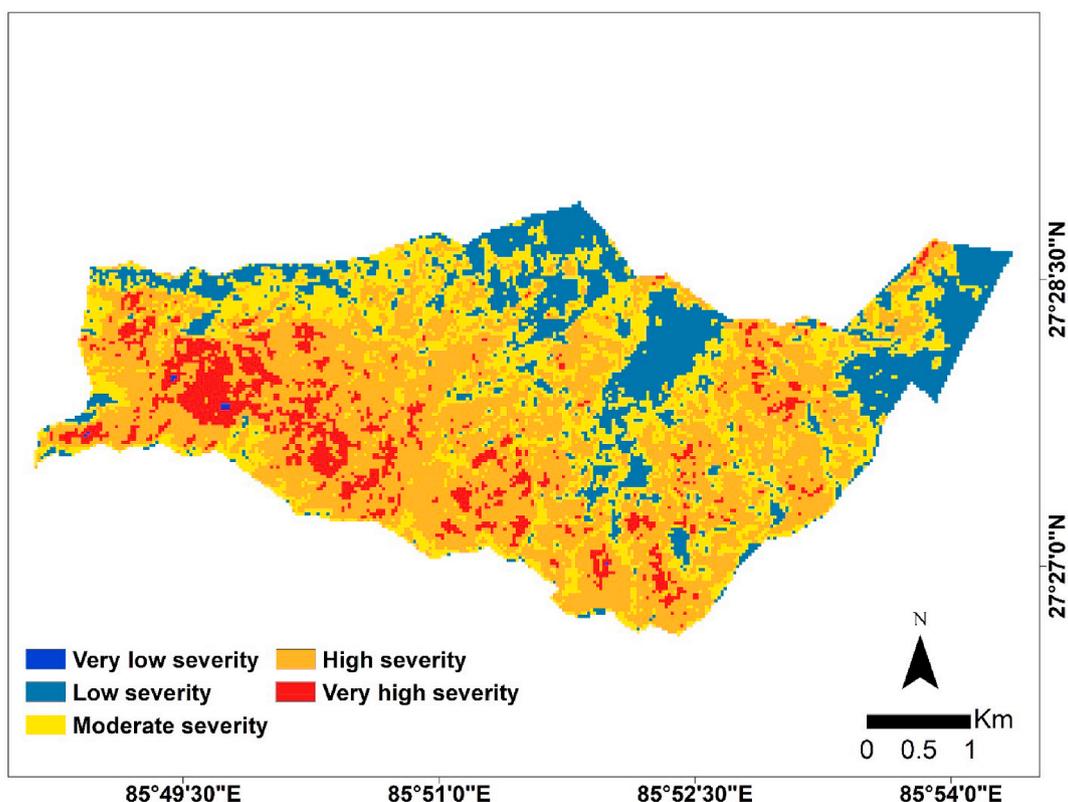


Fig. 2. Drought severity map reclassified into severity classes.

Table 2
Revised Universal Soil Loss Equation parameters.

RUSLE parameters	Equations used	Reference
R (Rainfall erosivity factor)	$R = 79 + 0.363 R_N$ $R_N =$ Average annual rainfall in mm	[27]
K (Soil erodibility factor)	From textural class and organic matter content (Annex 1)	[31]
LS (Topographic factor)	$LS = Pow$ ([Flow accumulation] * Resolution/22.13, m) * Pow (Sin [(slope of DEM)*0.01745/0.0896, 1.3]) $m = \beta/(1+\beta)$, where β is the ratio of rill erosion to inter-rill erosion and $\beta = \frac{sin\theta \cdot 0.0896}{3(sin\theta)^{0.8} + 0.56}$ $\theta =$ slope angle ($^\circ$)	[27]
C (Cover management factor)	$C = e^{(-a \cdot ((NDVI)/(b-NDVI)))}$ 'a' and 'b' are unitless parameters with values 2 and 1, respectively	[27]
P (Support Practice factor)	The slope map was prepared and P value for different slopes used considering contouring as a general conservation practice (Annex 2 and Annex 3)	[32]

Table 3
Pairwise disaster ranking.

	1	2	3	4	5	6	Score	Rank
Drought (1)		1	1	1	1	1	5	1
Landslide (2)			3	2	2	2	3	3
Soil erosion (3)				3	3	3	4	2
Diseases and pests (4)					5	4	1	5
Forest fire (5)						5	2	4
Thunder/Windstorm (6)							0	6

Table 4
Drought severity classes and size of affected areas.

NDDI Value	Severity Class	Area (km ²) in Khaniyapani	% of land in Khaniyapani	% of land in Ramechhap [24]
<-2	Very low severity	0.01	0.0	24.3
-2-0.7	Low severity	3.91	18.5	41.3
0.7-1.25	Moderate severity	5.58	26.4	21.6
1.25-3	High severity	9.77	46.2	10.5
>3	Very High Severity	1.88	8.9	2.3

study [24] in the Ramechhap district. The comparison shows that droughts are much more severe in Khaniyapani. Fig. 2 shows the various scales of drought severity in the study area.

The trend of total precipitation from 1988 to 2017 is shown in Fig. 3. The precipitation shows irregularity, but the trend is declining. The maximum rainfall recorded was 1778 mm, which occurred in 1999. The minimum rainfalls recorded were 639.2 mm and 728 mm, which occurred recently in 2016 and 2017, respectively. With reference to Ref. [24], months with less than 60 mm of rainfall were categorized as 'dry months.' The trend of dry months is shown in Fig. 3. The total number of dry months has increased slowly over the years. The maximum number of dry months (nine) was recorded 2015, whereas the minimum was four in both 1988 and 2004. Month-wise average precipitation (1988–2017) is shown in Fig. 3. The months of January (12.08 mm), February (17.9 mm), March (35.66 mm), October (54.9 mm), November (6.1 mm), and December (7.65 mm) are dry months that receive less than 60 mm of average rainfall in a year.

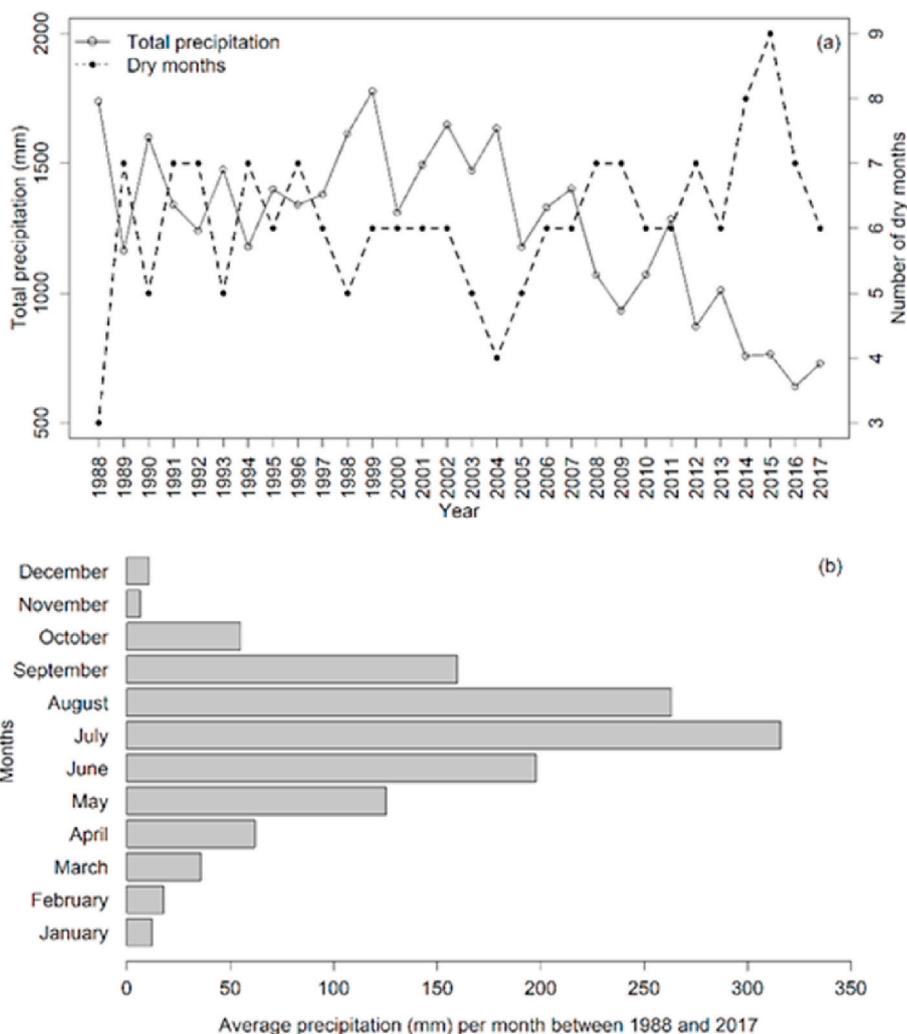


Fig. 3. Total precipitation and number of dry months (a) and average precipitation (mm) per month between 1988 and 2017 (b).

3.2. Erosion severity map

Soil erosion in Khaniyapani was found to range from 0 to 847 tons $ha^{-1} yr^{-1}$. The map was then prepared by reclassifying the erosion rates into six severity classes, as classified by Ref. [33], shown in Fig. 4. The soil erosion rates, classified into six severity classes, along with the area occupied by each class are shown in Table 5.

3.3. Impacts of drought on livelihood

Some of the significant drought impacts on the livelihoods of people were identified and discussed in the FGD and the list was then incorporated into the household questionnaire, where each respondent had to provide their degree of agreement to each of the impacts that were measured using the Likert scale. The results are presented in Table 6. Most respondents strongly agreed with statements concerning the impact of drought on several factors that directly impact livelihoods.

The descriptive analysis of irrigation status on two distinct and dominant agricultural land-use systems, i.e. Khet land (lowland) and Bari land (upland) in Khaniyapani. Of the families owning Khet land, 36.1% have no irrigation at all, 47.4% have seasonal irrigation opportunities, and only 16.5% have year-round irrigation. Similarly, 78% of the families who own Bari land have no irrigation at all, 22% have seasonal availability of irrigation, and none have year-round irrigation.

3.4. Seasonal migration

Seasonal migration is a common practice in Khaniyapani. In total, 64 out of 100 interviewed households had someone from the family involved in seasonal migration. Most seasonal migrants were males in the age group 20–40 years, who worked in various brick kilns in Kathmandu valley. They generally move out of the village after the festival of Dashain (September/October) and do not return until the pre-monsoon period (May/June) for agriculture cultivation. The ratio of the independent population (16–60 years) to the dependent population (<16 and >60 years) in the study area was 0.74, of which most of the independent members were women.

Fifty-four percent of respondents strongly agreed and 43% agreed that increased out-migration in Khaniyapani is due to increased drought conditions. However, to further emphasize that drought is one of the most significant factors affecting seasonal migration, respondents were asked to rank four major push factors of migration that were identified during the FGDs, with rank one being the most significant and rank four being the least significant factor (Annex 4). People considered agricultural productivity and livestock decline, and water scarcity to be the first and second significant factors affecting seasonal migration, respectively (Fig. 5). Also, these two factors are directly linked with drought.

Fig. 6 shows how seasonal migration is affected by irrigation opportunities in the fields. On Khet land, as irrigation improves from no irrigation to seasonal to year-round irrigation, the percentage of families involved in seasonal migration has decreased from 82.86% to 63.04%–

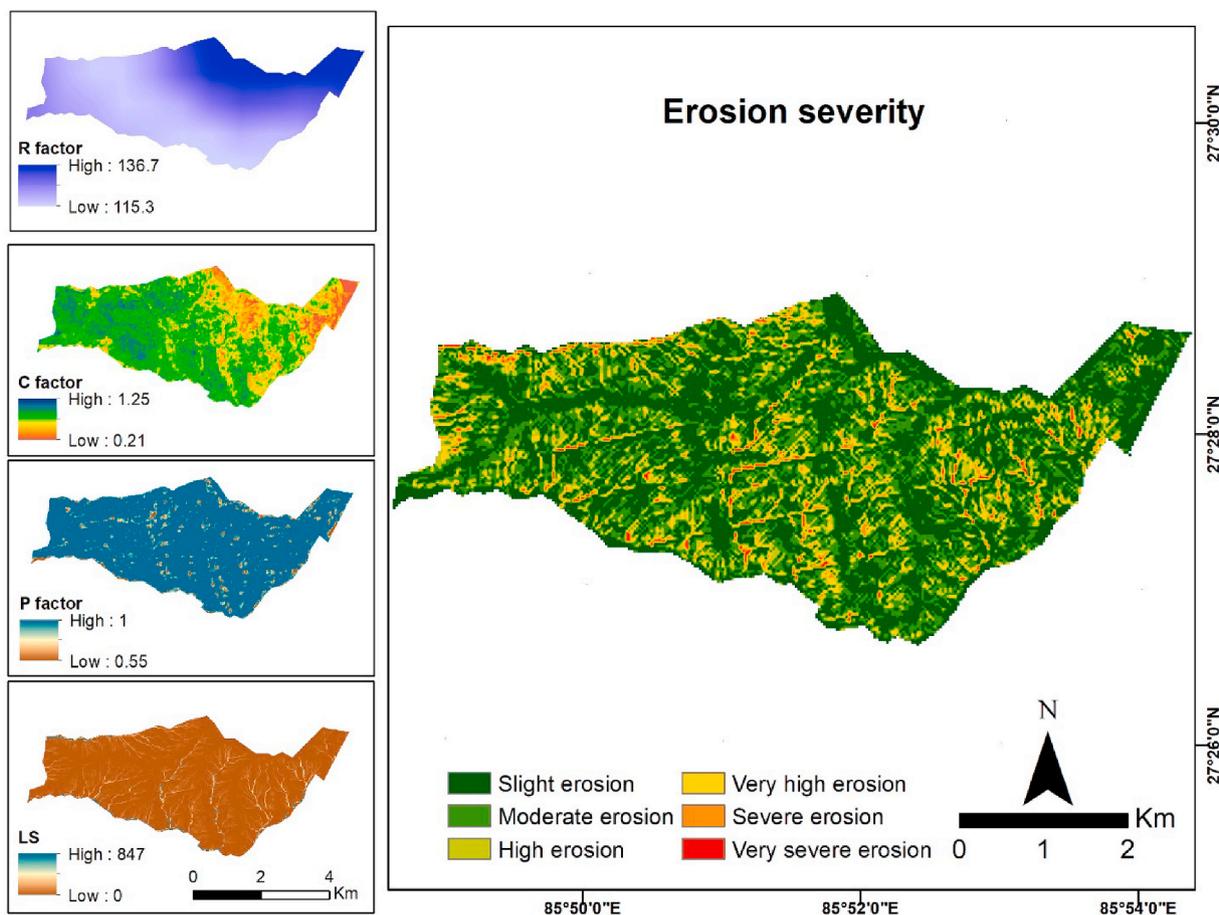


Fig. 4. Potential soil erosion map reclassified into severity classes.

Table 5
Soil erosion severity class and area occupied.

Erosion rates (t ha ⁻¹ yr ⁻¹)	Erosion class	Area (Km ²) in Khaniyapani	% of land in Khaniyapani	% of land in Nepal [32]
0–5	Slight erosion	10.53	49.78	44.1
5–10	Moderate erosion	6.40	30.23	14.2
10–20	High erosion	2.09	9.88	10.6
20–40	Very high erosion	1.25	5.89	13.3
40–80	Severe erosion	0.56	2.65	6.8
>80	Very severe erosion	0.33	1.56	11.0

31.25%, respectively. On Bari land, families with no irrigation and seasonal irrigation have nearly the same migration rates (64.8% and 60%), i.e. seasonal irrigation on Bari land has no significant effect on reducing migrations. In contrast, families with access to year-round irrigation were not found to migrate. Thus, providing seasonal facilities on Khet land may reduce migration, but year-round irrigation is crucial for reducing migration from both lands.

The total annual income of a hundred respondent families was grouped into seven categories, starting from NRS 25 000 and an interval of NRS 50 000 (Fig. 7). As the income class increases, the percentage of people involved in seasonal migration increases. Fifty percent of people in income class NRS 325 000–375 000 were involved in seasonal migration, 16.7% of which participated in foreign migration and only

Table 6
Peoples' perceptions of drought impacts.

Impacts	Respondents (%)				
	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Agricultural productivity decline	77	23	0	0	0
Previously suitable crop lost	43	57	0	0	0
Drying of water source	89	11	0	0	0
Scarcity of drinking water	81	19	0	0	0
Wildlife population decline	3	60	37	0	0
Livestock number decline	72	26	2	0	0
Forest degradation increase	33	55	12	0	0
Migration increase	54	43	3	0	0

33.3% were involved in domestic migration. The percentages of total family members involved in foreign or domestic seasonal migration are plotted against the income class in Fig. 7.

The percentages of total family members involved in foreign and domestic seasonal migration are plotted against the total number of dependent members in a family in Fig. 8. As the number of dependent members increases initially, the percentage of members involved in seasonal migration decreases, but as the number of dependent members increases further, the seasonal migration percentage increases. The

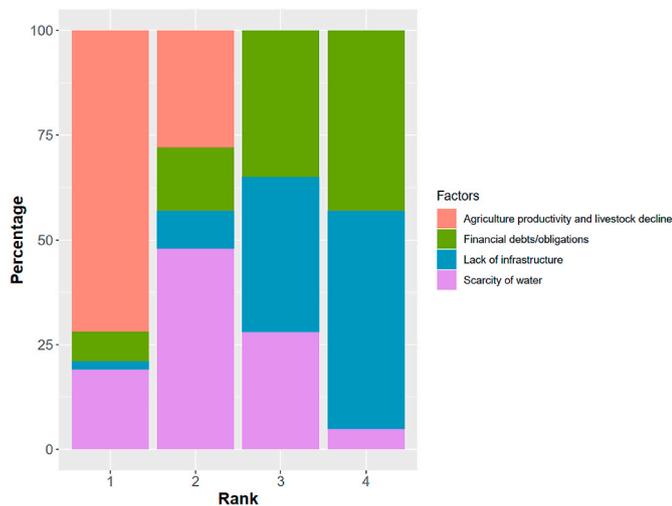


Fig. 5. Ranking of drought push factors.

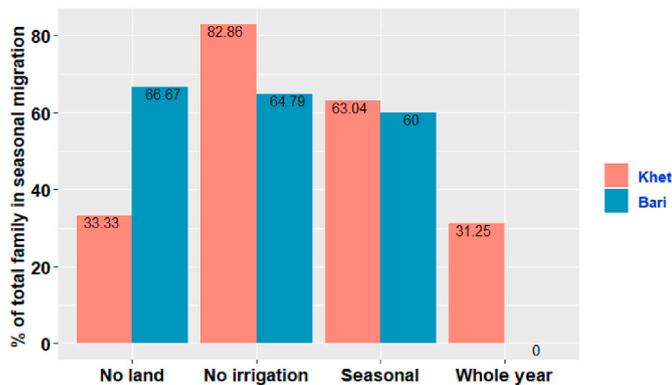


Fig. 6. Seasonal migration and irrigation status.

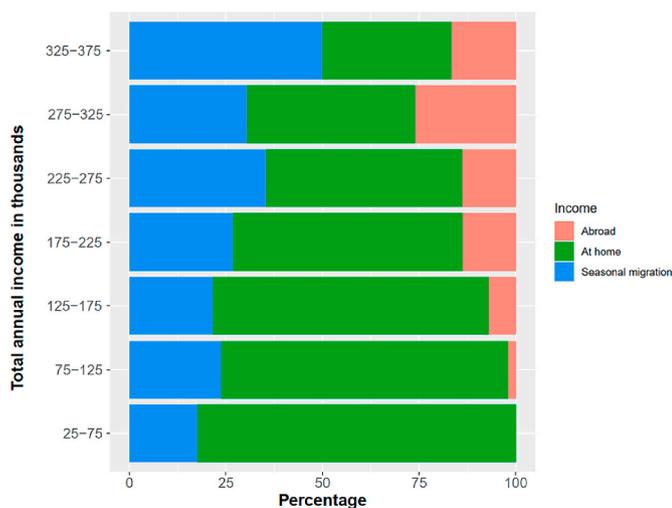


Fig. 7. Total annual income in NRS and seasonal migration.

initial increment of the dependent population in the family demands maximum presence at home. However, as it further increases, it places economic pressures on the families, which results in more seasonal migration.

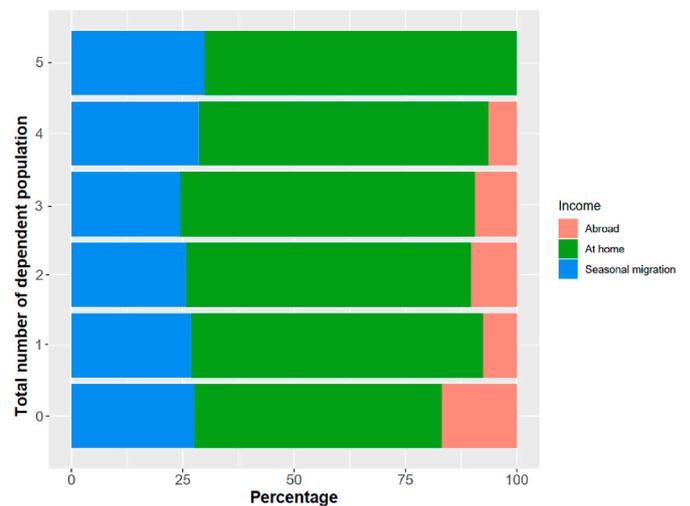


Fig. 8. Total number of dependent population (age group of <16 and >60) and seasonal migration.

4. Discussion

Khaniyapani was found to experience severe droughts, with 55.1% of the land having an NDDI value over 1.25, whereas only 12.8% the land in Ramechhap district experienced severe droughts. A study conducted in the Gandaki River Basin in central Nepal found an increasing trend of drought from 1991 to 2012 [34]. A drought assessment of Khoshi River Basin, which also includes Ramechhap district, shows extreme to moderate drought conditions [35].

The risk of a drought period occurring is mainly due to the increase in temperature with a decrease in precipitation rate, and average temperature has remarkably increased at a rate of 0.03 °C year⁻¹ while the average precipitation has decreased at a rate of -5.12 mm year⁻¹ in Nepal [36], and we also found a similar trend of temperature and precipitation in this study.

In contrast with drought severity, Khaniyapani was found to suffer less severe erosion, as only 20% of the land experiences more than 10 tons ha⁻¹yr⁻¹ of erosion compared to the erosion severity in the whole country, where 42% of the land [32], 56.11% of the land in Karnali River Basin [37], and 13% of the land in Khosi River Basin [38] experienced more than 10 tons ha⁻¹yr⁻¹ of erosion. The study conducted in the two middle mountain sub-watersheds (Madhav khola and Jogi and Bhandare Khola) in central Nepal also concluded that these areas experienced less erosion severity [39].

The increasing temperatures of the high Himalayas and the mountains of central Nepal cause droughts, erosion, and associated problems [40], and people out-migrate from rural areas to urban areas due to climate change, which impacts agricultural lands, causes changes to water conditions, and creates difficulties in continuing and enhancing livelihoods [41,42]. We explored similar conditions in this study. A study conducted on the rural community of western mountainous Nepal also shows that climate change is causing problems related to land and environment, which ultimately decreases land productivity, decreases in natural resources, social inequalities, and lastly severely affects the livelihoods of poor people [43].

Seasonal changes in temperature and precipitation massively affect the livelihoods of rural communities in Nepal, which broadly depend on agriculture supported by livestock and forest products. Marginalized people extensively face the impact of climate change, with no ability to cope with or tolerate the extra burden of practicing adaptation measures [44].

Many problems revolve around water stress, including shortages for drinking, irrigation, and other purposes, and people cope with these problems rather desperately and not always successfully [45].

Increasing drought events have greatly affected the agriculture of many developing countries, which greatly depend upon rain for irrigation. Globally, rain-fed agriculture is practiced in 80% of the total physical agricultural area and it generates 62% of the world's staple food [46]. The drought of 2008–2009 in Nepal had a severe impact on local food security. During this period, most monitoring stations received less than 50% of the normal rainfall, 30% recorded no precipitation at all, and temperatures 1–2 °C above average were recorded [47]. According to the United Nation's World Food Programme (WFP), more than 300 000 people in nine hill districts of far western and mid-western Nepal faced a precarious food situation after crops failed in 2008 due to drought [48]. Approximately 40 districts in Nepal have faced food shortages due to droughts, inducing a decline in productivity [45].

The report from the United Nation's University Institute for Environment and Human Security (UNU-EHS) in 2005 stated that at least 20 million people were displaced due to environmental reasons worldwide, which was more than those displaced by wars and political repressions combined. This number was predicted to reach 50 million by 2010 and 150 million by 2050 [49]. Considering that a major portion of the Nepalese economy relies on climate-sensitive industries, such as agriculture, forestry, ecotourism, etc., the vulnerability of the Nepalese people is extremely high [12].

5. Conclusions

Drought and soil erosion are major climate-induced disasters faced by the people in Khaniyapani. A significant portion of the area is under severe drought conditions that are becoming more severe with every

passing year. Water sources have dried, and a family must walk an average of 3 h to fetch drinking water. More than 60% of the land is left fallow for most of the year, and 25% of the land is barren throughout the year due to lack of irrigation. People are reducing the number of cattle they hold due to a scarcity of feeding materials and the stress of fetching water. As a result, seasonal migration has increased. Most young men engage in seasonal migration, where they are away from home for a significant fraction of the year. This seasonal migration reduces the resilience of the entire village during unfavorable situations and further increased the impacts of climate change.

The local government, with coordination and collaboration among various stakeholders at different levels, should address these issues and prepare plans for water conservation (conservation ponds, water lifting plans, and rainwater harvest), crop and land management (conservation agriculture, drought-resistant crop varieties), and monitoring facilities to fight the drought conditions. Also, alternative income generation activities should be promoted to extenuate the seasonal migration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Hari Adhikari acknowledges funding from the Academy of Finland for the SMARTLAND project (decision number 318645).

Annex.

Annex 1

Soil erodibility for textural classes

Textural class	Organic matter content		
	0.5	2	4
Fine sand	0.16	0.14	0.1
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.1	0.08
Loamy very fine sand	0.44	0.38	0.3
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silt clay loam	0.37	0.32	0.26
Silty clay	0.25	0.23	0.19

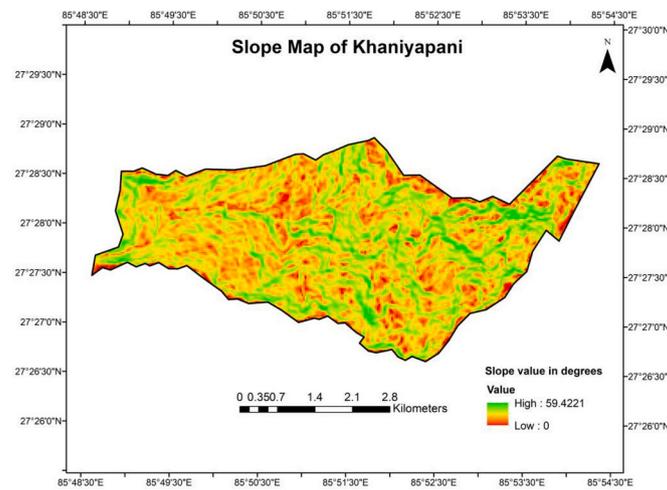
Source [31].

Annex 2

P factor for different slopes

Slope %	Contouring
0–7	0.55
7–11.3	0.609
11.3–17.6	0.80
17.6–26.8	0.95
>26.8	1.00

Source [32].



Annex 3. Slope Map.

Annex 4

Evaluation of ranks

Ranks	Weights	Factors			
		Agricultural productivity and livestock decline	Financial debts and obligations	Water scarcity	Lack of infrastructure
1	1	72*1	7*1	19*1	2*1
2	0.75	28*0.75	15*0.75	48*0.75	9*0.75
3	0.5	0	35*0.5	28*0.5	37*0.5
4	0.25	0	43*0.25	5*0.25	52*.25

References

[1] D.E. Reichle, Anthropogenic alterations to the global carbon cycle and climate change, in: *Glob. Carbon Cycle Clim. Chang.*, Elsevier, 2020, pp. 209–251, <https://doi.org/10.1016/b978-0-12-820244-9.00011-1>.

[2] T. Stocker (Ed.), *Climate Change 2013: the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge university press, 2014, 2013.

[3] W. Leal Filho, H. Taddese, M. Balehegn, D. Nzengya, N. Debela, A. Abayineh, E. Mworozi, S. Osei, D.Y. Ayal, G.J. Nagy, N. Yannick, S. Kimu, A.L. Balogun, E. A. Alemu, C. Li, H. Sidsaph, F. Wolf, Introducing experiences from African pastoralist communities to cope with climate change risks, hazards and extremes: fostering poverty reduction, *Int. J. Disaster Risk Reduct.* 50 (2020) 101738, <https://doi.org/10.1016/j.ijdr.2020.101738>.

[4] IPCC, *Climate Change 2007, Synthesis Report*, Geneva, Switzerland, 2007.

[5] R. Danovaro, A. Dell’Anno, A. Pusceddu, Biodiversity response to climate change in a warm deep sea, *Ecol. Lett.* 7 (2004) 821–828, <https://doi.org/10.1111/j.1461-0248.2004.00634.x>.

[6] NPC, *Climate-Resilient Planning*, 2011. Kathmandu, Nepal.

[7] D. Eckstein, M.-L. Hutfils, M. Wings, *Global Climate Risk Index 2019*, fourteenth ed., Germanwatch e.V, Gonn, 2018.

[8] UNFCCC, *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*, 2007. Bonn, Germany.

[9] S. Adhikari, Drought impact and adaptation strategies in the mid-hill farming system of western Nepal, *Environments* 5 (2018) 101, <https://doi.org/10.3390/environments5090101>.

[10] D. Bhatt, S. Maskey, M.S. Babel, S. Uhlenbrook, K.C. Prasad, Climate trends and impacts on crop production in the Koshi River basin of Nepal, *Reg. Environ. Change* 14 (2014) 1291–1301, <https://doi.org/10.1007/s10113-013-0576-6>.

[11] D.P.N.N. MoHA, *Nepal Disaster Report 2015*, 2015. Kathmandu, Nepal.

[12] USAID, *Environment and Global Climate Change*, 2019.

[13] S. Tripathi, R. Subedi, H. Adhikari, Forest cover change pattern after the intervention of community forestry management system in the mid-hill of Nepal: a case study, *Rem. Sens.* 12 (2020) 2756, <https://doi.org/10.3390/rs12172756>.

[14] D.M. Anderson, A.K. Gupta, D.M. Anderson, D.N. Pandey, A.K. Singhvi, Adaptation and human migration , and evidence of agriculture coincident with changes in the Indian summer monsoon during the Holocene Adaptation and human migration , and evidence of agriculture coincident with changes in the Indian summer monsoon during, *Curr. Sci.* 90 (2006) 1082–1090, <https://doi.org/10.2307/24089270>.

[15] O. Gómez, *Climate Change and Migration: A Review of the Literature*, 2013.

[16] J. Mcadam, *Climate Change, Forced Migration, and International Law*, Oxford University Press, New York, the United States, 2012.

[17] P. Bohra-Mishra, M. Oppenheimer, S.M. Hsiang, Nonlinear permanent migration response to climatic variations but minimal response to disasters, *Proc. Natl. Acad. Sci. U.S.A.* 111 (2014) 9780–9785, <https://doi.org/10.1073/pnas.1317166111>.

[18] M.R. Islam, Climate change, natural disasters and socioeconomic livelihood vulnerabilities: migration decision among the char land people in Bangladesh, *Soc. Indicat. Res.* 136 (2018) 575–593, <https://doi.org/10.1007/s11205-017-1563-y>.

[19] E. Piguat, A. Pécoud, P. de Guchteneire, Migration and climate change: an overview, *Refug. Surv. Quaterly.* 33 (2011) 1–23.

[20] F. Laczko, C. Aghazarm, Migration, Environment and Climate Change: Assessing the Evidence, 2009.

[21] W.F.P. Nepal, *The Future of Food: Creating Sustainable Communities through Climate Adaptation*, 2009.

[22] D. Chalise, L. Kumar, P. Kristiansen, Land degradation by soil erosion in Nepal: a review, *Soil Syst* 3 (2019) 12, <https://doi.org/10.3390/soilsystems3010012>.

[23] S. Sharma, N. Khadka, K. Hamal, D. Shrestha, R. Talchabhadel, Y. Chen, How accurately can satellite products (TMPA and IMERG) detect precipitation patterns, extremities, and drought across the Nepalese Himalaya? *Earth Sp. Sci.* 7 (2020) <https://doi.org/10.1029/2020EA001315>.

[24] N. Joshi, R. Dongol, Severity of climate induced drought and its impacts on Migration : a study of Ramechhap district , Nepal, *Trop. Agric. Res.* 29 (2018) 194–211.

[25] Y. Gu, E. Hunt, B. Wardlow, J.B. Basara, J.F. Brown, J.P. Verdin, Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data, *Geophys. Res. Lett.* 35 (2008), <https://doi.org/10.1029/2008GL035772>.

[26] W.S. Merritt, R.A. Letcher, A.J. Jakeman, A review of erosion and sediment transport models, *Environ. Model. Software* 18 (2003) 761–799, [https://doi.org/10.1016/S1364-8152\(03\)00078-1](https://doi.org/10.1016/S1364-8152(03)00078-1).

[27] R. Parveen, U. Kumar, Integrated approach of universal soil loss equation (USLE) and geographical information system (GIS) for soil loss risk assessment in upper south koel basin, Jharkhand, J. Geogr. Inf. Syst. 4 (2012) 588–596, <https://doi.org/10.4236/jgis.2012.46061>.

[28] G. Wang, G. Gertner, V. Singh, S. Shinkareva, P. Parysow, A. Anderson, Spatial and temporal prediction and uncertainty of soil loss using the revised universal soil loss equation : a case study of the rainfall – runoff erosivity R factor, *Ecol. Model.* 153 (2002) 143–155, [https://doi.org/10.1016/S0304-3800\(01\)00507-5](https://doi.org/10.1016/S0304-3800(01)00507-5).

[29] D.K. Chapagain, A. Shrestha, N.D. Acharya, N.B. Shrestha, H. Adhikari, T. Bhatta, S.K. Shrestha, An Assessment of Drought in Ramechhap District (A Case Study from Rampur and Khaniyapani VDCs), Manthali, Ramechhap, 2010.

- [30] Ministry of Environment, Climate Change Vulnerability Mapping for Nepal, Kathmandu, 2010. Nepal.
- [31] G.O. Schwab, D.D. Fangmeier, W.J. Elliot, Soil and Water Conservation Engineering, John Wiley & Sons, Inc, Newyork, 1981.
- [32] P. Koirala, S. Thakuri, S. Joshi, R. Chauhan, Estimation of Soil Erosion in Nepal Using a RUSLE Modeling and Geospatial Tool, vol. 9, 2019, <https://doi.org/10.3390/geosciences9040147>.
- [33] G. Singh, R. Babu, P. Narain, L.S. Bhushan, I.P. Abrol, Soil erosion rates in India, *J. Soil Water Conserv.* 47 (1992).
- [34] P. Dahal, N.S. Shrestha, M.L. Shrestha, N.Y. Krakauer, J. Panthi, P.M. Soni, A. Jha, T. Lakhankar, Drought risk assessment in central Nepal: temporal and spatial analysis, *Nat. Hazards* 80 (2015) 1913–1932, <https://doi.org/10.1007/s11069-015-2055-5>.
- [35] N.K. Shrestha, F.M. Qamer, D. Pedreros, M.S.R. Murthy, S.M. Wahid, M. Shrestha, Evaluating the accuracy of Climate Hazard Group (CHG) satellite rainfall estimates for precipitation based drought monitoring in Koshi basin, Nepal, *J. Hydrol. Reg. Stud.* 13 (2017) 138–151, <https://doi.org/10.1016/j.ejrh.2017.08.004>.
- [36] B. Baniya, Q. Tang, Z. Huang, S. Sun, K. anan Techato, Spatial and temporal variation of NDVI in response to climate change and the implication for carbon dynamics in Nepal, *Forests* 9 (2018) 329, <https://doi.org/10.3390/f9060329>.
- [37] A. Pandey, S.K. Mishra, A.K. Gautam, D. Kumar, Soil erosion assessment of a Himalayan river basin using TRMM data, *Proc. Int. Assoc. Hydrol. Sci.* 366 (2014), <https://doi.org/10.5194/piabs-366-200-2015>.
- [38] K. Uddin, M.S.R. Murthy, S.M. Wahid, M.A. Matin, Estimation of soil erosion dynamics in the Koshi basin using GIS and remote sensing to assess priority areas for conservation, *PloS One* 11 (2016), e0150494, <https://doi.org/10.1371/journal.pone.0150494>.
- [39] D.P. Shrestha, Assessment of soil erosion in the Nepalese Himalaya, a case study in Likhu Khola valley, middle mountain region, *L. Husb.* 2 (1997) 59–80. Oxford (accessed September 8, 2020).
- [40] M.B. Dangi, R.P. Chaudhary, K. Rijal, P.D. Stahl, S. Belbase, K.G. Gerow, D. Fernandez, B. Pyakurel, Impacts of environmental change on agroecosystems and livelihoods in Annapurna Conservation Area, Nepal, *Environ. Dev.* 25 (2018) 59–72, <https://doi.org/10.1016/j.envdev.2017.10.001>.
- [41] A. Maharjan, I. Kochhar, V.S. Chitale, A. Hussain, G. Gioli, Understanding rural outmigration and agricultural land use change in the Gandaki Basin, Nepal, *Appl. Geogr.* 124 (2020) 102278, <https://doi.org/10.1016/j.apgeog.2020.102278>.
- [42] P. Sapkota, R.J. Keenan, J.A. Paschen, H.R. Ojha, Social production of vulnerability to climate change in the rural middle hills of Nepal, *J. Rural Stud.* 48 (2016) 53–64, <https://doi.org/10.1016/j.jrurstud.2016.09.007>.
- [43] P. Gentle, T.N. Maraseni, Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal, *Environ. Sci. Pol.* 21 (2012) 24–34, <https://doi.org/10.1016/j.envsci.2012.03.007>.
- [44] M. Paudel, Adaptation mechanisms in agriculture for climate change in Nepal, *Hydro Nepal J. Water, Energy Environ.* 11 (2012), <https://doi.org/10.3126/hn.v11i1.7219>.
- [45] J.C. Baral, D.R. Bhuju, D.B. Shrestha, P. Yonjan, Institutional responses to local-level climate change adaptation in Nepal, in: *Reg. Clim. Chang. Adapt. Knowl. Platf. Asia*, 2012. Bangkok.
- [46] A. Bhattacharya, Sustainable Livelihood Based Watershed Management – “Watershed Plus” Approach, 2008.
- [47] R. Sapkota, CLIMATE CHANGE AND ITS IMPACTS IN NEPAL, Tribhuvan University, 2016.
- [48] IRIN, Drought Compounds Food Insecurity in Western Regions, 2008. New Humanit, <https://www.thenewhumanitarian.org/report/78909/nepal-drought-compounds-food-insecurity-western-regions>.
- [49] N. Myers, Environmental refugees: an emergent security issue, in: *13th Econ. Forum, prague*, 2005. <https://www.osce.org/eea/14851?download=true>.