The Geographical Journal of Nepal
Vol. 17: 53-70, 2024
DOI: https://doi.org/10.3126/gjn.v17i01.63935
Central Department of Geography,
Tribhuvan University, Kathmandu, Nepal

Agricultural land abandonment and its impact on soil erosion in the Madi Watershed, Gandaki Province, Nepal

Ravi Sitaula, Puspa Sharma, Chhabi Lal Chidi*

Central Department of Geography, Tribhuvan University, Kathmandu, Nepal.

*Corresponding email: chhabi.chidi@cdg.tu.edu.np

Received: 03 November, 2023; Accepted: 21 December, 2023; Published: March, 2024

Abstract

Agricultural land abandonment is the crucial issue of land use /land cover change in many parts of the world and it is directly related to soil erosion in the mountain areas. Nepal has also faced heavy agricultural land abandonment from the mountain regions in the last two decades. This study is concerned with agricultural land abandonment and its impact on soil erosion in the Madi Watershed, Gandaki Province of Nepal. This study used high-resolution aerial photography and Google Earth images to map cultivated land and its abandonment in 1995 and 2020. The Revised Universal Soil Loss Equation (RUSLE) model has been used to estimate soil erosion. Studies revealed that more than 40% of the agricultural land was abandoned from 1995 to 2020 and there is higher spatial variability of abandonment intensity. High altitude and steeper slope areas have a higher intensity of abandonment than in lower altitude and lower slope gradients. There is a significant impact of abandonment of agricultural land on reducing soil erosion from 1995 to 2020. The average rate of soil erosion was quite high in 1995 but decreased to 51.5 percent in 2020. There are higher rates of reduction in soil erosion at higher altitudes and marginal lands like steeper slopes and the areas having lower solar radiation because of the higher proportion of agricultural land abandonment. Thus, it can be concluded that agricultural land abandonment during the last 25 years significantly impacts soil erosion control in the study area.

Keywords: agricultural land abandonment, cultivated land, RUSLE model, satellite image, soil erosion

Introduction

Soil erosion is a global challenge caused by water and wind forces dislodging and transporting soil particles, degrading soil quality (Benchettouh *et al.,* 2021).The rates of soil erosion vary in different regions of the globe because of physical conditions like topography and rainfall intensity, and anthropogenic factors such as land use, and management practices (Xiong *et al.,* 2019). Traditional farming practices on the hill slope and torrential rainfall in the summer season are a major threat to soil erosion in the Himalayan regions like Nepal (Chalise *et al.,* 2019). In the past, the conversion of forested land into agriculture and rapid population growth worsened environmental impacts. A different perspective, challenging the idea that the Himalayan environment was extensively degraded (Ives & Messerli, 1989).). Steep slopes, human activities, and anthropogenic factors accelerate soil erosion (Walther, 1986; Vogel, 1988; MacDonald *et al.,* 2000).

Agricultural land abandonment has been a global issue of LULC change in recent decades (Prishchepov, 2020) and it has affected almost a third (32%) of the global land area in just six decades (1960-2019). It is around four times greater in extent than previously estimated from long-term land change assessments. Afforestation and agricultural land abandonment to the Global North and expansion of agricultural land in the South are major causes of LULC changes (Winkler, 2021). Agricultural land abandonment leads to regrowth of natural vegetation and conversion to forest, shrubs, and grassland. This helps reduce soil erosion on rural slope lands (Cerdà *et al.,* 2018; Rodrigo-Comino *et al.,* 2018).

Agricultural land abandonment helps to control soil erosion rates because of decreasing detachment of soil particles and recovery of natural vegetation (Cerdà *et al.,* 2018; Rodrigo-Comino *et al.,* 2018). Severe land degradation in Nepal's Mountain and Hill Regions in the past was due to the extension of cultivated land on marginal and steep slopes to feed the growing population, which was the major factor of soil erosion, landslides, and floods (Gurung, 1981; Ives & Messerli, 1989). In recent decades, Nepal has been experiencing heavy agricultural land abandonment in the mountain and hill areas because of depopulation, limited productivity in traditional agriculture, and resistance to modern farming practices (Chaudhary *et al.,* 2020; Chidi, 2016a; Chidi, 2016b; Chidi *et al.,* 2021; Khanal & Watanabe, 2006; Rai *et al.,* 2019; Paudel *et al.,* 2014). Past literature reveals that there was heavy soil erosion from the steep hill slopes because of the extension of cultivated land in the steep hill slope but the impact of the present release of extended cultivated land from these areas is still unknown. The information on the impact of agricultural land abandonment on soil erosion has a greater implication and it requires the suitable policies for sustainable mountain agriculture and the environment. To date, the impact of abandoned agricultural land on soil erosion is very limited except a very few studies in the eastern mountain regions of Nepal (Zhang *et al.,* 2024). Thus, this study aims to estimate the dynamics of the soil erosion process due to the abandonment of agricultural land in the Madi Watershed of Nepal.

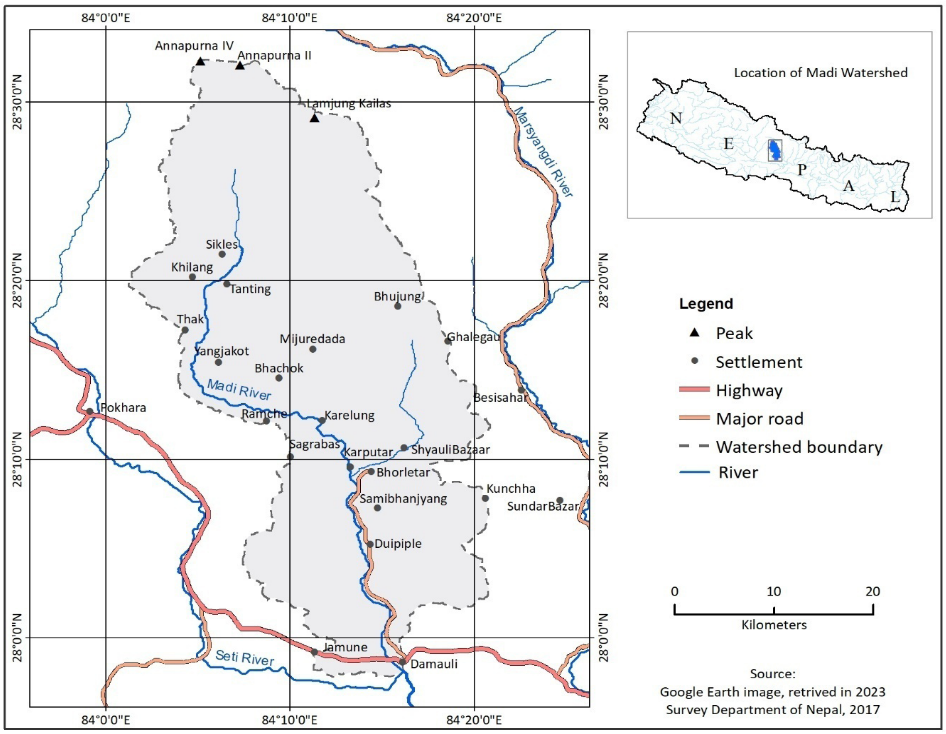
Methods and materials

The study area

The Madi Watershed area was the study site. This watershed area extends from the High Himalayas to the Middle Hills of Nepal, the most vulnerable areas of soil erosion due to the extension of cultivated land in the marginal hill slope in the past (Gurung, 1981; Ives & Messerli, 1989). This is a part of the Gandaki Watershed where the abandonment of agricultural land has been increasing very fast in the last two decades (Chidi, 2021a; Khanal& Watanabe, 2006).

Figure 1

Location of study area



The Madi Watershed (28°32'9.69" N - 28°19'33.58" N latitude, 84°7'11.83" E-84° 5'22.22" E longitude) covering about 1122 sq. km lies 23 km northeast of Pokhara city. It is one of the major tributaries of the Sapta Gandaki River. The Madi watershed spans an altitude range from 300 m in the southern region to 7937 m in the northern region, covering an aerial distance of 68 km from north to south (Figure 1). The climatic conditions in the watershed range from subtropical in the south to alpine and arctic in the north.

Mean annual precipitation in the watershed ranges from 1,795 mm at Damauli in the south to 3,743 mm at Sikles in the northwest. Nearly 70-80 percent of the total precipitation occurs in four summer months. The study area is characterized by a combination of agricultural land, forested areas, snow-covered regions, rocky terrain, settlements, and water bodies. It represents the typical features of a mountain watershed and exhibits a fragile geology with rugged topography.

Data source

This study is based on secondary information. The topographic maps of the scale 1:25,000 and 1:50000, and aerial photographs taken in 1995 were collected from the Survey Department of Nepal. Shuttle Radar Topography Mission (SRTM), Digital Elevation Model (DEM) data of 30-meter spatial resolution data, is freely available, was downloaded. Similarly, rainfall erosivity data (one km spatial resolution) is also freely available on the site https://esdac.jrc.ec.europa.eu/ of the European Soil Data Centre (ESDAC). Soil particle size and organic matter contained in soil data were collected from the Survey Department of Nepal.

Aerial photography is an important source of historical mapping information, which provides detailed information on cultivated land (Varga *et al.,* 2014). Thus, the aerial photography of 1995 was collected from the Survey Department of Nepal. High-resolution image is the first requirement for the detection of detail mapping of agricultural land and its abandonment but high resolution image is quite expensive. Google Earth image is a potential source of images for detailed land use/ land cover mapping for scientific analysis (Jaafari & Nazarisamani, 2013). Thus, this study used Google Earth images for the detection of cultivated land and its abandonment in 2020.

Mapping cultivated land

Aerial photography was orthorectified using digital photogrammetry processing. Then, this orthophoto was used to verify and correct the cultivated land map of 1995 of a topographic map of scale 1:25000. The cultivated land of 2020 was derived from the online digitization of the Google Earth image. Furthermore, the abandoned area of cultivated land in 2020, which was cultivated in 1995 was derived from erasing the cultivated land map in 1995 and by cultivated land map in 2020. Land use/ land cover in 2020 in the abandoned agricultural land in 1995 was also derived by the direct digitization of the Google Earth image platform. For the accuracy test of the abandoned land map, a total of 200 locations at different elevations, slope gradients, slope aspects, and spatial distances were selected over the entire study area. Those locations were verified by field visits whether those locations were abandoned or not. The mapping of abandoned agricultural land was found to be highly accurate, with an overall accuracy of 91.2% and a kappa statistics (K) value of 0.82%. It revealed that the mapping of abandoned cultivated land is highly accurate which is suitable for further analysis.

Elevation, slope gradient, and slope aspect

Elevation, slope gradient, and slope aspect maps were developed from the collected DEM data using GIS software. Elevations were categorized in different regions of 500-meter intervals of altitudes up to 2500-meter because cultivation land is not above 2500 in the study area. Slope gradients were categorized into five groups. Those categories are based on the land capability map of Nepal (LRMP, 1986) but it has a further breakdown of 5º to 30º degrees into 5º to 15º and 15º to 30º. Similarly, slope aspects were categorized into nine groups of which one was flat and others were default eight slope faces.

Estimation of soil erosion

The RUSLE model estimates average annual soil erosion rates caused by water-induced erosion in sectors like agriculture, conservation, mining, construction, and forestry. The updated approach enhances factor estimates, incorporates rill to inter-rill erosion, and introduces a novel cover factor calculation (Renard *et al.,* 1997). However, the RUSLE model has limitations, as it only estimates sheet and rill erosion and does not assess dispersive soils or gully erosion rates (Thapa, 2020; Rowlands, 2019; Wang *et al.,* 2002). The raster data format was analyzed, and soil erosion was calculated using map algebra functions within the ArcGIS software. The RUSLE model is to predict the mean annual soil loss. The erosion model of the following factors to develop this equation:

$$A=R*K*LS*C*P \text{--} \text{Eqn.1}$$

Where,

A is annual average soil loss in ton per hectare per year (t/h/y), R is rainfall erosivity factor (MJ mm ha-1 h -1 yr-1), K is soil erodibility factor (t ha h ha-1 MJ-1 mm-1), LS is slope length and slope steepness factor (dimensionless), C is a cover-management factor (dimensionless), and P is support practices factor (dimensionless).

Rainfall-runoff erosivity factor (*R*)

Rainfall erosivity (*R* factor) data were obtained from the European Soil Data Centre (ESDAC) at a spatial resolution of 1 km. This data is freely available on the website https://esdac.jrc.ec.europa.eu/. The data were calculated based on rainfall data spanning a temporal coverage of 30-40 years, expressed in units of MJ mm/ha/h/y. This data was produced in collaboration with the European Commission (Joint Research Centre), the University of Basel, and the Meteorological and Environmental Institute.

Soil erodibility factor (*K*)

Soil data collected from the Survey Department of Nepal was derived from a detailed field soil survey conducted in 2020, followed by systematic laboratory analysis performed by TSLUMD. The calculations were performed using Microsoft Excel, utilizing equations provided by Sharpley & Williams (1990) and Wischmeier & Smith (1978).

K = Fcsand * Fsi-cl * Forgc * Fhisand * 0.1317---------------------------------------Eqn.2

$$Fcsand = \left[0.2 + 0.3exp\left(-0.0256SAN\left(1 - \frac{SIL}{100}\right)\right)\right]$$

$$Fsi - cl = \left[\frac{SIL}{CLA + SIL}\right]^{0.3}$$

$$Forgc = 1 - \left[\frac{0.25\,ORG}{ORG + exp\left(3.72\ \ -2.95\,ORG\right)}\right]$$

$$Fhisand = 1 - \left[\frac{0.70\left(1 - \frac{SAN}{100}\right)}{\left(1 - \frac{SAN}{100}\right) + exp(-5.51 + 22.9\left(1 - \frac{SAN}{100}\right)}\right]$$

Where, the variables CLA, SIL, SAN, and ORG represent the percentage of clay, silt, sand, and organic carbon content, respectively. The term "Fcsand" refers to a low soil erodibility factor for soils with a higher proportion of coarse sand, while it indicates a higher erodibility value for soils with lower sand content. Similarly, "Fsi-cl" represents an erodibility factor influenced by a high clay-to-silt ratio, resulting in lower erodibility. "Forgc" denotes the reduction of soil erodibility in soils with higher organic content. Lastly, "Fhisand" signifies the reduction of soil erodibility in soils with a higher proportion of sand (Koirala *et al.,* 2019). Lastly, using an appropriate conversion tool for vector to raster, a soil erodibility map was generated in ArcGIS.

Slope length and slope steepness factor (*LS*)

Slope length (*L*) and slope steepness factors were calculated using 30m spatial resolution DEM. Slope length (*L*) (Wischmeier & Smith, 1978) and slope steepness (*S*) (Sudra *et al.,* 2007) were calculated using the following equations.

L = (Cell size/22.13) m--Eqn.3

where cell size = grid cell size (30 m for this study), m = 0.2 to 0.5 (0.2 for slopes less than 1%, 0.3 for 1–3%, 0.4 for 3–4.5%, and 0.5 for slopes exceeding 4.5%);

$S = 0.0138 + 0.0097\ s + 0.00138\ s^2$---Eqn.4.

where s is the slope in percent

Cover management factor (*C*)

The *C*-factors are crucial in crop management as they consider the impact of various Land Use/Land Cover (LULC) types on soil erosion. Vegetation cover is crucial in reducing soil erosion risk by improving soil water holding capacity, minimizing surface runoff, protecting against raindrop impact, controlling sheet erosion, and enhancing interception and infiltration rates (Chen *et al.,* 2019). The study consisted of eleven land categories (Table 1) and the *C* factor values for each Land Use/Land Cover (LULC) type were assigned based on the findings by Kayet *et al.,* (2018) and Thapa, (2020). The *C* values range from 0 to 1, with lower values indicating minimal soil loss due to robust coverage, while higher values indicate an uncovered surface with a greater potential for soil loss.

Table 1

Cover management factor (C)

Land use land cover	***C*-factor**
Sand	0.45
Bare soil	0.45
Barren land	0.45
Agricultural land	0.21
Built-up Area	0.04
Forest	0.03
Shrubland	0.03
Grassland	0.01
Bare rock	0.001
Water Body	0
Snow glacier	0

Source: (Kayet *et al.,* 2019; Thapa, 2020)

Support practice factor (*P*)

The *P*-factor quantifies the influence of support practices on the average annual erosion rate (Kouli *et al.,* 2009). In the hill slope areas, conservation practices of hill slope cultivations are contouring, strip farming, and terracing. That is the support practice factor (*P*) of soil erosion. Terracing of slope for crop cultivation is the support practice factor in the hill slope agricultural areas in Nepal. The values of the support practice factor (*P*) are assigned 0.1 to 0.2 according to the average percent slope of the terraces and it is categorized into 5 groups (Shin, 1999). The average value of the percent rise of the terrace is 10.12 (7-11.3) in the study area and falls into the second category (Chidi *et al.,* 2021b), which is assigned a *P* factor value of 0.12.

Data analysis

The area of cultivated land in 1995 and 2020 and the area of abandoned agricultural land were calculated. Areas and cultivated land and percentage changes of abandoned land from 1995 to 2020 were calculated in different elevation zones, slope gradients, and slope aspects. Those calculated areas and percentage change of abandoned cultivated lands in different elevations, slope gradients, and slope aspects were compared. The Average soil erosion rate is given in the unit of t/h/y as calculated by the RUSLE model. Soil loss was calculated by multiplying t/h/y by the area to derive the total amount of soil lost by a specific area. Its unit is soil loss in tons per year. Average soil erosion rates and amount of soil loss in different elevation zones, slope gradients, and slope aspects were compared.

Results and discussion

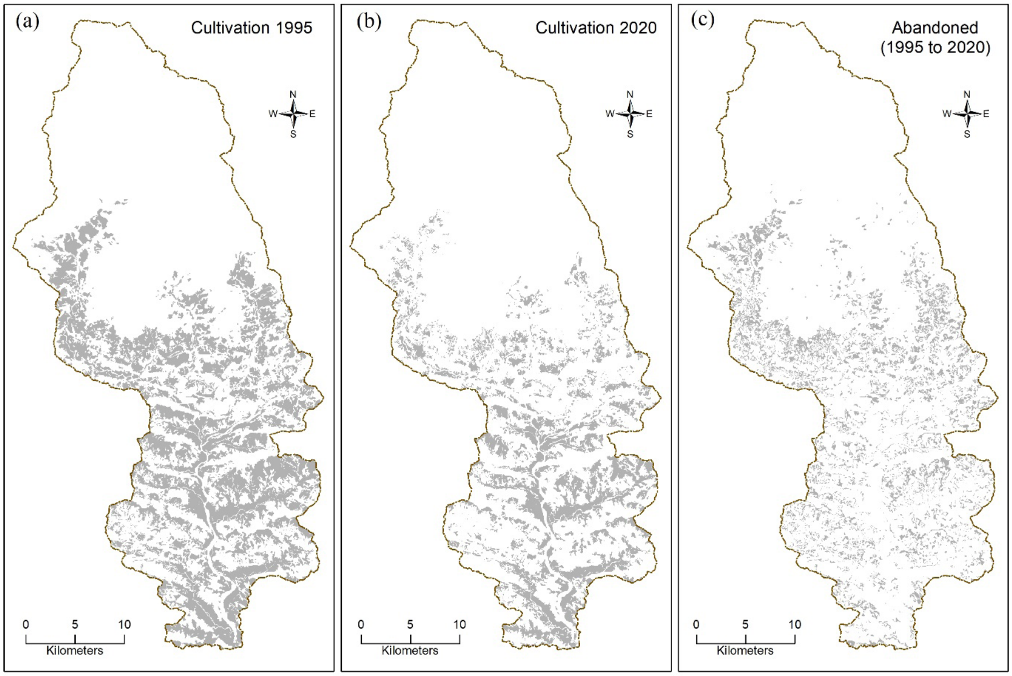
This study assesses the dynamics of soil erosion and agricultural land abandonment in the study area. The first one is the dynamics of agricultural land abandonment and the second is the dynamics of soil erosion.

Agricultural land abandoned

Figure 2 shows that the cultivated land in 1995(a) is quite higher compared to 2020(b). The higher proportion of cultivated land in 1995 in the north does not exist in 2020(c). The abandoned map also shows a higher proportion of abandonment in the north compared to other parts. However, abandonment is everywhere in the entire study area but the central parts have a little abandonment. The total agricultural land was 28,886 hectares in 1995 and it became only 17747 hectares in a 25-year period, which is a reduction of 11139 hectares. The extended agricultural land during this period was only 447 hectares. The actual abandoned agricultural land in this period is 11,586 hectares, which is 40.11%.

Figure 2

Cultivation and abandonment (1995-2020)

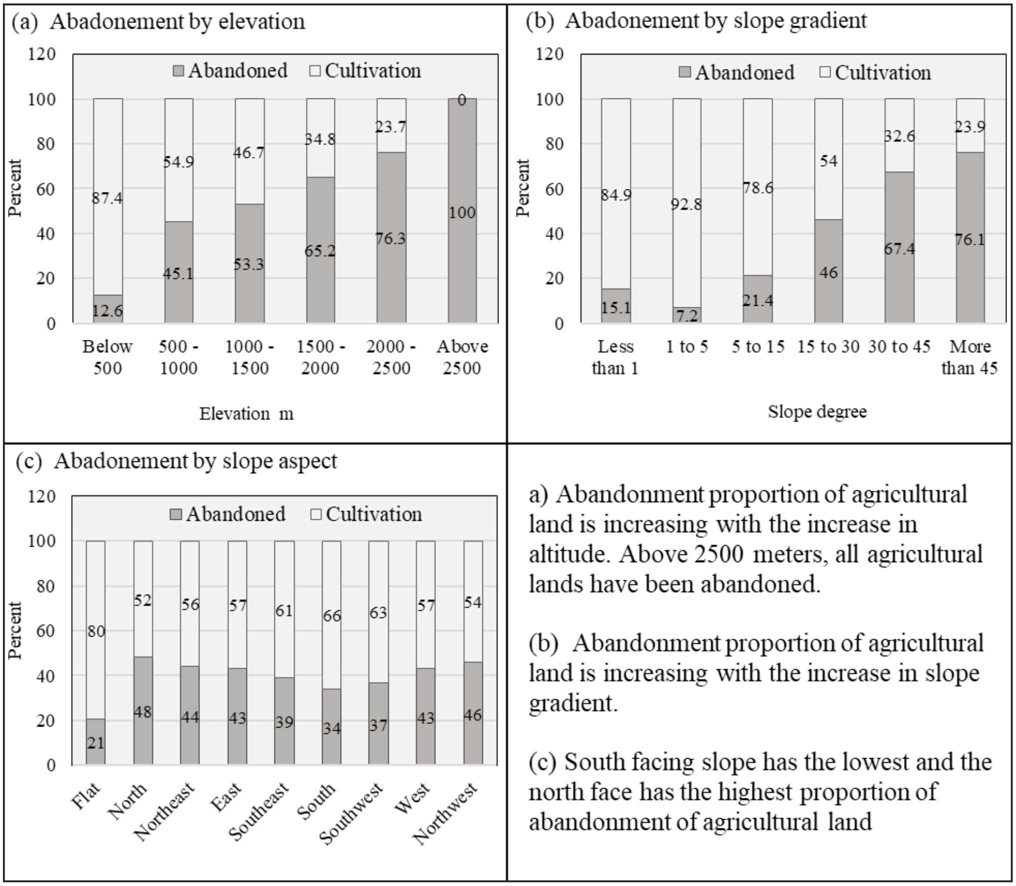


The abandonment of agricultural land seems quite high and its intensity is highly variable. The variation in intensity of agricultural land abandonment is dependent on various factors. The study area is mountainous terrain and they have different elevations, slope gradients, and slope aspects, which are the major controlling factors on the distribution pattern of abandonment of agricultural land. Figure 3 shows the proportion of abandonment and cultivation of agricultural land in different elevations, slope gradients, and slope aspects during the period of 1995 to 2020.

Elevation is one of the important controlling factors for variation in the intensity of abandonment. The lowest elevation zone has only 12,6% abandonment but all cultivated lands were abandoned above 2500 m until 2020 (Figure 3a). Slope gradient is one of the dominant factors in the intensity of abandonment of agricultural land. The proportion of abandonment increases with the increase of slope steepness but there is a higher proportion of abandoned agricultural land in less than 1º slope than in 1º to 5º slope category (Figure 3b). It is because of the presence of lands having lower slope gradients at the higher altitude ridge top, where there is the higher proportion of abandoned agricultural land.

Figure 3

Proportion of abandonment of cultivated land by (a) altitude, (b) slope gradient, and (c) slope aspect in 1995 and 2020

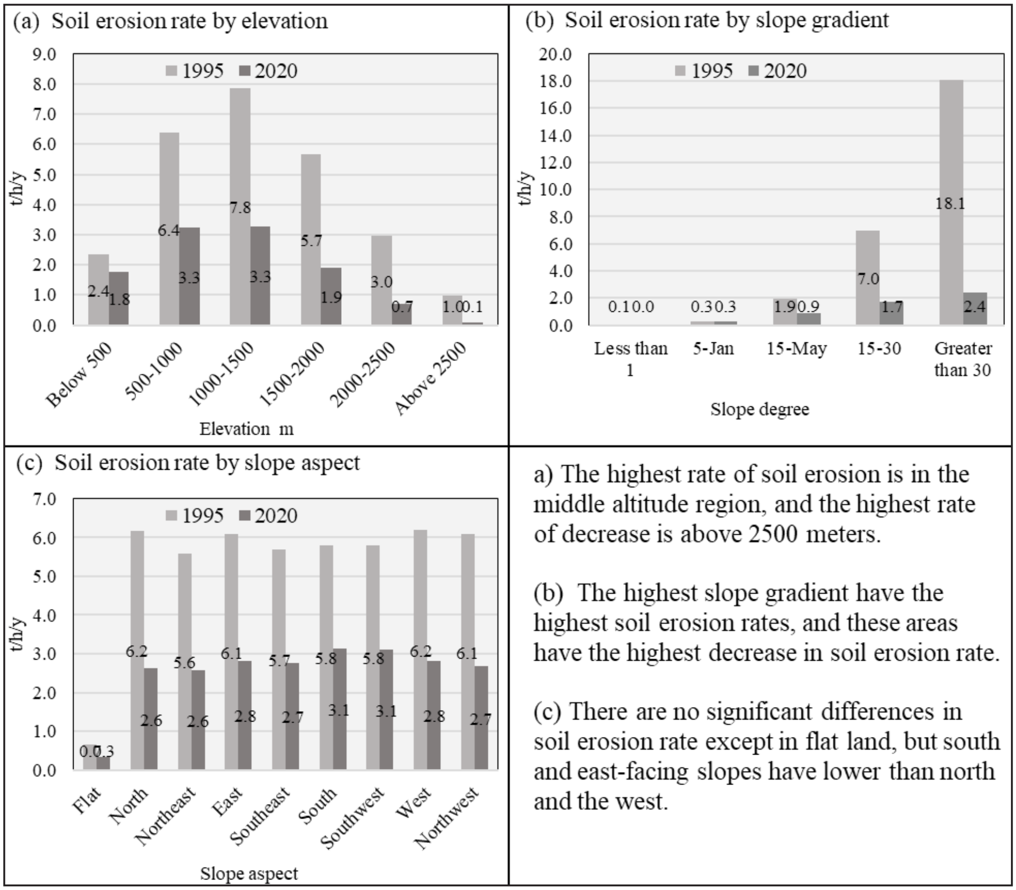


Soil erosion rate

The rate of average soil erosion from the cultivated land in 1995 was 29.15 t/h/y and it became 14.4 t/h/y in 2020. There is a 48.5% decrease in the average soil erosion rate, which is a similar decrease in soil erosion rate as the abandonment of agricultural land. The average soil erosion has significantly changed in different elevation zones, slope gradients, and slope aspects from 1995 to 2020. Soil erosion rates are quite higher in the middle elevation range from 500 to 2000 meters. There are the highest soil erosion rates in the altitude range of 1000-1500 meters in 1995 while it is similar even in the 500 to 1000-meter altitude range. There is a high correlation between the decrease in average soil erosion rates with altitudinal variation. The higher the altitude higher the percentage decrease in soil erosion rates from 1995 to 2020. The percentage changes of average soil erosion rate below 500 meters is only a 25.4% reduction, (2.4 t/h/y to 1.8 t/h/y in 1995 to 2020 respectively), while there is 89.4% decrease (1.0 t/h/y to 0.1 t/h/y in 1995 to 2020 respectively) in average soil erosion rate above 2500 meter during the same period (Figure 4a). This is because of the higher proportion of abandonment of agricultural land in higher altitude regions.

Figure 4

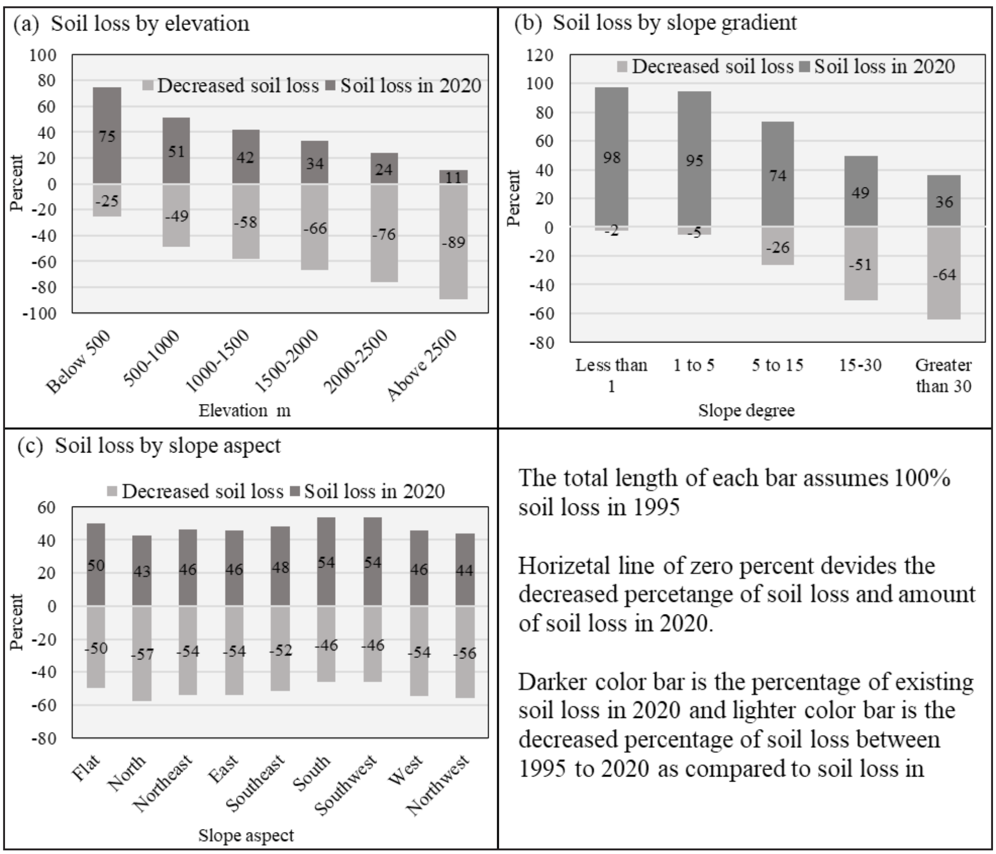
Differences in average soil erosion rates by (a) elevation, (b) slope gradient, and (c) slope aspect in 1995 and 2020.



Average soil erosion rates are higher in steeper slopes and it is quite high at the steepest slope more than 30º compared to lower slope gradients. The decrease of the average soil erosion rate in this area is also the highest because of the higher proportion of abandonment of agricultural land in this region. The decreasing percent is the lowest 4.1% at the slope gradient of 1º to 5º, while the highest percentage of decrease is greater than the 30º slope (Figure 4b). The decrease in average soil erosion rates from 1995 to 2020 is because of the higher proportion of abandonment of agricultural land in the steeper slope than in the lower slope gradients. Different slope aspects have little effect on average soil erosion rates. Flat land areas have the lowest rates of average soil erosion, and north and west slope faces have the highest rate of soil erosion compared to the south face. However, the average soil erosion rates are significantly different in flat land areas. There are some differences in the decrease in average soil erosion rates in different slope aspects from 1995 to 2020 which is 46% in the south face and 57.4% in the north face (Figure 4c).

Figure 5

Percentage of soil loss in 2020 and decreased percentage of soil loss in 2020 as compared to the soil loss in 1995 by (a) elevation, (b) slope gradient, and (c) slope aspect in 1995 and 2020.



Amount of soil loss

Soil loss is the total amount of soil loss from the surface within one year by rainfall. Nearly, 46.4 million tons of soil has been lost per year from the cultivated land in 1995 from the entire study area, which became only 22.5 million tons in 2020. It is a 51.5% decrease in soil loss in 2020 in comparison with the total soil loss of 1995. It shows that abandonment of agricultural land has a significant impact on decreasing soil loss, which helped to reduce nearly 24 million tons of soil loss per year from 19995 to 2020.

The changes in total soil loss are highly variable in different elevations, slope gradients, and slope aspects. The percentage decrease in soil loss per year from 1995 to 2020 is correlated with different elevation zones. The higher the altitude, the higher the percentage decrease of soil loss. There is only a 25% decrease in soil loss below 500 meters, while it is 89% above 2500 meters (Figure 5a). There is a significant amount of decrease in soil loss at steeper slopes in comparison to flat land areas. There is only a 2% decrease in soil loss at the less than 1º slope gradient, while a 64% reduction at the slope gradient of more than 30º slope (Figure 5b). There are no significant differences in the reduction of soil loss in different slope aspects but there is a clear picture of spatial variability of soil loss from different slope faces ranging from 46% to 57% (Figure 5c).

Soil erosion by intensive rainfall from the cultivated land in the steep hill slope areas of Nepal is an important issue from an environmental perspective. The impact of soil erosion is the reduction of soil fertility and sediment supply into the river system (Chalise *et al.,* 2019). Past population pressure in the mountains has reduced resulting in heavy abandonment of cultivated land at present but till today the impact of agricultural land on environmental aspects like changes in soil erosion is very little known in Nepal. Thus, this study contributes to the impact of agricultural land abandonment on the hill slopes of Nepal. It is based on high-resolution aerial photography and Google Earth images with higher accuracy of detection of cultivated land and its abandonment that cannot be achieved by coarse resolution satellite image in such a complex terrain and complex land use /land cover areas. Although the estimated rate of soil erosion has not been validated, the range of average soil erosion rates estimated by this study is under the range of previous field-measured soil erosion rates in different parts of Nepal (Gardner *et al.,* 2003; Nakarmi *et al.,* 1999). Abandonment of marginal areas of agricultural land is because of the past degradation of marginal land and farmers abandoned marginal areas first and vegetation regeneration on the abandoned land protecting land surface by vegetation cover (Cillis *et al.,* 2021). Thus, soil erosion has decreased more in marginal areas like high-altitude regions, and steeper slopes. The findings of heavy agricultural land abandonment are crucial issues for land use policy and planning for environment and sustainable development perspectives. The findings of the significant impact on soil erosion because of the abandoned agricultural land is a crucial subject matter for the government and other development planners for the sustainable future of the mountains of Nepal.

Conclusion

High-resolution aerial photography and Google Earth images are very useful for detailed mapping of agricultural land and its abandonment. In the absence of a high-resolution image, it was not possible to accurately map and detect of its actual area in such a complex mountain terrain and complex land use/ land cover patches. Heavy agricultural land abandonment is also a similar finding in other parts of Nepal but the spatial variability of abandonment gives a clear idea that the intensity of abandonment is quite higher in the marginal parts than in other parts of the mountain region. The higher rate of abandonment of marginal parts of the cultivated land was because of the extension of cultivated land in the marginal areas because of the population pressure in the past, where the soil erosion rates were also quite higher than in other parts. Thus, the significant reduction of soil erosion in the marginal part is because of the abandonment of past agricultural land and the regeneration of vegetation. Therefore, it is concluded that the land use planning and policies of the mountain areas should be carefully analyzed because abandoned agricultural land has a significant contribution to reducing soil erosion, which is one of the important aspects of the mountain environment and sustainable development.

Acknowledgments

This study was supported by the National Priority Research Project of Tribhuvan University (Project Code: TU-NPAR-078/079-ERG-07), to the Central Department of Geography, Tribhuvan University, entitled "Landscape, Soil and Vegetation Dynamics of Abandoned Agricultural Land in the Madi Watershed, Gandaki Province of Nepal."

References

Benchettouh, A., Jebari, S., & Kouri, L. (2021). Spatial Estimation of Soil Erosion Risk Using RUSLE/GIS Techniques and Practices Conservation Suggested for Reducing Soil Erosion in Wadi Mina Catchment (Northwest, Algeria). IntechOpen. doi: 10.5772/intechopen.96190

Cerdà, A., Rodrigo-Comino, J., Novara, A., Brevik, E. C., Vaezi, A. R., Pulido, M., Giménez-Morera, A., & Keesstra, S. D. (2018). Long-term impact of rain-fed agricultural land abandonment on soil erosion in the Western Mediterranean basin. *Progress in Physical Geography: Earth and Environment*, *42*(2), 202-219. https://doi.org/10.1177/0309133318758521

Chalise, D., Kumar, L., & Kristiansen, P. (2019). Land degradation by soil erosion in Nepal: A review. *Soil systems*, *3*(1), 12. https://doi.org/10.3390/soilsystems3010012

Chaudhary, S., Wang, Y., Dixit, A. M., Khanal, N., Xu, P., Fu, B., . . . Li, M. (2020). A synopsis of farmland abandonment and its driving factors in Nepal. *Land, 9*, 84. https://doi.org/10.3390/land9030084

Chen, J., Xiao, H., Li, Z., Liu, C., Wang, D., Wang, L., & Tang, C. (2019). Threshold effects of vegetation coverage on soil erosion control in small watersheds of the red soil hilly region in China. *Ecological Engineering, 132*, 109-114. https://doi:10.1016/j.ecoleng.2019.04.010

Chidi, C. (2016a). Depopulation and rural land abandonment in the Hills of Nepal. *SSARSC International Journal of Geo-Science and Geo-Informatics, 3*(1): 1-7.

Chidi, C. (2016b). Determinants of cultivated land abandonment in the Hills of Western Nepal. *STUDIA UBB GEOGRAPHIA, LXI*(1), 101–116.

Chidi, C.L., Sulzer, W., Xiong, D.H., Wu, Y.H., Zhao, W., & Pradhan, P.K. (2021a). Land use intensity dynamics in the Andhikhola watershed, the middle hill of Nepal. *Journal of Mountain Science, 18*(6), 1504-1520. https://doi.org/10.1007/s11629-020-6652-8

Chidi, C.L., Zhao, W., Chaudhary, S., Xiong, D., & Wu, Y. (2021b). Sensitivity assessment of spatial resolution difference in DEM for soil erosion estimation based on UAV observations: an experiment on agriculture terraces in the middle hill of Nepal. *ISPRS International Journal of Geo-Information*, *10*(1), 28. https://doi.org/10.3390/ijgi10010028

Cillis, G., Nolè, G., Lanorte, A., Santarsiero, V., Tucci, B., Scorza, F., & Murgante, B. (2021). Soil erosion and land degradation in rural environment: A preliminary GIS and remote-sensed approach. *Lect. Notes Comput. Sci.*, *12954*, 682–694.

Gardner, R.A.M., & Gerrard, A.J., (2003). Runoff and soil erosion on cultivated rain-fed terraces in the Middle Hills of Nepal. *Applied Geography, 23*, 23–45.

Gurung, H. (1981). *Ecological changes in Nepal: A native interpretation. An Occasional Paper 1.* Kathmandu: New Era. pp. 1-12.

Ives, J.D., & Messerli, B. (1989). *The Himalayan dilemma: Reconciling development and conservation*. London/New York: Routledge. pp. 1-324.

Jaafari, S., & Nazarisamani, A. (2013). Comparison between land use/land cover mapping through Landsat and Google Earth imagery. *American-Eurasian Journal of Agricultural & Environmental Sciences, 13*(6), 763-768. http://www.idosi.org/aejaes/jaes13(6)13/4.pdf. Accessed: 20.06.2023.

Kayet, N., Pathak, K., Chakrabarty, A., & Sahoo, S. (2018). Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hillslope mining areas. *International Soil and Water Conservation Research*, *6*(1), 31-42. https://doi.org/10.1016/j.iswcr.2017.11.002

Khanal, N. R., & Watanabe, T. (2006). Abandonment of agricultural land and its consequences. *Mountain Research and Development, 26*(1), 32-40. https://doi.org/10.1659/0276-4741(2006)026[0032:AOALAI]2.0.CO;2

Kouli, M., Soupios, P., & Vallianatos, F. (2009). Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environmental geology*, *57*(3), 483-497. https://doi.org/10.1007/s00254-008-1318-9

LRMP. (1986). *Land Capability Report.* Land Resource Mapping Project (LRMP), Kenting Earth Science, Canada.

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Lazpita, J. G., & Gibson, A., (2000). Agricultural abandonment in mountain areas of Europe. Environmental consequences and policy response. *Journal of Environmental Management, 59*(1), 47–69. https://doi.org/10.1006/jema.1999.0335

Mandal, U.K. (2017). Geo-information-Based Soil Erosion Modeling for Sustainable Agriculture Development in Khadokhola Watershed, Nepal. *In:* Li, A., Deng, W., Zhao, W. (eds) *Land Cover Change and Its Eco-environmental Responses in Nepal.* Springer Geography. Springer, Singapore. https://doi.org/10.1007/978-981-10-2890-8_10

Nakarmi, G., Schrier, H., Merz, J., & Mathema, P. (1999). Erosion dynamics in the Jikhu and Yarsha Khola watersheds in Nepal. In Proceedings of the People and Resource Dynamics Project, Baoshan, China, 2–5 March 1999, pp. 209–217.

Prishchepov, A. V. (2020). Agricultural land abandonment. Oxford Bibliographies. Environmental Science. Oxford University Press. https://doi.org/10.1093/obo/9780199363445-0129

Rai, R., Zhang, Y., Paudel, B., & Khanal, N. R. (2019). Status of farmland abandonment and its determinants in the transboundary Gandaki River Basin. *Sustainability, 11*(19). https://doi:10.3390/su11195267

Rodrigo-Comino, J., Martinez-Hernandez, C., Iserloh, T., & Cerda, A. (2018). Contrasted impact of land abandonment on soil Erosion in Mediterranean agriculture fields. *Pedosphere, 28*(4), 617-63. https://doi.org/10.1016/S1002-0160(17)60441-7

Rowlands, L. (2019). Erosion and Sediment Control - WSUD During the Construction Phase of Land Development. *Approaches to Water Sensitive Urban Design.* Chapter 8, 163-176. https://doi.org/10.1016/B978-0-12-812843-5.00008-3

Sharpley, A. N., & Williams, J. R., (1990). Erosion/Productivity Impact Calculator: 1. Model Documentation. *USA Dep. Agric. Tech. Bull. 1768*, 235.

Shin, G. J. (1999). *The analysis of soil erosion analysis in watershed using GIS*. Ph.D. Thesis, Kangwon National University, Chuncheon, South Korea.

Thapa, P. (2020). Spatial estimation of soil erosion using RUSLE modeling: a case study of Dolakha district, Nepal. *Environmental Systems Research*, *9*,15. https://doi.org/10.1186/s40068-020-00177-2

Varga, K., Szabo, S., Szabo, G., Dévai, G., & Tóthmérész, B. (2014). Improved land cover mapping using aerial photographs and satellite images. *Central European Journal of Geosciences, 7*(1) https://doi.org/10.1515/geo-2015-0002.

Vogel, H. (1988). Deterioration of a mountainous agro-ecosystem in the third world due to emigration of rural labor. *Mountain Research and Development, 8*(4), 321–329. https://doi.org/10.2307/3673555

Walther, P. (1986). Land abandonment in the Swiss Alps: A new understanding of a land-use problem. *Mountain Research and Development, 6*(4), 305–314. https://doi.org/10.2307/3673371

Wang, G., Gertner, G., Singh, V., Shinkareva, S., Parysow, P., & Anderson, A. (2002). Spatial and temporal prediction and uncertainty of soil loss using the revised universal soil loss equation: a case study of the rainfall–runofferosivity R factor. *Ecol Model*, *153*(1-2),143-155. https://doi.org/10.1016/S0304-3800(01)00507-5

Winkler, K., Fuchs, R., Rounsevell, M., & Herold, M. (2021). Global land use changes are four times greater than previously estimated. *Nat Commun 12*, 2501. https://doi.org/10.1038/s41467-021-22702-2

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning* (No. 537). Department of Agriculture, Science, and Education Administration.

Xiong, M., Sun, R., & Chen, L., (2019). A global comparison of soil erosion associated with land use and climate type. *Geoderma, 343*, 31-39. https://doi.org/10.1016/j.geoderma.2019.02.013.

Zhang, J., Ma, K., Fan, H., & He, D. (2024). Land cover change and its response to water level around Tonle Sap Lake in 1988–2020. *Journal of Geographical Sciences*, *34*(2), 329-354.