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Vegetation dynamics in the Madi watershed, Gandaki Province of Nepal

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Abstract

Monitoring of Spatio-temporal vegetation dynamic is one of the most important indicators used to track environmental quality. Spatial and temporal dynamics of Normalized Difference Vegetation Index (NDVI) values are the most useful and reliable technique to analyze the general vegetation dynamics at the regional level. Thus, this study analyzed the spatial pattern and temporal trend of NDVI values of naturally vegetated areas in the Madi Watershed of Nepal relating to its geomorphic and built-up density factors in 2000, 2010,and 2020. Lands at images were used to derive NDVI values and SRTM DEM and the topographic map were used to derive geomorphic factors and built-up density. This study excluded cultivated land, built-up area, water body, cliff, snow-cover area, glacier, and glacier moraine areas to derive only naturally vegetated areas. Human population data was collected from the population censuses. Field observation and information collected from the field to verify ground reality in 15 different watersheds. This study revealed that there is a significant increase in natural vegetation in all parts of the watershed. However, there is the highest rate of increase in vegetation in lower plain areas, where the population density is the highest. The overall increase in natural vegetation is because of the decreasing human and livestock population, changes in lifestyle, etc. The highest increase in natural vegetation in lower plain areas is because of the alternative use of cooking energy and building materials in urban and accessible areas, decreasing the number of livestock. Thus, it can be concluded that there is a significant impact of population dynamics on vegetation in the Madi Watershed of Nepal.

Keywords: Natural vegetation, Normalized difference vegetation index, Population change, Spatio-temporal, Vegetation dynamic

Introduction

Vegetation plays a crucial function to make the earth livable. Important ecological services, carbon sequestration, and biodiversity are all provided by plants, and they also help to lessen the impact of the urban heat island effect. They help maintain moisture in the air, chill it, give out oxygen, filter out dangerous gases and contaminants, and cool the air. Thus, vegetation, a vital component of the earth's ecosystem, is sensitive to climate change, and its feedback has a significant impact on the climate, hydrology, ecology, and other factors (Bao *et al.* 2021).Vegetation cover is important for protecting the soil surface from raindrop splashing, increasing soil organic matter, soil aggregate stability, water holding capacity of the soil, hydraulic conductivity, retarding and reducing surface water runoff, etc. Plants are the essential foundation of food chains in all ecosystems. Plants use photosynthesis to capture solar energy, giving other living things food and a place to live. Many indigenous plants can be used as food, fiber, and animal feed. Additionally, native plants help regulate ecosystem processes including flood control and climate regulation (Amarasinghe *et al.*). The total forest-covered area in the world is 4.24 billion hectares, which is 30% of the total land surface of the earth. The average forest area is 0.52 hectares per person in the world but the areas are highly variable in different parts of the world. (FAO, 2020). There was enormous literature on the degradation of vegetation because of population pressure mostly in developing countries (Carr 2004, Jha & Bawa 2006, Mani & Griffiths 1997, Ryan *et al.* 2017). Despite the global population's explosive increase, certain rural areas have been gradually abandoned over the past few decades. The majority of studies on this subject have focused on urban population growth, whereas depopulation has rarely been discussed (Bruno *et al.* 2021).

Re-vegetation is an essential stage to successfully restore the soil in disturbed sites (Chen *et al.* 2020, Mensah 2015, Zhang *et al.* 2020). It can happen naturally as a result of plant succession and colonization or more quickly as a result of human-driven land modifications made to restore damage from extreme occurrences like floods, wildfires, or mining.In recent decades, agricultural land abandonment and regeneration of natural vegetation is being a general scenario in many rural areas in the world (Bruno *et al.* 2021, Chidi *et al.* 2021, Huang *et al.* 2020a). Rural depopulation has not resulted in only agricultural land abandonment but also overall vegetation growth even in not cultivated land in the past. Natural vegetation growth is because of the result of decreasing number of humans and livestock. The result is not only the decreasing number of humans and livestock but lifestyle changes of the remaining population, availability of alternative energy sources, and change in the use of construction materials are also equally important for the protection of natural vegetation (Huang *et al.* 2020b, Yu *et al.* 2020).

Normalized Difference Vegetation Index (NDVI) is a measure of surface reflectance and gives a quantitative estimation of vegetation growth and biomass, which is the most extensively used indicator for tracking vegetation dynamics at both regional and global scales (Huang *et al.* 2021, Vrieling *et al.* 2013, Zhu *et al.* 2013). Thus, NDVI is a valuable index to monitor the general scenario of vegetation dynamics.

Very little literature is available on vegetation change in the mountain of Nepal and most of them are overall greenery change and increasing greenery on abandoned agricultural land rather than in the former non-cultivated region (Baniya *et al.* 2019, Dahal *et al.* 2020). Preliminary observation has revealed a significant increase in the intensity of natural vegetation even in non-cultivated land. Thus, this study is concerned with the vegetation dynamics of the naturally vegetated area outside the former and present cultivated land.

The study area

This study is in the Madi Watershed of Nepal, which is one of the depopulated regions of Nepal. The Watershed area extends into three districts Kaski, Lamjung, and Tahahun. The upper parts are in Kaski and Lamjung and the lower parts are in Tanahun district.

The watershed extends from the peak of Annapurna II (7937 m) in the north to Damauli (300 m) in the south, which are the parts of the Higher Himalayas, Middle Mountains, and Middle Hill(KES 1986). The total surface area coverage is 1122 sq. km. The geographical coordinates of the Madi Watershed are from 27º57'51" to 28º32'20" north latitude and from 84º01'17" to 84º20'52" east longitude. This area is one of the fast population-decreasing areas of Nepal. During the last two decades, 17% of the rural population of the Watershed has decreased but some urban areas like Dalauli, and Bhrletar, have an increasing population. This study is concerned only with NDVI values of the naturally vegetated areas, which have been given in green color (Figure 1).

The general elevation of the watershed is south-facing, and altitude is lowering from the north to the south (Figure 2a). The northern part is extremely high 7937 m and the southern end is as lower as nearly 300 m above the mean sea level. Thus, the altitudinal variation is very high, which is the major controlling factor of temperature and vegetation growth. Above 3000 m are seasonal snowfall areas and above 5000 m are permanent snow cover areas in Nepal. Thus, the higher elevation reaches far below 0º C and lower parts have subtropical climates warm in winter and summer becomes hot. Population has been decreasing in higher elevation areas due to the out migration of rural population in the study area during the beginning of the last two decades (Khanal 2002).

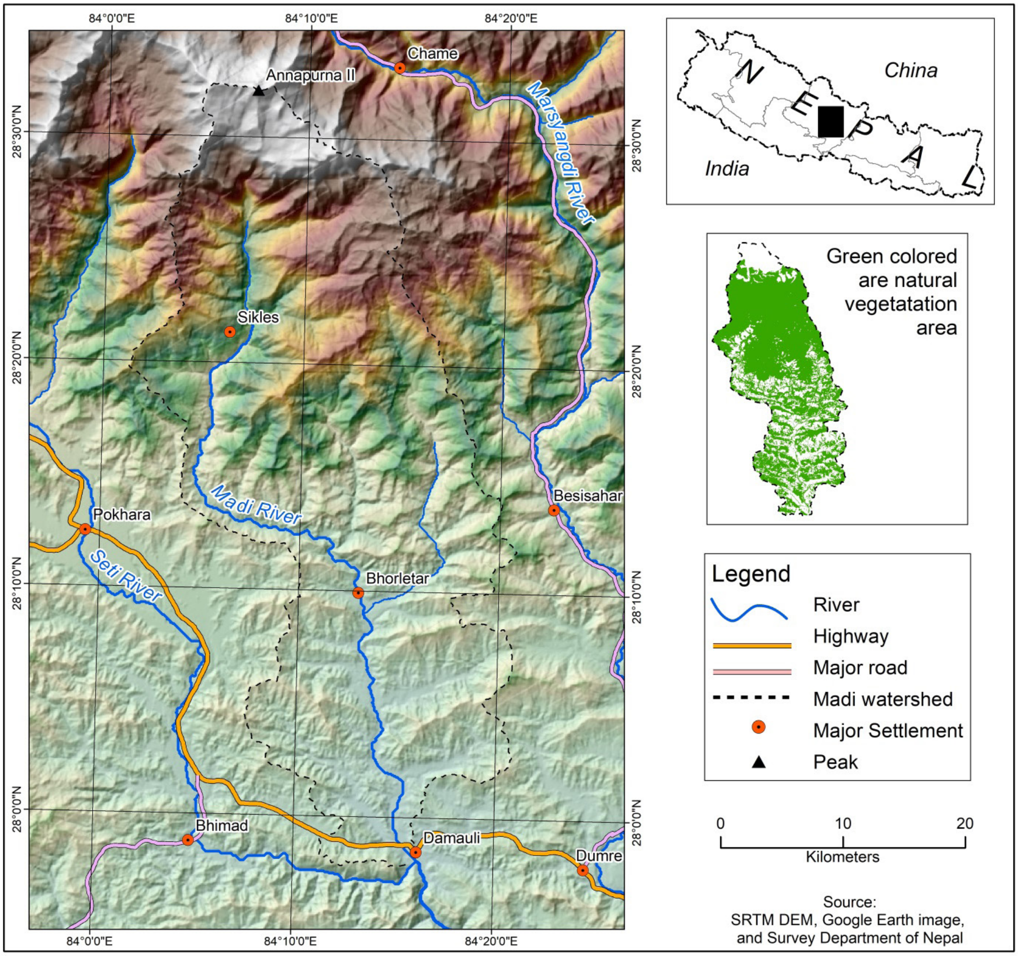

Figure 1: The study area (the Madi Watershed)

The slope gradient increases to the north and the highest slope gradient are at high altitude Himalayan region. The southern parts of the river basin have the lowest slope gradient. The build-up density is quite correlated with the slope gradient. The most built-up areas are distributed to the south's lower elevation and lower slope gradient. Thus the built-up density is increasing with decreasing elevation and slope gradients (Figures 2a, 2b, and 2d). The watershed has all types of slope aspects and they are comparatively uniformly distributed in all parts of the watershed and have no quite correlation with slope gradient and elevation (Figure 2c).

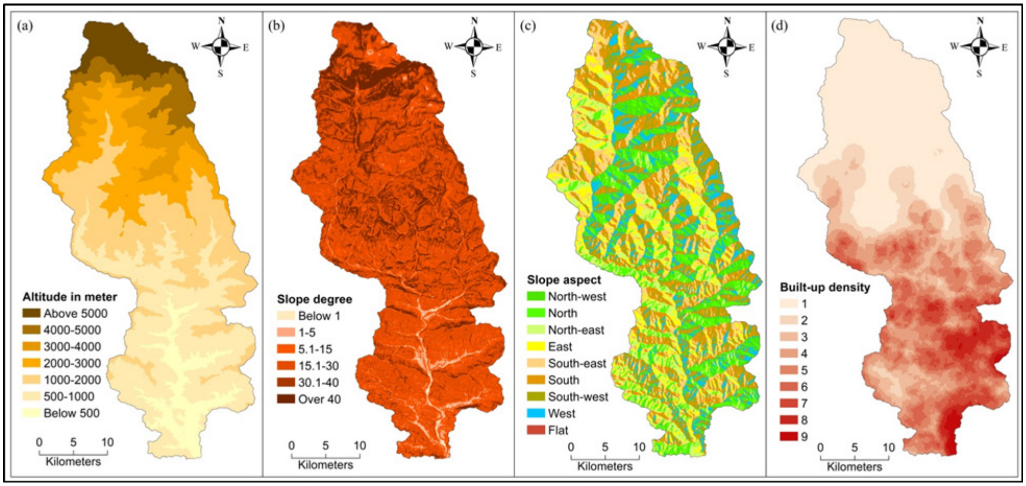

Figure 2: Topography and built-up density in the Madi Watershed: (a) elevation, (b) slope gradient, (c) slope aspects, and (d) built-up density.

Methods and materials

Landsat-5, Landsat-7, and Landsat-8, and the Digital Elevation Model (DEM) of 30 m spatial resolution were data sources of this study that are freely available on the webpage https://earthexplorer.usgs.gov/. Landsat images of the dry season of November, December, and January in each year 2000, 2010, and 2020 were downloaded. Visible bands of images were combined into one file and atmospheric corrections were done to make cloud-free images.

The NDVI index was used, which is the most popular index for vegetation analysis based on remote sensing images. NDVI was first developed by a research team at Texas A & M University in 1972, which needs to compare the values of absorption and reflection of red and NIR light (Kinyanjui 2011, Pervez *et al.* 2021). NDVI indices were calculated using the formula.

$$\text{NDVI} = \frac{Red - NIR}{Red + NIR}$$

Red is a red band and NIR is a near-infrared band of the image. The minimum to maximum values of NDVI ranges from -1 to +1. Minimum vegetated surfaces like barren rock, sand, and snow usually show very low NDVI values of 0.1 or even less. Sparsely vegetated areas like shrubs and grasslands result in values of 0.2 to 0.5.

Average values of three months NDVI were calculated to minimize the errors from the actual average situation in 2000, 2010, and 2020 because vegetation varies with the rainfall variation in the same months in different years. DEM was used to determine the watershed boundary, elevation, slope gradient, and slope aspects of the watershed boundary. Built-up kernel density was calculated using the built-up point of a topographic map of scale 1:25000 and 1:50000. The calculated built-up density was classified into nine categories from 1 to 9. One is the least densely populated and 9 is of having the highest density.

For the study of natural vegetation only, this study excluded NDVI values on cultivated land, water body, cliff, glacier, glacier moraines, and snow-cover areas. The average and total values of NDVI in the watershed were calculated. Accordingly, Average values of NDVI according to 500 m interval elevation zones, different slope gradients and slope aspects, and built-up density were calculated. Calculated average values have been represented by diagrams for the comparative analysis of NDVI values in each elevation zones, different slope gradients, slope aspects, and built-up density values.

For the ground reality check based on changing patterns of NDVI values, an observation survey was conducted, and 30 knowledgeable people were selected for the key informant's survey. Key informants were more than 45 years of age and nearby settlements in the observed areas. Changing situation of human and livestock population, vegetation, human lifestyle, occupation, migration, livestock, and consumption of forest products like livestock grazing, fuel wood, and construction materials during the last 30 years in their locality were analytically studied. Just qualitative information on changing situations was derived to verify the ground reality of NDVI values rather than to acquire quantitative data.

Results

General changes in NDVI values

The general pattern of NDVI is continuously increasing from 2000 to 2020. NDVI values are highly darker in the lower parts of the Himalayas in all years. More human settlements are also located in this region. Overall greenery is increasing in 2010 and 2020 even higher increasing greenery just below 5000 m and lower elevations nearby the settlements (Figure 3). The greenery (Figure 1) in the middle and lower elevations cannot be confirmed about the vegetation increase in natural areas because most parts of this region are cultivated land. Greenery may be because of the crops rather than natural vegetation. It requires average values of NDVI excluding cultivated land, water body, cliff, glacier, glacier moraines, and snow-cover areas.

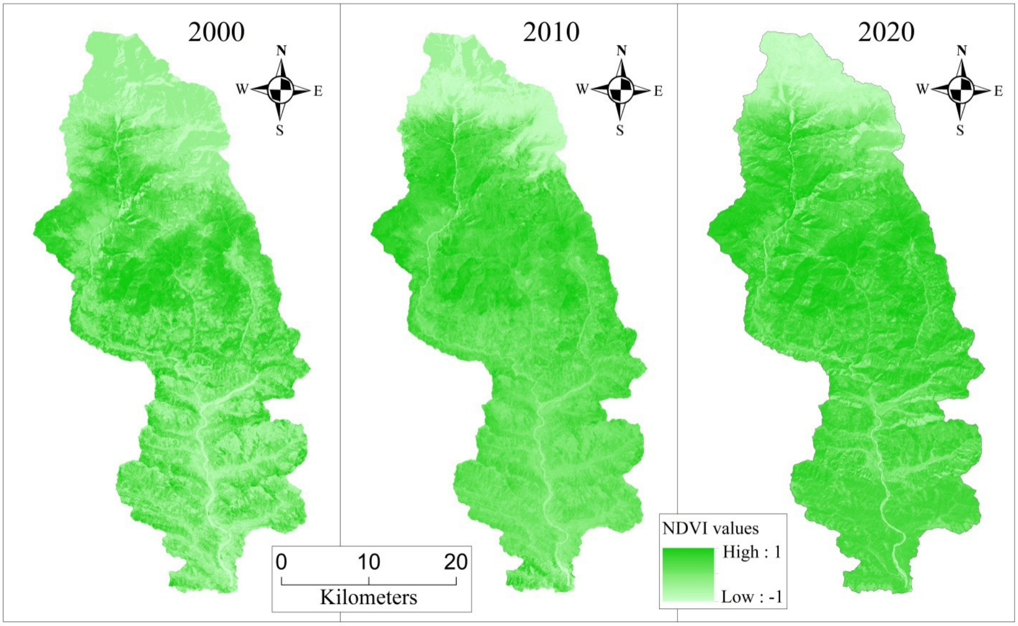

Figure 3: Distribution pattern of NDVI values in 2000, 2010, and 2020.

Similar results were also identified in the average values of NDVI as in the general picture in figure 3. The average NDVI value increased to 0.3 in 2010 and 0.5 in 2020 (Figure 4). This proves that there is a significant increase in natural vegetation from 2000 to 2020 and the same result was also identified during the case study of the same region during 1999/2000 (Khanal 2002).

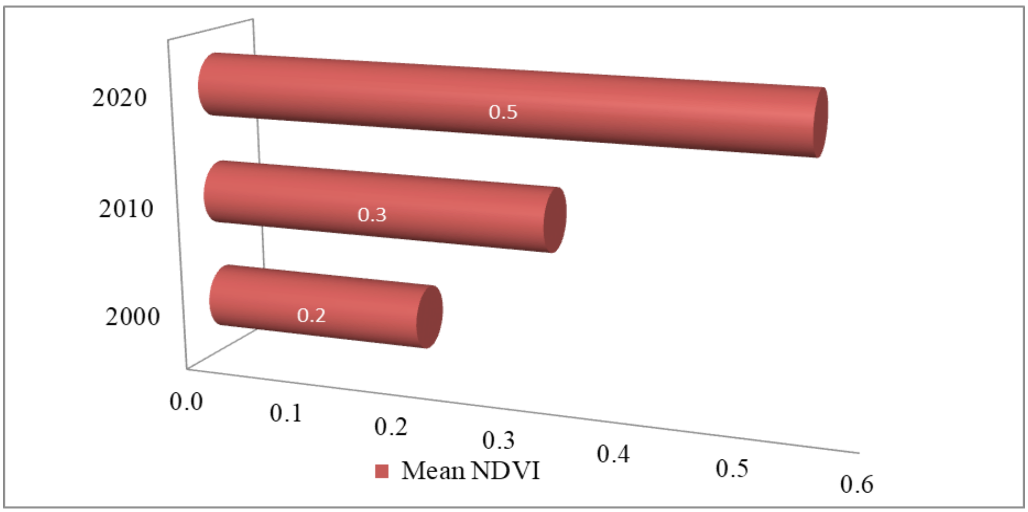

Figure 4: NDVI values and its changing trend in 1990, 2000, 2010, and 2020

The general increasing trend of NDVI change is because of the changes in vegetation intensity and biomass. The general trend of population change and vegetation changes are quite correlated in the study area. Thus, it gives the general scenario of population change as the major driver of natural vegetation change in the study area.

NDVI changes by elevation

The atmospheric temperature decreases with increasing altitude at a certain rate known as the lapse rate, which decreases at the rate of 10°C in dry air and of 6.5° C in wet air in temperature per 1000 m altitude increase (Kattel *et al.* 2015). Primarily, temperature controls the cell development of a plant for its growth. Different plant species have different responses to temperature in their growth and development and they require a different range of temperatures for their comfortable life cycles (Li *et al.* 2019). Himalayan mountains are a unique and complex ecosystem, where elevation controls spatial heterogeneity in vegetation due to the large climatic variation in a short spatial distance (Tai *et al.* 2020). The degradation of vegetation by human consumption is one of the most important parts of the distribution of vegetation intensity and biomass. The highest values of average NDVI are between 1000 to 3000 meters because of the more forest cover in this middle altitude region. Above 4000 m in the Himalayas is an extremely cold region thus the vegetation growth is very low. However, increasing NDVI values in the last two decades may be because of plant growth due to climate change (Sabin et al., 2020) and decreasing numbers of nomadic sheep herding activities (Dahal 2019). Increasing temperature in the Himalayas due to the climate change and decreasing number of livestock for grazing may be a suitable environment for plant growth in this region but it requires further validation of ground reality. The high rate of increase of NDVI values in lower altitudes during the last two decades (Figure 5) is because of the decreasing human and livestock population, and decreasing demand for grazing land, fodder, building materials, and fuel wood in the last two decades (Bhandari & Pandit 2018).

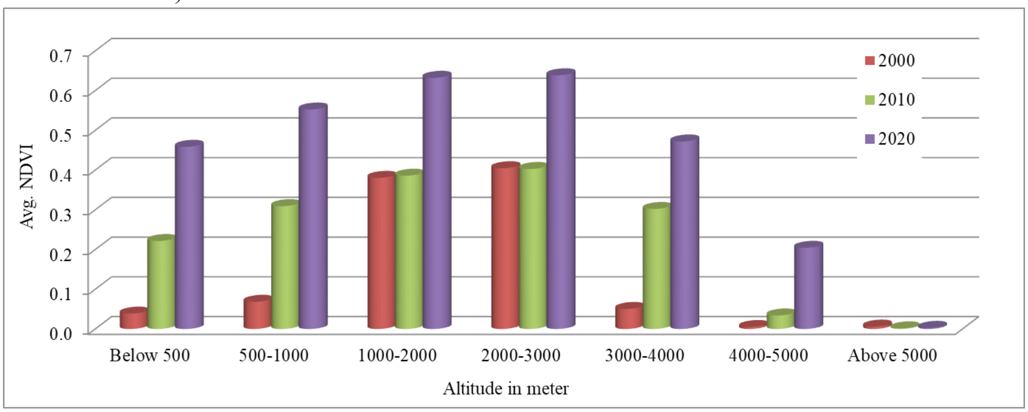

Figure 5: NDVI values and its changing trend in 2000, 2010, and 2020

NDVI changes by slope gradient

Slope gradient has no direct impact on vegetation but soil properties and their depth are highly determined by it,on which vegetation growths are highly dependent (Brosens *et al.* 2020, Zhang *et al.* 2018). Thus, the slope gradient is one of the determining factors of plant growth. Generally, a higher slope gradient is prone to more soil erosion and organic matter in the soil is removed faster compared to a lower slope gradient (Kapolka & Dollhopf 2001) but in the study area, NDVI values are higher in a medium slope gradient rather than in lower slope gradient (Figure 6). There was higher population density in the lower flat land thus most of the natural vegetation was highly degraded in flatland areas of lower altitude. The highest slope gradient has also lower slope gradients because the highest slope gradients are mostly located in the high-altitude Himalayan Region, which is very cold. Thus, there is very low vegetation growth in the past and the present. The areas of lower slope gradients mostly located in lower altitude southern region have higher population density and higher proportion areas were occupied by cultivated land. Thus, a very lower proportion of areas were left for natural vegetation. Therefore, higher demand for forest products and grazing land resulted in higher pressure in lower slope gradient areas compared to higher slope gradient areas. The rate of increase in NDVI values is quite higher in lower slope gradients because of the regeneration of vegetation due to the sharp decrease in livestock numbers, and decreasing demand for fuel wood and building materials. Another cause of increasing NDVI values is the successful implementation of community forests in limited public land. Similarly, all slope gradients have increasing average NDVI values because of depopulation and decreasing demand for forest products. However, increasing NDVI values in the region of higher population density is because of the alternative use of energy for cooking and decreasing the number of grazing livestock.

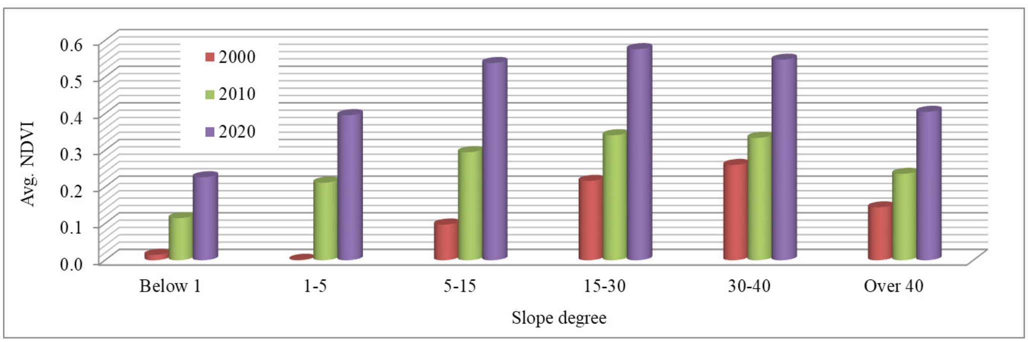

Figure 6: Average NDVI values by slope gradient

NDVI changes by slope aspects

The slope aspect is one of the most important factors in plant growth due to the variations in solar radiation. Solar radiation directly affects on photosynthesis process of vegetation, temperature, and soil moisture condition (Tong *et al.* 2021, Yang *et al.* 2021). Vegetation growth is highly dependent on soil properties and soil properties are highly dependent on the materials that are made in which microclimatic conditions like temperature and moisture and vegetation condition itself (Mohammad 2008, Yang *et al.* 2020). Thus, solar radiation is the most important factor for plant growth, which is highly dependent on slope aspects in mountain areas.

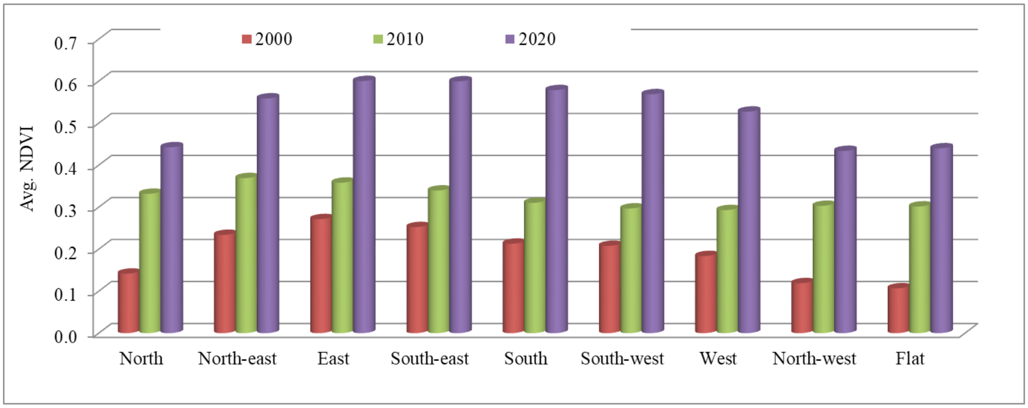

Figure 7: Average NDVI values by slope aspect

As the location of the study area in the northern hemisphere, solar radiation is higher in the southern and eastern slope faces and lower in the northern and western part. Average NDVI values are the highest in the east-facing slope followed by the southeast face and the lowest is in the flat followed by the northwest. East facing slope has the highest NDVI values because the highest solar radiation is before the afternoon, which is followed by the south face. After all, the south face gets direct sunlight in the afternoon only. Flat land has the lowest NDVI values because of its location in a highly human-populated area. In the last, two decades, these areas have had the highest rate of increase in NDVI values (Figure 7) because of the protection of vegetation by community forestry, decreasing demands of forest products, and grazing land. Average NDVI values are increasing very fast during the last two decades.

NDVI changes by built-up density

People get food, shelter, fuel, and food for their livestock and various materials from the natural vegetation. In traditional agrarian regions, rural farmers are highly dependent on public forest resources such as fooder, fuel wood, building materials, etc. because they have an integrated farming system among cultivated land, livestock, and forest resources (Jha & Bawa 2006, Paramesh *et al.* 2022, Wenhua & Min 1999). The mountain and hills of Nepal have a traditional intensive subsistence farming system and the majority and most of them are still in the same condition. This agriculture system is highly integrated with primitive types of agricultural practices. Thus, if one part of this system is intervened, the whole system is disturbed (Chidi *et al.* 2021). Thus, the natural vegetation is an integral part of the agriculture system in the study area. The average NDVI values look quite correlated with built-up density in 2000 but the least densely populated area has lower because of the cold climatic condition rather than its relationship to built-up density. The average values of NDVI are very low at more than 7 built-up density values in 2000. The highest density values are at the built-up density value of 2 in the remote high-altitude forest-covered areas. The highest rate of increase in NDVI values in the highly populated regions is because of the decreasing human and livestock population including the use of alternative fuel wood and building materials in accessible and urban areas. The NDVI values are increasing in all regions during the last two decades but the rate of increase is the highest in the regions of higher built-up density (Figure 8).

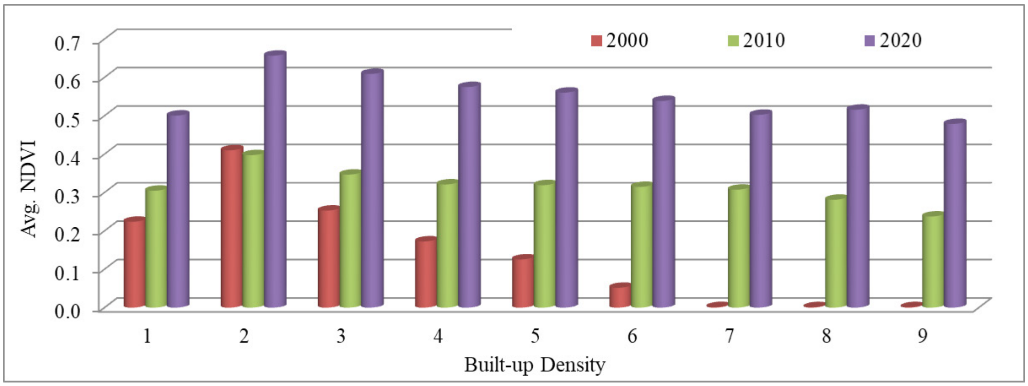

Figure 8: Average NDVI values by built-up density

Discussion

The relationship between the human population and vegetation is high. There is several historical evidence of the interrelationship between the human population and vegetation in the world (Ren *et al.* 2021). Depopulation and agricultural land abandonment including vegetation growth in abandoned farmland is a general phenomenon in many parts of the world (Bruno *et al.* 2021, Huang *et al.* 2020b) but the relationship between human and natural vegetation dynamics is being neglected part of the study in the world in response to such context this study has tried to address the gap and open a new dimension in academic research.

The out migration of mountain and hill people to the lower plain area and outside the country is not a new phenomenon. Depopulation in several rural areas in this region has decreased population before but the decreasing rate of the population became very fast during the last two decades. International labor migration was the major driver of out migration but later it is accelerated by interlinked globalization, education, lifestyle, and occupational changes (Khanal & Watanabe 2006, Singh *et al.* 2007, Suwal 2014). Although there is no reliable data on decreasing livestock numbers due to the decreasing population and shortage of agricultural labor in the study sites, from the field survey this study has identified that livestock numbers have significantly decreased during the last two decades and it has been further proved by a case study in Madi Watershed (Khanal 2002). There is very little livestock for grazing cows and goats in each village, which had hundreds of numbers before the last two decades. Not only grazing animals but also stall-feeding livestock like buffalo's numbers have also been highly decreased during the same period. In many parts of the study sites, local people informed that hundreds of grazing animals used to go into the public forest for grazing in the past but now only a few orno animals are there for grazing in those areas. Similarly, hundreds of villagers used to go to the public forest everyday for collecting forest products like fodder, litter, fuel wood, and building materials but now they rarely visit the forest because there are no more people in the village, which requires forest products from the public forest. Most of the villagers in the villages have sufficient forest products from their private land. Local villagers have no sufficient humanpower to take care of their private land. Consequently, there is a significant decrease in demand for forest products in rural areas. Increasing off-farm activities, an increasing number of school-going children, including lifestyle changes of the villagers because of the increasing living standard are also other causes of decreasing demand for forest products, which is similar to other rural areas of Nepal (Bhatta & Kharel 2018).

Increasing use of alternative sources of fuel wood like LP gas and electricity in commercial areas including some rural areas are also other causes of decreasing demand for fuel wood. Before two decades, fuel wood was the major energy source for cooking in commercial areas, which was mostly supplied from forest land, which is similar to other regions of Nepal (Sharma 2018). Now, it is rarely used for household purposes in urban areas. Hence, the community forest is being successfully implemented in the last period even in the lower accessible areas, there was a high-pressure demand for forest products and grazing land for livestock. The sharp decrease in demand for forest products and grazing land has resulted in a sharp increase in the vegetation intensity as a result highest rate of increased NDVI values in lower plain areas, where the population density is the highest.

Conclusion

In traditional agrarian region population change is a major driver of whole landscape change. In recent decades, most studies have focused on agricultural land abandonment because of depopulation, and changing vegetation dynamics due to depopulation are highly neglected aspects of the study. Thus, this study analyses aspect of landscape change due to depopulation in the traditional agrarian region. It has revealed the significant relationship between depopulation and vegetation change in the naturally vegetated area outside the cultivated land. The highest rate of increase in natural vegetation nearby settlement areas in the recent period in contrast to the human population increase. It is because of the decreasing livestock numbers and use of alternative fuels for cooking. The significant increase in NDVI values between 4000 to 5000 m can be one of the sensitive research issues related to decreasing numbers of livestock populations and climate change in the range land of the high altitude region. Successful implementation of community forestry is not only because of the efficiency of the institution and community but it is made possible to be a success because of the demand for forest products and grazing land. It is concluded that depopulation does not result only in agricultural land abandonment but also vegetation growth outside the cultivated land in traditional agricultural regions as well. Although this study has revealed a clear picture of natural vegetation regeneration in the study sites because of population dynamics, it is the initial observation of a general trend, which requires a further more detailed analysis of vegetation richness and biodiversity as well, which is highly related to the environmental and ecological system.

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