# ECOLOGICAL RISK ASSESSMENT USING SATELLITE DERIVED NDVI, HFP AND RAINFALL EROSIVITY IN NEPAL

Dr. Binod Baniya[1*], Jaya Ram Karki[1]

***Abstract:***

*Understanding vegetation dynamics is becoming increasingly crucial to maintain ecosystem in the Himalaya region. An assessment of the normalized difference vegetation index (NDVI) and human foot print pressure indicates the ecological risk scenario of Nepal. The original NOAA NDVI product available from 1981-2015 were used. Similarly, Human footprint pressure data for 1993 and 2009 were used. The study purpose was to develop ecological risk map based on NDVI dynamics and human pressure to natural resources. The result showed that the intensity of vegetation dynamics was 0.065 yr-1 with large positive and negative intensities observed in 2006 and 1984, respectively. Both of the intensity of vegetation changes and variance of NDVI showed increased ecological fragility in the Tran-Himalyan region. However, negative correlation between NDVI and rainfall erosivity showed reduced soil erosion and ecological risk in the region. The human footprint pressure has increased up to 43 which together with increasing annual population growth trend (1.35 yr-1) has exerted pressure on the natural system and created ecological risk. The results have important implications for a better understanding of the vegetation dynamics in response to ongoing climatic variability and associated ecological risks in Nepal.*

**Keywords:** Human Footprint Pressure, Ecological Risk, NDVI, Nepal

## 1. Introduction

Vegetation change is an important indicator of ecosystem dynamics (Walther et al., 2002).Vegetation change has considerable implications for surface radiation, temperature, energy exchange and terrestrial carbon uptake (Bonan, 2008; Jeong et al., 2011; Myneni et al., 1997; Schaefer et al., 2005). Satellite technology has been used to understand the dynamics of vegetation comprehensively (Jeong et al., 2009; Myneni et al., 1997; Zhou et al., 2001). NDVI provides spatial and temporal information about the vegetation and biomass distributions (Reed et al., 1994), $CO_2$ fluxes (Vourlitis et al., 2003; Wylie et al., 2003), vegetation quality and the extent of land degradation in various ecosystems (Holm et al., 2003; Thiam, 2003). NDVI also indicates the effect of climate change on vegetation biomass, productivity and photosynthetic activities in terrestrial ecosystems (Pettorelli et al., 2005). For example, studies of NDVI suggest that climate change contributes 28.4% for greening in the earth (Zhu et al., 2016) which is further accentuated by land use management(Chen et al., 2019). Today, NDVI is becoming increasingly useful tool to assess ecological risks under rapidly changing climatic conditions in many part of the world including the high mountain regions of Nepal Himalaya. Surface vegetation covers are capable of maintaining the intact ecological health. Any deviation of the vegetation dynamics would lead to probability of occurring undesirable events

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[1] Department of Environmental Science, Patan Multiple Campus, Tribhuvan University, Nepal; karkischems@yahoo.com

[*] Correspondence: binod.baniya@pmc.tu.edu.np; Tel: +977-9841832743; Kathmandu, 44700, Nepal

and expected ecological damage (EPA, 1998). The end point of ecological risk is a characteristic exposure of ecological components to various stressors. The environmental problems have induced ecological risks as indicated by NDVI assessment.

Areas with lesser NDVI are found to have increased exposure to ecological risks. It has been argued that plant growth depends on increased environmental complexity (Billings, 1952)with tolerance and ecological optima. However, stressors such as outmigration (Oldekop et al., 2018), human land use management (Chen et al., 2019), deforestation, livestock grazing, altitude and ecological restoration practices are affecting widespread changes in the vegetation landscape in different geographic regions (DoFRS, 2017). NDVI is becoming increasingly useful tool to assess ecological risks under rapidly changing climatic conditions in many part of the world including the high mountain regions of Nepal Himalaya. The rainfall erosivity or capacity of rainfall causing soil erosion in the hill slopes due to water seepage (Cook, 1937; Nearing et al., 2017; Wischmeier and Smith, 1958) has been major concern for ecological risk in Nepal. As the surface vegetation cover and rainfall erosivity are reciprocal between each other and capable of maintaining the intact ecological health. Any deviation of the vegetation dynamics would lead to probability of occurring undesirable events and expected ecological damage (EPA, 1998). The end point of ecological risk is a characteristic exposure of ecological components to various stressors. The exposure to rainfall erosivity and human-derived footprint, in particular, is the fundamental of NDVI-based ecological risk assessment in the mountain regions of Nepal.

A large body of literatures detects changes in vegetation in response to changing physical environments. However, there is an increasing interest in studying the vegetation dynamics and intensifying ecological risk in Nepal. Identifying ecological risk using NDVI and human footprint pressure (HFP) index is one of the major aims of this research. In Nepal Himalaya, the role of vegetation in combating ecological disaster not yet been documented comprehensively. Identifying the ecological zones with increased human footprints is important to evaluate human-induced ecological disasters in the mountain that helps to mitigate or reduce associated risks and appropriate planning for biodiversity conservation. Studies suggest that relationship between soil erosion potential based on erosivity index and surface vegetation cover shows the variable degree of ecological risk. In Nepal Himalaya, the role of vegetation in combating ecological disaster such as the soil erosion has not yet been documented comprehensively. Identifying the ecological zones with increased human footprints is important to evaluate human-induced ecological disasters in the mountain that helps to mitigate or reduce associated risks. This study provides the comprehensive assessment of the ecological risk using vegetation dynamics, human foot print pressure and estimating rainfall erosivity in the Nepal Himalaya.

## 2. Study Area

Nepal (26$^{o}$ 22' and 30$^{o}$ 27' N latitude and 80$^{o}$ 04' and 88$^{o}$12' E longitude) is located in the central part of the Himalayan region characterized by unique topography and land use difference (Figure 1). The altitude varies from 70 m a.s.l in southern low lands to the highest peak at8,848 m a.s.l Mount Everest in the north (Figure 1). Based on this altitudinal variation, Nepal has been divided in to 6 bioclimatic zones; each 1000 m altitude represents different bio-climatic zone i.e. Tropical (<1000 m), sub-tropical (1000-2000m), Temperate (2000-3000 m), Sub-alpine (3000-4000 m), Alpine (4000-5000 m) and Nival (>5000 m).Accordingly, forest ranges from the tropical to Nival climatic zone(Dobremez, 1976; LRMP, 1986). The forests are further categorized in to needle leaved closed forest (9.47%), needle leaved open forest (5.62%), broadleaved closed forest (14.40%) and broadleaved open forest (9.61%) (Uddin et al., 2015). Climate is distinctly characterized by four seasons. The growing seasons begins in the spring and ends in the autumn overlapping the monsoon season (DHM, 2015). Only a few stations have been established in very high altitudes of Nepal Himalaya. As result, the number of stations selected for this study is relatively large from the low land regions. Stations above 3000 m altitude were very low in number (Figure 1).

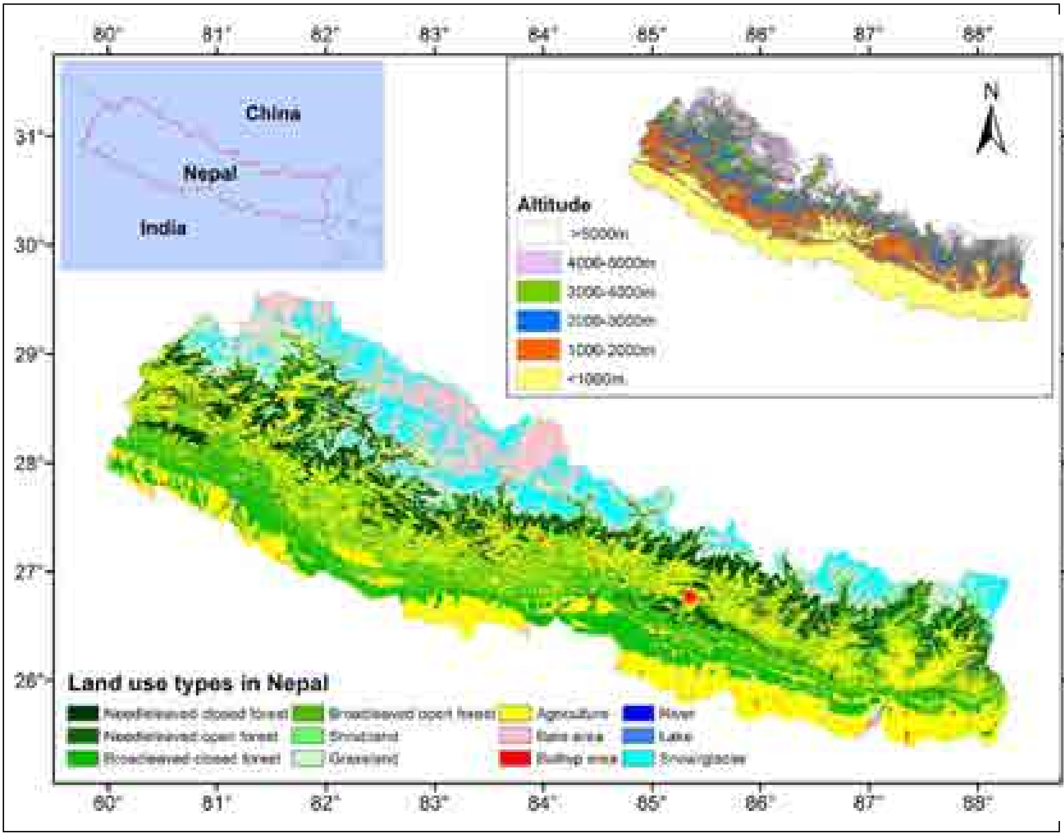

*Figure 1: Land use land cover types; in Nepal, the left inset map is the geographic and right inset map is altitude (DEM) map of the Nepal*

## 3. Materials and Methods

### 3.1. Environmental data collection

The original NDVI data sets were generated from National Oceanic and Atmospheric Administration (NOAA), Advanced Very High-Resolution Radiometer (AVHRR) sensors under the framework of Global Inventory Monitoring and Modeling System (GIMMS). The GIMMS NDVI product has the temporal resolution of 15 days and the spatial resolution of 8 km (Tucker et al., 2005). The monthly precipitation data was used from Department of Hydrology and Meteorology (DHM) for same time period from 1982-2015. Human footprint pressure data were used for 1993 and 2009 because this year falls under our study periods. The foot print data was also verify using national population census data of Nepal. The values of global human footprint pressure is ranges from 0 to 46 in which high values corresponds with the high level of human pressure and vice versa (Venter et al., 2016).

### 3.2. Intensity of NDVI changes and ecological risk

The intensity of the NDVI was computed based on proxy anomaly it is defined as the standardized departure from the average growing season NDVI (Liu et al., 2015; Lotsch et al., 2005; Xu et al.,

2015) during 1982-2015.The proxy  represents intensity of the vegetation dynamics was identified using Equation (2).

$$e(i)=\frac{NDVI_i-Mean(NDVI)}{SD(NDVI)}\ldots\ldots(2)$$

$NDVI_i$ is the average NDVI for year i, and mean and SD are the average and standard deviation of the NDVI for the period of 1982-2015, respectively. We used three absolute standard deviation categories for both positive and negative changes: 1)  indicates weak intensity; 2) referred to as the moderate intensity and 3)   as large intensity. The positive weak, moderate and large intensity refers to moderate, mild and slightly fragile but negative week refer to severely fragile and negatively moderate and large intensity i.e.refer to extreme ecological fragile.

### 3.3. Ecological risk based on rainfall erosivity

Rainfall erosivity refers to the potential ability of rain to cause soil erosion. The soil erosivity empirical equation such as the Fournier Index (Fournier, 1960) and Fournier Index Modified(Arnoldus, 1980) was calculated using Equation (3) and Equation (4)

$$FI=\frac{p2_{max}}{P}\ldots\ldots\ldots\ldots(3)$$

Where, $P_{max}$ is the monthly average amount of precipitation of the most rainy month (mm) and P is the average annual quantity of precipitation (mm)

$$FMI=\sum_{i=1}^{12}\frac{p_i^{\,2}}{P}\ldots\ldots\ldots\ldots(4)$$

Where $p_i$ is the monthly average amount of precipitation for month i (mm) and p is the average annual quantity of the precipitation (mm). The erosivity i.e. soil erosion risk were classified (Table 1)

**Table 1** Soil erosivity classes by Fournier Index (FI) and Modified Fournier Index (MFI)

| Erosivity classes | FI | Erosivity classes | MFI |
|---|---|---|---|
| Very low | 0-20 | Very low | 0-60 |
| Low | 20-40 | Low | 60-90 |
| Moderate | 40-60 | Moderate | 90-120 |
| Severe | 60-80 | High | 120-160 |
| Very severe | 80-100 | Very high | >160 |
| Extremely severe | >100 | | |

### 3.4. Correlation analysis between NDVI, Climate and Rainfall erosivity

Pearson correlation between NDVI and rain erosivity index were computed. This approach has been widely applied to analyze the correlation between NDVI and climatic factors (Baniya et al., 2018; Jiang et al., 2017; Pang et al., 2016; Sun and Qin, 2016; Tian et al., 2015). If the *p* value of correlation between NDVI and rainfall erosivity index are less than the significance level of 0.05 the correlation is statistically significant and vice versa.

## 4. Results and Discussion

### 4.1. NDVI and Human Footprint Pressure (HFP)

Over the past one and half decade, the human footprint pressure has significantly increased in Nepal Himalaya. The maximum footprints have reached to 43 mainly in the large cities such as Kathmandu, Pokhara and southern Terai region. The footprints as low as 0-6 were found in the western mountain regions. On temporal pattern, the human footprint pressure was higher in 2009 compared to in 1993(Figure 2c and 2d).Spatially, the footprint pressure was found increased towards western and central regions indicating the exerting pressures on natural system in those regions. The increased human footprint pressure also corresponded to the population growth rate. In which, the total population in Nepal was 26,494,504 with annual growth rate of 1.35%,while the average and maximum population density were 260 and 15355 people/km$^2$, respectively (Figure 2b).The population density is higher in the southern Terai and urban areas of the central regions. The spatial expansion of the human footprint pressure from south to central regions extending from West to East during 2009 compared with 1993 warned for the ecological risk in Nepal.

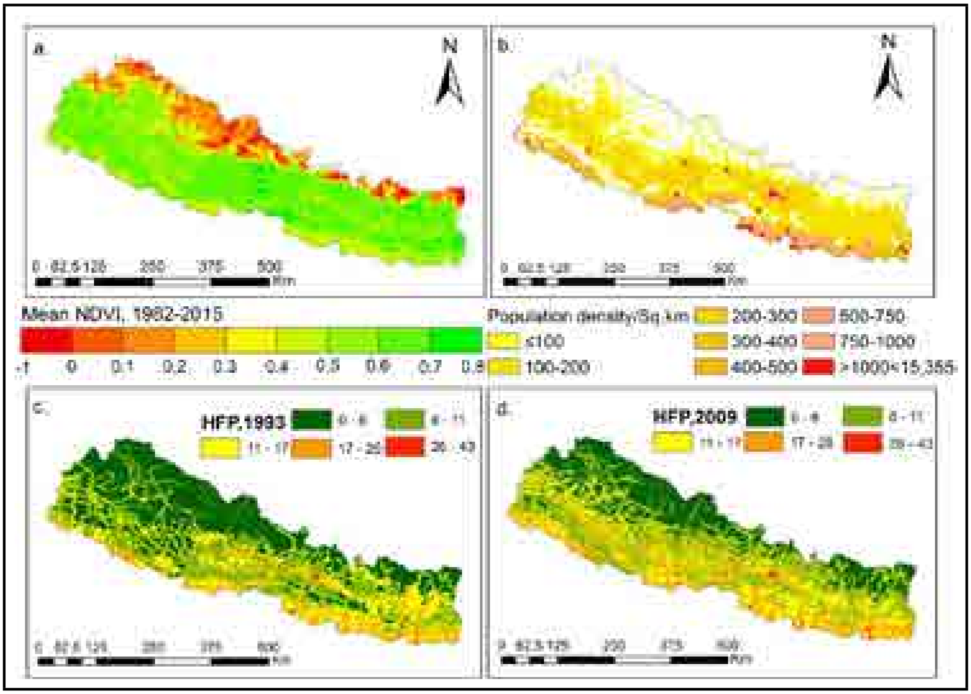

***Figure 2.*** *NDVI and 1 km gridded Human footprint pressure in natural system in Nepal; a. growing season average NDVI during 1982-2015; b. population density of Nepal based on national inventory Census, 2011; c. Human footprint pressure, 1993; d. Human footprint pressure 2009 in Nepal*

In southern parts, the higher population density, HFP and lower average NDVI indicates higher ecological risk. Neither population pressure nor good vegetation in northern parts showed natural risk for human and natural ecosystem. In mid hills, the NDVI distribution have found higher and increased (Figure 2a). However, population density and footprint pressure in mid hills have dramatically increased which is the symbol of ecological risk that would effects on both upstream and downstream regions. The human foot print pressures such as built environments, croplands, pasture lands; population density and night lights have also increased in Nepal Himalaya over the past 2-3 decades. The increased human footprint pressure (HFP) in 2009 compared with 1993 and increased population density in 2011 was identified as priority areas for ecosystem management and restoration in the region. The increased HFP alter natural system and deteriorate environments if it is not manage well. Till now, the human involvement has played positive role on NDVI increases such as the expansion of the community forest development program which plays a positive role to increase vegetation landscape in Nepal Himalaya after 1990 AD. Prior to 1992, a total of 0.034 million ha forests were handed over to the community forest user's group which became 1.02 million ha by 1992-2002 and extended to 1.23 million ha by 2002-2008 (MoFSC, 2009). However, rapid population growth and high human pressure on natural resource limits the carrying capacity of the environments consequently it deteriorates environments and creates ecological risk.

### 4.2. *Ecological risk based on NDVI and rainfall erosivity*

Intensity of vegetation dynamics showed different level of ecological risk in Nepal Himalaya (Figure 3). The negative NDVI changes refer high ecological risk and positive NDVI changes refer low ecological risk. Temporally, the intensity of vegetation changes was 0.065 $yr^{-1}$ during 1982-2015. The large positive and negative intensity of vegetation changes were identified in 2006 (2.20) and 1984 (-2.05). Spatially, the mountain regions mainly the Trans-Himalayan regions were found extremely fragile where the negative intensity of NDVI changes was greater than -1 while the mid hills showed mild fragile regions in term of changing NDVI. Interestingly, the central and some parts of eastern hills had the positive intensity of NDVI which is greater than 2 (Figure 3a).

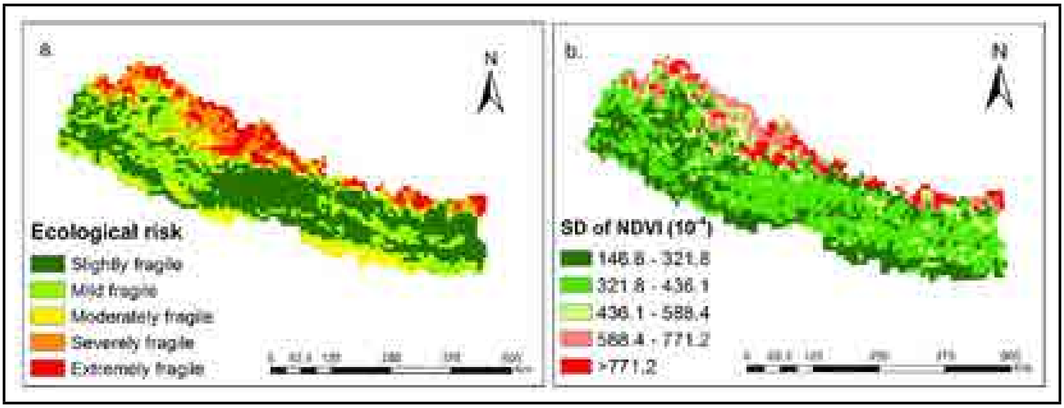

***Figure 3.*** *Risk categorization based on a. intensity of vegetation changes and b. Standard deviation of average NDVI during 1982-2015 in Nepal*

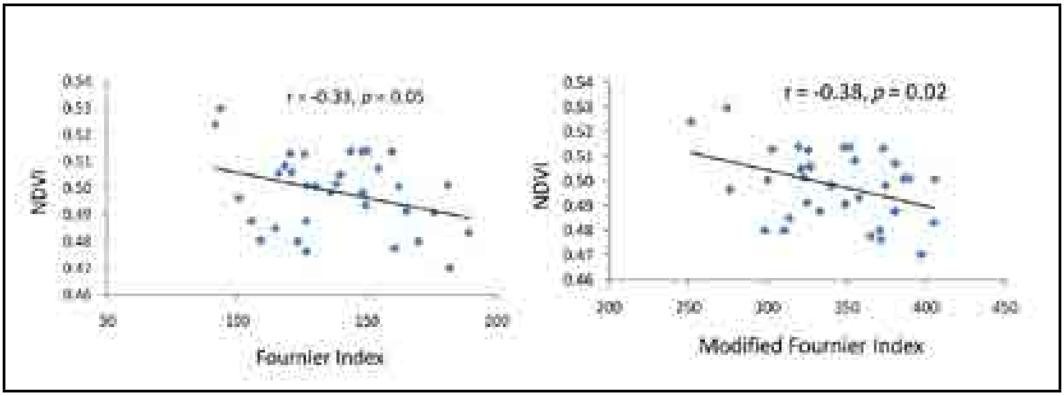

*Figure 4. Correlation between NDVI and rainfall erosivity in Nepal during 1982-2015*

The standard deviation of NDVI was very high in the mountain mainly in the Trans-Himalayan regions but relatively lower in the mid hills and Terai. Majority in the mountain, the standard deviation was more than $500 \times 10^{-4}$ but in the hills and Terai the standard deviation was lesser than $436 \times 10^{-4}$(Figure3b). The risk parameter such as rainfall erosivity derived from Fournier Index and Modified Fournier Index has shown 138.36 and 342.01, respectively showing extremely severe and very high soil erosivity. The NDVI and soil erosivity were negatively correlated with both Fournier and Modified Fournier Index (Figure 8). However, the temporal soil erosivity trend as shown by Fournier index and Modified Fournier Index was found decreasing with the Sen's slope of -0.72yr$^{-1}$ ($p = 0.15$) and -1.38yr$^{-1}$ ($p = 0.07$), respectively during 34 years periods.

Based on the yearly intensity of vegetation dynamics, relatively high ecological risk was experienced in 1982, 1984, 1987, 1991 and 1999 where the negative intensity of vegetation dynamics were higher than -1. Conversely, the good ecological conditions were experienced in 1990, 2006, 2007, 2009, 2011 and 2015 this is because the positive intensity of vegetation dynamics was greater than 1. The intensity of vegetation changes are used to identify risk exposure. Ecological risk has been categorized based on the positive and negative intensity of vegetation changes, variance from the average NDVI (standard deviation) and rainfall erosivity. The areas of negative NDVI changes have more ecological exposure such as biodiversity loss, loss of productivity and biomass, soil erosion, land degradation, drought and vice versa. The standard deviation of spatially average NDVI for each pixel was also estimated. It has assumed that high variance i.e. high standard deviation of NDVI refer more ecological fragile and low variance refer low ecological fragile. The principle of NDVI indicates that annual average and maximum NDVI reflects more productivity and biomass i.e. good ecology. Similarly, the rate of greening represents acceleration of photosynthesis i.e. lower ecological risk in which rate of senescence represent deceleration of photosynthesis i.e. higher ecological risk (Reed et al., 1994). We considered that the positive intensity of NDVI changes and lower variance of NDVI represents lower ecological risk and negative intensity of NDVI changes and higher variance of NDVI represents higher ecological risk in Nepal. The spatially averaged Fournier and Modified Fournier Index also showed high ecological risk. However, the trends of erosivity index have decreased in Nepal during 1982-2015. The negative correlation between NDVI and rainfall erosivity indicated that increased NDVI were combating soil erosion and reduce ecological risk. Thus, the vegetation can play a significant role to decrease soil erosivity in Nepal.

## 5. Conclusion

This study provides a comprehensive synthesis of vegetation change and consequent ecological risk in Nepal. The intensity of vegetation changes, rainfall erosivity and human footprint pressure has been identified to connect with ecological risk in Nepal. Over the past decade, the human footprint pressures are increased in Nepal. Temporally, the intensity of vegetation changes was 0.065 yr$^{-1}$ during 1982-2015. The large positive and negative intensity of vegetation changes were identified in 2006 (2.20) and 1984 (-2.05).Spatially, the Trans-Himalayn regions showed ecological fragile with a higher ecological risk in 1984 and 1999 in entire Nepal. The human footprint pressure has shown increased in lowlands and mid hills in between 1993 and 2009.The negative correlation between NDVI and rainfall erosivity indicated that increased NDVI were combating soil erosion and reduces ecological risk. Thus, the vegetation can play a significant role to decrease soil erosivity in Nepal. Although, NDVI has increased, the HFP has also increased which bring the ecological challenges in Nepal. The results possess important implications for environmental planning and ecological management in Nepal.

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