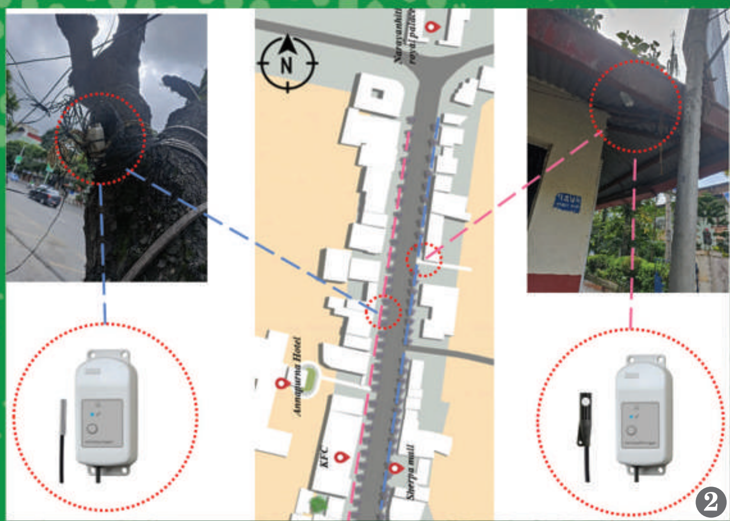
ISSN 2392-4705
URL: http://www.doenv.gov.np

JOURNAL OF ENVIRONMENT SCIENCES

(JoEnvSc)- Volume IX, 2023



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Editorial Board

Cover photo credit:
[1]Ananta K Karki : Birds resting on a tree located in the middle of Taudaha lake
[2]Arpana Shakya : Placement of Hobo data loggers on east facing sidewalk (left) and west facing sidewalk (right) respectively

Printing:
M.S. Offset Press, Jyatha, Kathmandu
Tel: 5904388, Email: msoffsetpress17@gmail.com

Date of Publication, July, 2023

Department of Environment (DoEnv)
Babarmahal, Forestry Complex, Kathmandu, Nepal
Tel: 01-5320837/01-5320497 Email- info@doenv.gov.np
ISSN:2392-4705
The issue can be retrieved from http://www.doenv.gov.np; https://www.nepjol.info/index.php/jes

Editorial

It is our pleasure to bring out the current issue of Journal of Environment Sciences. Twelve articles on different thematic areas and cross cutting issues have been included here. Environmental knowledge generated in environmental sectors by different researchers, GOs/NGOs/INGOs, academic institutions has been assembled in the form of Journal of Environment Sciences, Volume IX, 2023 as our yearly publication.

Journal of Environment Sciences aims to share environmental information and also promote to establish link among professionals, researchers, academicians and policy makers by providing them a common platform for further coordination and cooperation. We believe that the findings, outcomes, and suggestions obtained from these researches could serve for betterment of society and help to achieve environmental governance. We also believe that this journal will further help to pile up the scattered knowledge, information, techniques, technologies that have been generated in different paradigm of environment.

We want to assure here that the views expressed in the articles are those of authors and do not represent the official views of the Department of Environment. We acknowledge the valuable contribution from authors, researchers, reviewers and other personnel of the Department of Environment to continue this publication. With your cooperation, coordination and feedback, this Journal will remain uninterrupted.

Thank you !

Editorial Board

Journal of Environment Sciences (2023), **Volume IX**, 1-12
https://doi.org/10.3126/jes.v9i1.56417

Relation between Modis-based Aerosol Optical Depth and Particulate Matter in Kathmandu using Regression Model

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Abstract

Ambient fine Particulate Matters have been linked to various adverse health outcomes. Exposure to the high level of such particles would increase the risk of premature death, especially for people with weak immune systems, such as children and elder people. This research derives the relation between particulate matter and AOD from the Regression model on the seasonal (Pre-monsoon season (March 2020) and winter season (December 2019) basis of Kathmandu. Here two models have been developed one linear single-variable regression model and the other multivariable regression model. For the multivariable regression model, meteorological factors like Wind speed, Temperature, and Relative Humidity were adopted from the wunderground and the Planetary boundary layer height was simulated from WRF. Particulate matter ($PM_{2.5}$) was adopted from the US Embassy air quality station and MODIS Level 2 AOD having 10 km resolution was analyzed for regression modeling. The linear single variable and linear multivariable regression model were developed seasonally one from December 1st to December 31st, 2019 (winter season) and the other from March 1st to March 31st, 2020 (Pre-monsoon season) using Python. The seasonal correlation coefficient of these two models was obtained. In both seasons, the multivariable linear regression model showed a good correlation between AOD and Particulate Matter R^2 (Pre-monsoon) = 0.72657, R^2 (winter) = 0.4687) compared to the single variable regression model having R^2 (Pre-monsoon) = 0.45, R^2 (winter) = 0.133). In both these regression models using the evaluated regression coefficients, two seasonal equations were derived from which Particulate Matter can be estimated.

Keywords: *Multivariate Linear Regression, PM-AOD Relationship, Regression Model*

Introduction

Airborne particulate matter is a crucial pollutant affecting the environment, human health, and the climate (Ferrero et al., 2019). Particulate matter (PM), also defined as an atmospheric aerosol, is the general term used to define a complex mixture of solid and liquid particles. These particles vary in size and composition and remain suspended in the air for a long period (Arvani et al., 2015). Aerosol Optical Depth (AOD) is the extinction of radiation in the atmospheric column at a certain wavelength while atmospheric aerosols are a complex and multiphase system formed by gases, liquid, and solid particles suspended in the atmosphere, at a scale ranging from 10^{-3} to 10^2 microns (Chen et al., 2014; Stirnberg et al., 2018). PM including fine particles; $PM_{2.5}$ and coarse particles; PM_{10} (Particulate Matter with aerodynamic diameters less than 2.5 μm and 10 μm, respectively) have proven to have strong associations with adverse health effects (Chen et al., 2014; Ghotbi et al., 2016). Short and long-term exposure to PM causes an increase in mortality rates and morbidities such as a variety of cardiovascular diseases (Ghotbi et al., 2016).

PM_{10} is a major component of aerosol and is suspended in the air under a dispersed phase. Some particles are emitted directly from both human activities and natural events, while others are formed in the atmosphere through secondary chemical transformation (Tsai et al., 2011; Zhao et al., 2018). Inhaling fine particulate matter with an aerodynamic diameter of less than 2.5 μm is a serious health hazard. Health studies demonstrate that $PM_{2.5}$ has substantially greater toxicity than larger particles (Goldberg et al., 2019). Many recent epidemiological studies have shown that fine particles in populated regions are emitted primarily from anthropogenic and biogenic sources, and are associated with various health outcomes, including increased risk of cardiovascular and respiratory diseases, myocardial infarction, and significantly reduced heart rate variability. Aerosols influence the radiation balance of the earth-atmosphere system through direct and indirect radiation effects, which is one of the most important factors in weather and climate change (Chen et al., 2014). The increasing level of air pollutants has become a complex issue affecting public health and the environment in various cities in developing countries in recent years. When sunlight passes through the atmosphere, aerosol particles can scatter and absorb sunlight, reducing atmospheric visibility and solar radiation, thereby changing the temperature of the environment and affecting the growth rate of plants (Chen et al., 2014). Particulate Matter (PM) is nowadays one of the major air quality issues in South Asia. In many developed and developing nations, air pollution has caused an estimated side effect of approximately two million premature deaths worldwide per year. The unfriendly health hazards of Particulate Matter (PM) on the human respiratory and cardiovascular system are notable and incorporate asthma, emphysema, and lung cancer (Tian & Chen, 2010). Aerosols, both natural and anthropogenic, play an important role in air quality and the climate. Their presence leads to pollution events, and they have a direct and indirect role in modifying the Earth's radiation budget and cloud/precipitation properties, respectively and dominate the health effects of air pollution, as well as affecting the energy balance of the Earth-atmosphere system (Lennartson et al., 2018). Respiratory and cardiovascular diseases are provoked by particulate matter pollution.

Ground-level measurements just provide PM values within a small area that may not be a good representative for areas far from monitoring stations. The sparse spatial distribution of monitoring stations and lack of dense monitoring network due to economic and feasibility considerations could cause bias in epidemiological research. To overcome these issues, researchers have tried to find new approaches to attain accurate predictions in addition to ground PM measurements. In the recent decade, satellite remote sensing has been used as a powerful and cost-effective tool to estimate PM concentrations. AOD data, representing PM loading in the air, are non-dimensional parameters calculated by integrating the light extinction of aerosols from ground level up to the top of the atmosphere (Ghotbi et al., 2016). As the world continues to industrialize and increase in population (especially in developing countries), it is imperative to understand and mitigate the effects pollutants have on air quality, climate, and human health, on various spatial and temporal scales (Lennartson et al., 2018). It is necessary to monitor particulate matter pollution. Satellite remote sensing can step in to monitor regional air quality where ground monitors are not available or sparsely distributed and satellite-derived aerosol optical depth (AOD) is related to ground-level PM concentration and can be empirically converted into PM mass (You et al., 2015). In urbanized and populated Kathmandu city there are only five air quality measuring stations. Hence using satellite data estimation of the PM of every corner could be possible. Satellite data have the potential to complement air quality stations.

Materials and Methods

Study Area

The main study area of our research is the Kathmandu District. We have chosen the US

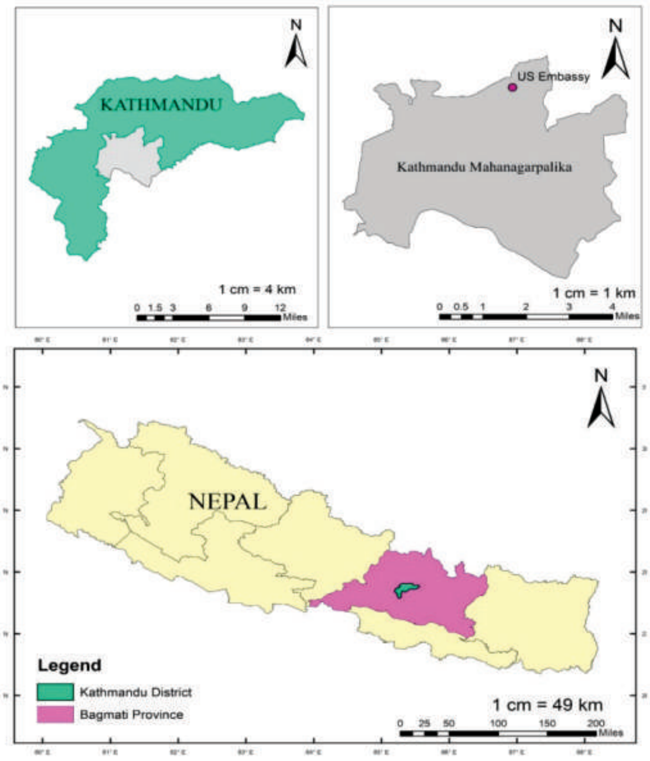

Figure 1: Study Area of the research

Embassy (latitude of 27.75805°N and longitude of 85.336383°E) situated in Maharajgunj, Kathmandu, Bagmati Province, Nepal as our primary station for the collection of essential data. It is around 1300 m above sea level spreading with an area of 433.6 km².

The study area of the project is shown in Figure 1 above. For our study period, we have chosen one month of the winter season i.e., December 2019 and March 2020 as the pre-monsoon season. To observe the variations in PM and AOD in two different seasons, we have adopted these months.

PM Data Extraction

The daily PM concentration data for December 2019 and March 2020 were collected from the air pollution monitoring network operated by the U.S. Department of State (DOS) and the U.S. Environmental Protection Agency (EPA). There are two air quality monitors (AQMs) installed by the US Embassy in Kathmandu (Embassy, 2020). We choose the US embassy at Maharajgunj station and the open data was downloaded from their website. The $PM_{2.5}$ data were downloaded from https://www.airnow.gov/international/us-embassies-and-consulates/. Initially, the raw data given to us were continuous (hourly) $PM_{2.5}$ mass concentration measurements and for the daily analysis, a 24-hour average of each mass concentration data was done through Python.

MODIS AOD Extraction

With a 2330 km wide swath, the MODIS sensor onboard Terra and Aqua satellites provide near-global coverage each day with AOD retrieval limited to cloud/snow/ice-free regions. MODIS sensor provides AOD, which is a unitless quantity and represents the integrated extinction of light by aerosols in the entire atmospheric column (Duncan et al., 2014). Here AOD 550 Dark Target Deep blue combined algorithm is used to extract the AOD from the HDF file using Python.

MODIS Level 2 aerosol data (MOD04, Collection 6) were obtained from the Atmosphere Archive and Distribution System (LAADS) at NASA's Goddard Space Flight Center (GSFC) (Gupta & Christopher, 2009). To fill out the missing data Level 2 collection 6 AOD at a spatial resolution 10 km from both Terra and Aqua satellite MOD04_10k and MYD04_10k of the winter season (December 2019) and pre-monsoon season (March 2020) respectively. HDF files were downloaded from https://ladsweb.modaps.eosdis.nasa.gov/. During extraction pyhdf and numpy libraries were used in Python.

Meteorological Data Extraction

Fine particular matter in the atmosphere is produced by gas-to-particle conversion mechanism as well as through various sources due to anthropogenic and natural activities. The meteorological conditions that strongly influence the concentration of PM particles include Temperature, Relative Humidity (RH), Wind speed, and Planetary Boundary Layer Height (PBLH). The variability in these meteorological conditions is primarily governed by large-scale high and low-pressure systems, diurnal heating and cooling, and topography (Gupta & Christopher, 2009). So, the open data of wind speed (*m/s*), temperature (°*C*), and relative humidity (%) were adopted from https://www.wunderground.com/ in December 2019 and March 2020.

But in the case of PBLH open-source data was not found so WRF simulated PBLH date of December 2019 and March 2020 was adopted. Mues et al., 2017 found that the mixing layer height changes on a diurnal basis (increasing during daytime and decreasing during nighttime and morning) at Kathmandu.

WRF Model

The Weather Research and Forecasting (WRF) Model is an atmospheric model designed, as its name indicates, for both research and numerical weather prediction (Powers et al., 2017). WRF produces atmospheric simulations. The process has two phases, with the first to configure the model domain(s), ingest the input data, and prepare the initial conditions, and the second to run the forecast model. The forecast model components operate within WRF's software framework, which handles I/O and parallel-computing communications. WRF is written primarily in Fortran, can be built with several compilers, and runs predominately on platforms with UNIX-like operating systems, from laptops to supercomputers (Powers et al., 2017).

Our WRF model used a Mercator projection with a grid resolution of 3 km. Here 66×58 grid was used with a vertical layer of 38 levels as shown in Table 1. We have done WRF only to simulate the value of PBLH in December 2019 and March 2020.

Table 1: WRF model setup

WRF Parameters	Domain
Grid resolution	3 km
Projection	Mercator
Grid	66×58
Vertical layers	38 levels

Regression Model

As the indicators of the changes in particle composition and vertical profile, the sensitive impact factors (e.g., relative humidity and temperature) can influence the association between satellite-retrieved AOD and ground-measured $PM_{2.5}$ significantly. To describe the numerical or quantitative relationship between these predictors and $PM_{2.5}$ effectively at the regional scale, two statistical models were developed: a general linear regression model and a multivariate regression model (Song et al., 2014).

Estimation of particulate matter is done by using two different models:

Single Linear Regression Modeling

We applied the daily-calibration model approach, allowing the AOD–$PM_{2.5}$ relationship to vary daily assuming that on any given day the relationship does not vary spatially within each of the study domains (Sorek-Hamer et al., 2015). First, we developed a simple linear equation where MODIS AOD is used to estimate surface-level $PM_{2.5}$ mass concentration.

$$[PM_x] = \alpha_0 + \alpha_{AOD}[AOD] \quad \text{............................} \ (1)$$

Where x represents $PM_{2.5}$ and PM_{10}, $\alpha_{0,}$ and α_{AOD} are the intercept and slope of single-variable linear models respectively.

Regression coefficients are calculated with the help of Python script using Python libraries like Pandas, NumPy, sklearn, linear_model, and then using the calculated regression coefficients from and AOD, particulate matters are estimated.

Multivariable Regression Modeling

Mirzaei et al., 2020 have shown that the spatial relationship between AOD and $PM_{2.5}$ varies daily and that is due to time-varying variables such as temperature, humidity, or $PM_{2.5}$ optical properties. Then, meteorological parameters are added to the analysis to form multiple linear regression equations to estimate $PM_{2.5}$ and PM_{10} mass concentration. Regression coefficients were calculated from Python code for equations (2) and (3) and then these equations are used to calculate $PM_{2.5}$ and PM_{10} mass concentration using input parameters from satellite and meteorological fields. We have used daily measurements of $PM_{2.5}$, matched with the MODIS Terra AOD closest to the satellite overpass time (Christopher & Gupta, 2010). The meteorological parameters are also obtained for each AOD-$PM_{2.5}$ data point by using the same spatial and temporal matching approach. Similar equations of Ghotbi et al., 2016 are adopted as multiple linear regression modelling.

$$[PM_{10}] = \alpha_0 + \alpha_t(T) + \alpha_w(W) + \alpha_{Dir}(Dir) - \alpha_{RH}(RH) + \alpha_{AOD}(AOD) - \alpha_{PBLH}(PBLH) \ (2)$$

$$[PM_{2.5}] = \alpha_{21} + \beta_{21}(AOD) + \beta_{22}(T) + \beta_{23}(RH) + B_{24}(W) + \beta_{25}(PBLH) \ (3)$$

where, *T, W, Dir, RH, AOD, PBLH* are the temperature, wind speed, wind direction, relative humidity, aerosol optical depth, and planetary boundary layer height parameters, respectively. α_0 is the intercept of the general equation and α_{is} are the regression coefficients of the independent variables and $[PM_{10}]$ is the ground concentration measured. And, $\alpha_{21, \ldots mn,}$ and $\beta_{21, \ldots, mn}$ represent the regression coefficients associated with corresponding variables. *AOD* is Aerosol optical depth (unitless), $PM_{2.5}$ is particulate matter concentration (μg/m^3), *T* is the temperature (°C), *W* is wind-speed (m/s), *PBLH* is plate boundary layer height (m) and *RH* is relative humidity (%).

Results and Discussion

Particulate matters were estimated through the Regression model. Both these models are validated with the nearest air quality monitoring station. The time series plot of $PM_{2.5}$ of the US Embassy Monitoring Station and MODIS AOD of the winter season and monsoon season of our study period is shown in Figures 2 and Figure 3. In these two figures, we can see the AOD missing which was due to the presence of the cloud. To reduce the missing data of AOD, we took an average of both aqua and terra satellite AOD. Even after doing so, we were not able to get the AOD for the whole month but we were able to fulfill the AOD for a few missing days.

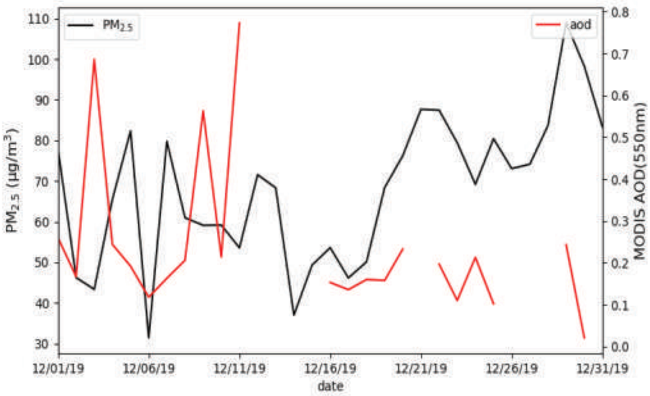

Figure 2: Observed Winter AOD-$PM_{2.5}$ Time series

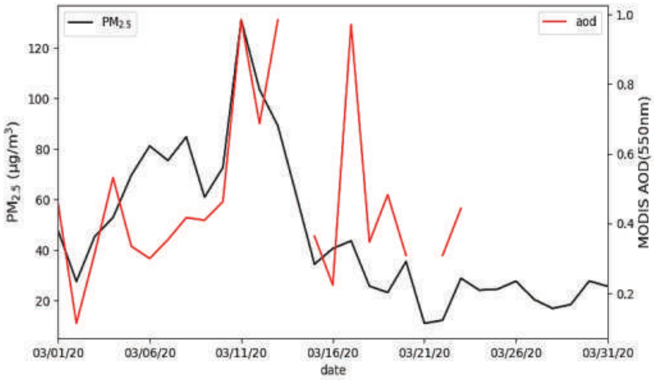

Figure 3: Observed Pre-monsoon AOD-$PM_{2.5}$ Time Series

Linear Single Variable Regression Model

Simple Linear regression analysis was performed between AOD and $PM_{2.5}$ in both seasons and the coefficient of determination (R^2) and the correlation coefficient was determined. Figure 4 and Figure 5 show the regression model graph of our specified winter and pre-monsoon seasons month

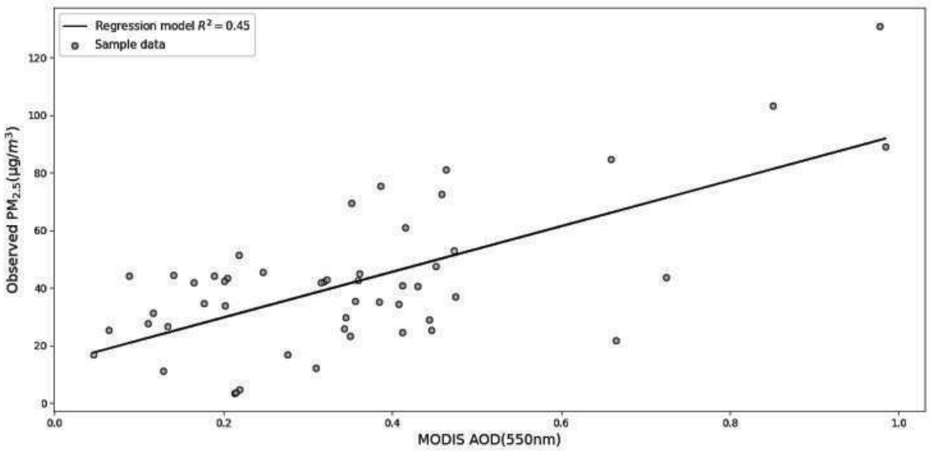

Figure 4: Pre-Monsoon Linear Regression Model

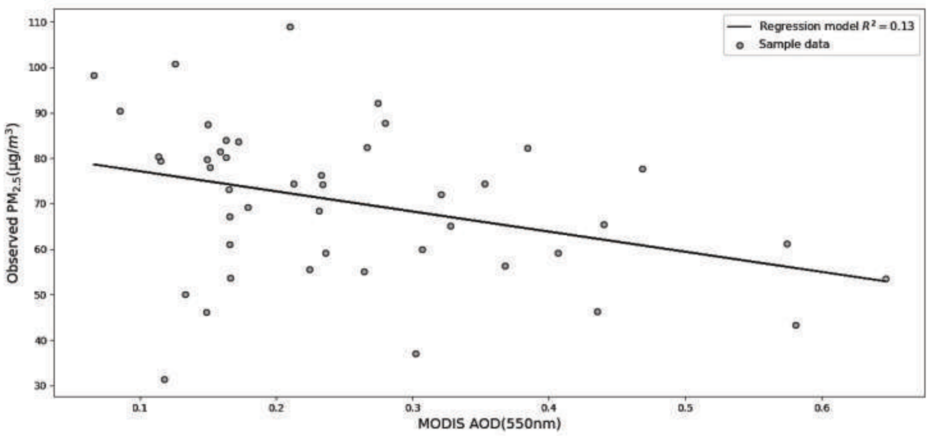

Figure 5: Winter Linear Regression Model

respectively. Here in this figure, US Embassy $PM_{2.5}$ was taken as the primary data.

The result of a single linear regression model is shown in Table 2. Pre-monsoon season (March and April) has good relation coefficients compared to that of the winter season (December and January) due to more available data on AOD in the pre-monsoon season. 27 data were used in evaluating the premonsoon season and there were more MODIS AOD pixels of the premonsoon season during MODIS AOD extraction. While 24 data sets were used in determining winter season R^2 and during the extraction of MODIS AOD in the winter season, it had fewer pixels in comparison with the premonsoon season. So, due to this factor premonsoon season had a good correlation coefficient compared with the winter season

Table 2: Results of Single Linear Regression Model

Parameters	R^2	α_0	α_{AOD}
Pre-monsoon Season (March 2020)	0.45	19.7976	73.5447
Winter Season (December 2019)	0.13	74.5447	-30.121

Now the equation to estimate the $PM_{2.5}$ directly from AOD for the pre-monsoon season is shown below in equation (4)

$$[PM_{2.5}] = 19.7976 + 73.5447[AOD] \quad (4)$$

Similarly, the equation to estimate the $PM_{2.5}$ directly from AOD for the winter season is shown below in equation (5)

$$[PM_{2.5}] = 74.5447 - 30.121[AOD] \quad (5)$$

From Table 2 we can see the results of a single-variable regression model. Here regression coefficients of AOD are positive in the premonsoon season while negative in the winter season. This is due to the presence of clear pixels of aqua and terra satellites in the premonsoon season. During the extraction of AOD in the premonsoon season there were more pixels with less standard deviation and the winter season had fewer pixels centered at our desired location having more standard deviation. So, this could be one cause for less correlation coefficient in the winter season compared to the premonsoon season.

Linear Multi-Variable Regression Model

In this model, other four variables like temperature, wind speed, relative humidity, and plate boundary layer height along with the AOD are taken from open source and $PM_{2.5}$ is referenced from US Embassy Maharajgunj Station. Using equation (2) in Python using the least square method, regression coefficients and correlation coefficients were obtained. The values of the regression coefficients of respective variables and the correlation coefficient are shown in Table 3. The Planetary Boundary layer height of March and December was only modelled so these two months were selected.

Now the equation to estimate $PM_{2.5}$ for the Pre-monsoon season will be shown in equation (6):

$$[PM_{2.5}] = 79.4116 + 83.0779(AOD) - 0.1932(T) - 1.6006(RH) - 1.6670(W) + 0.0907(PBLH) \quad (6)$$

And the equation to estimate $PM_{2.5}$ for the winter season is shown in equation (7) below:

$$[PM_{2.5}] = 267.674 + 6.6281(AOD) - 4.9866(T) - 1.3103(RH) - 12.0314(W) - 0.1442(PBLH) \quad (7)$$

From Table 3, looking at the values of correlation coefficients for March and December, it is seen that the correlation coefficient of March 2020 is greater than that of December 2019. we can see the positive regression coefficient in AOD in both seasons which means that AOD and PM are proportional to each other (increase in PM concentration, increase in AOD). Comparing this coefficient of AOD pre-monsoon season is dominant compared to the winter season. It is due to the good and predictable value of

Table 3: $PM_{2.5}$ Regression Coefficients for the Linear Multivariable Regression Model

Month	α_0	α_{Temp}	α_{RH}	α_{Wind}	α_{AOD}	α_{PBLH}	R^2	Adj R^2
March	79.4116	-0.1932	-1.6006	-1.6670	83.0779	0.0907	0.727	0.646
December	267.674	-4.9866	-1.3103	-12.0314	6.6281	-0.1442	0.469	0.358

AOD in the pre-monsoon season due to clear days compared to that of the winter season (more cloudy days). Wind can play some role in the dilution of PM concentration; it prevents the stable condition of PM concentration area and could flush away and dilute the particulate matter concentration in the wider region with height and area. In some cases, wind can carry suspended mineral and dust particles to the measuring station which in turn could increase the Particulate matter concentration in that station. In our research, the first case was the dominant regression coefficient had negative values (increase in wind value, decrease in PM concentration) in both months.

The generation of secondary particles through photo-chemical phenomena could be the effect of an increase in temperature which later on increases the particulate matter concentration. This is the case for a higher temperature. But in colder temperatures also Particulate matter concentration increases due to the temperature inversion effect. Here in our study in both seasons, we can observe the negative value of the regression coefficient of temperature. Comparing the values of these coefficients we can see both are negative and relatively there is less difference in the average temperature of the winter season (December 2019) and pre-monsoon season (March 2020).

Under high relative humidity conditions (RH $\geq$ 80%) hygroscopic particles (e.g., ammonium nitrate and ammonium sulfate) can grow to 2–10 times their normal size, increasing the light extinction efficiencies of the particle (Ghotbi et al., 2016). Hence, the same AOD value at high relative humidity corresponds to lower particle dry mass compared to the obtained value at low humidity (Liu et al., 1999). In our study, both season regression coefficients of Relative Humidity (RH) are negative which indicates the reverse effect of RH on AOD. Comparatively winter season has more RH compared with the pre-monsoon season. Here correlation coefficient of RH is negative but the regression coefficient of the winter season is more than that of the pre-monsoon season.

Planetary Boundary Layer Height (PBLH) also plays an important role in this analysis. Here PBLH in the pre-monsoon season is more compared to that of the winter season so the regression coefficient of PBLH is positive in the pre-monsoon season and that of the winter season is negative.

We have found that PBLH has a positive coefficient with PM concentrations in the pre-monsoon season and a negative coefficient with PM concentrations in the winter season. The reason for this difference is that the atmospheric conditions during the pre-monsoon and winter seasons are different, which can affect how PBLH influences PM concentrations. In the pre-monsoon season, the higher PBLH values may allow for greater vertical mixing of pollutants and greater dispersion of PM, leading to a positive correlation between PBLH and PM concentrations. In contrast, during the winter season, lower PBLH values may lead to the accumulation of pollutants near the surface, resulting in a negative correlation between PBLH and PM concentrations.

Model Validation

Two different concentrations of estimated $PM_{2.5}$ were obtained from the single variable regression model and multivariable regression model respectively. The estimated $PM_{2.5}$ concentrations of these two models were calculated for two seasons one winter season (December) and the other pre-monsoon season (March). And these estimated $PM_{2.5}$ concentrations were validated by taking reference to the station of Phora Durbar, Kantipath, Kathmandu, Nepal. Both the estimated and station $PM_{2.5}$ data were daily 24-hour average data. Statistical tools like correlation coefficient, Normalized root mean square error, and mean bias were evaluated from Python to validate the model.

$PM_{2.5}$ was estimated using a single variable regression model equation developed in equations

Table 4: Statistical Analysis of Single Variable Regression Model

	Mean Bias ($\mu g/m^3$)	Correlation Coefficient	Normalized Root mean square
$PM_{2.5}$ December	-8.94	0.1388	0.234
$PM_{2.5}$ March	2.828	0.3223	0.47

(4) and (5) for pre-monsoon and winter seasons respectively. Table 4 shows the statistical analysis of the single-variable regression model. Here this model underestimated $PM_{2.5}$ for winter while the estimation for pre-monsoon is good. For December, the model showed a lower correlation in both seasons. Comparatively, the correlation coefficient of the pre-monsoon season is higher. From the values of the Normalized Root Mean Square difference, we can see the difference between the observed PM and estimated PM. The scatter plot of observed $PM_{2.5}$ and estimated $PM_{2.5}$ for winter and pre-monsoon season is shown in Figures 6 and 7 respectively.

Here, Figure 8 and Figure 9 show the relationship between observed $PM_{2.5}$ and single variable regression model estimated $PM_{2.5}$ in winter and pre-monsoon season respectively. Here we can see the gaps in both figures which is the result of missing AOD in our model equations due to the cloudy days.

Similarly, as a single variable regression model, $PM_{2.5}$ was estimated using a multivariable regression model equation developed in equations (6) and (7) for pre-monsoon and winter seasons respectively. Table 5 shows the statistical analysis of the multi-variable regression model.

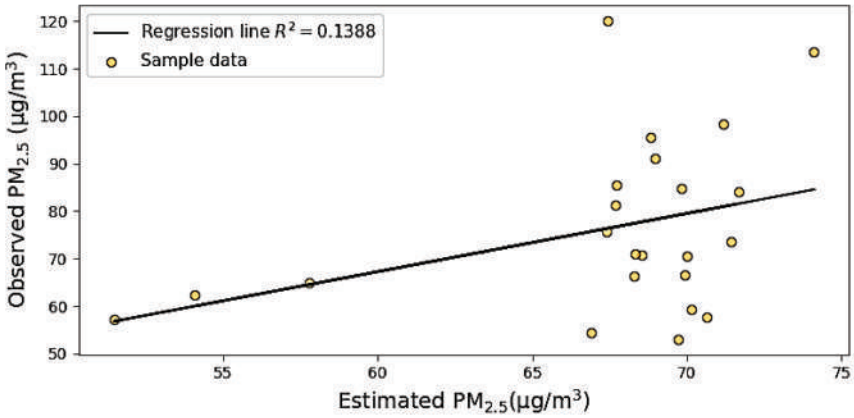

Figure 6: Scatter Plot of Phora Observed $PM_{2.5}$ and Single variable regression model Estimated $PM_{2.5}$ of Winter (December 2019)

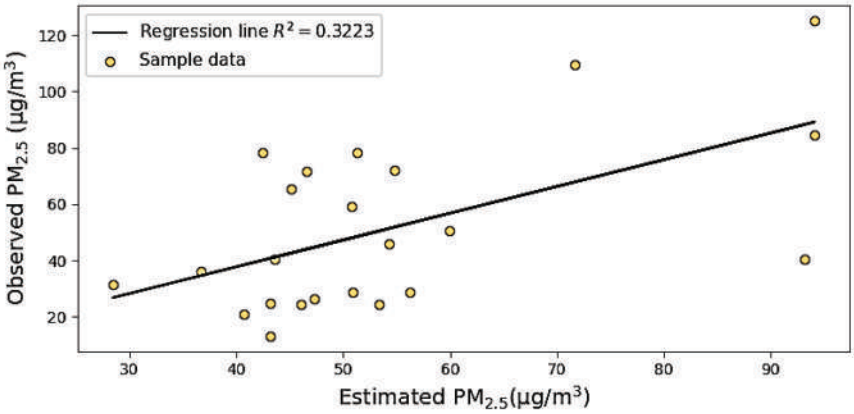

Figure 7: Scatter Plot of Phora Observed $PM_{2.5}$ and Single variable regression model Estimated $PM_{2.5}$ of Pre-monsoon (March 2020)

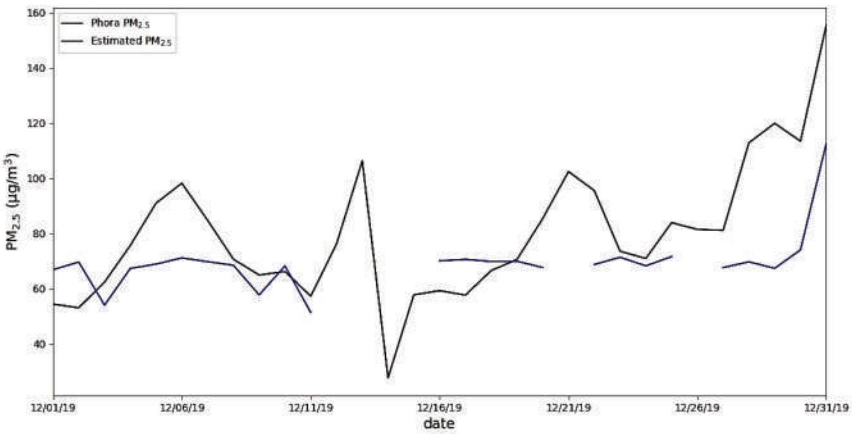

Figure 8: Comparison of Observed $PM_{2.5}$ and Single variable regression model Estimated $PM_{2.5}$ in Winter (December 2019)

Table 5: Statistical Analysis of Multi-Variable Regression Model

	Mean Bias (µg/m^3)	Correlation Coefficient	Normalized Root Mean square
$PM_{2.5}$ December	0.2307	0.4687	0.194
$PM_{2.5}$ March	-0.142	0.7266	0.292

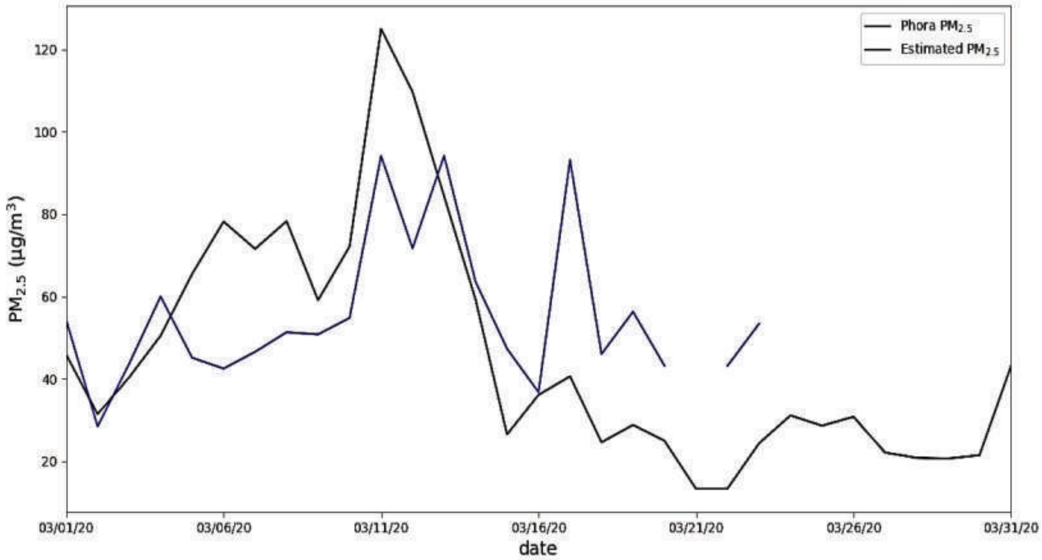

Figure 9: Comparison of Observed $PM_{2.5}$ and Single variable regression model Estimated $PM_{2.5}$ in Pre-monsoon (March 2020)

Here this model shows a good estimation of PM in both seasons. Here meteorological data are adopted from the station of New Road and PBLH from the WRF model. For December, the model showed a good correlation in the pre-monsoon season and a relatively lower correlation in the winter season. From the values of the Normalized Root Mean Square difference, we can see the difference between the observed PM and estimated PM. The scatter plot of observed $PM_{2.5}$ and estimated $PM_{2.5}$ for winter and pre-monsoon season is shown in Figures 10 and 11 respectively. Comparing the results with the single variable regression model has better results.

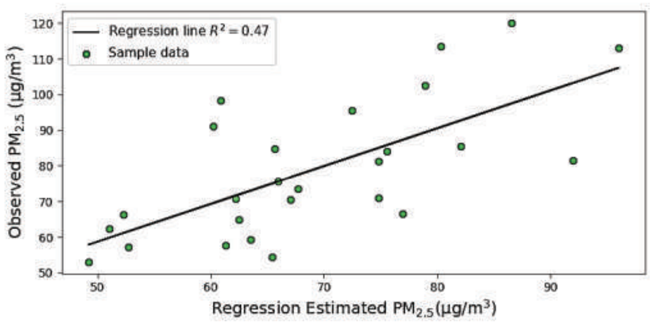

Figure 11: Scatter plot of Observed $PM_{2.5}$ and multi-variable regression model Estimated $PM_{2.5}$ of Winter (December 2019)

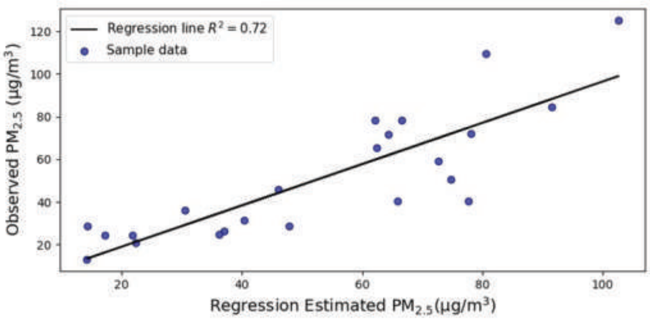

Figure 10: Scatter plot of Observed $PM_{2.5}$ and multi-variable regression model Estimated $PM_{2.5}$ of Premonsoon (March 2020)

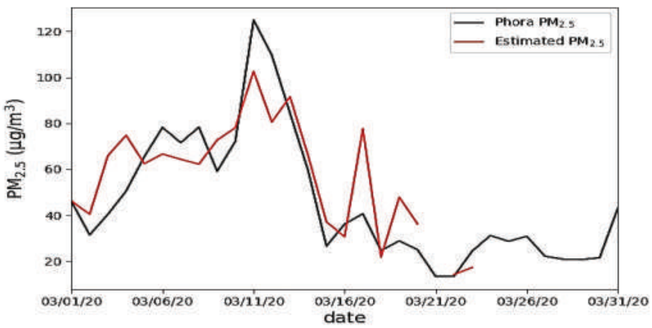

Figure 12: Comparison of Observed $PM_{2.5}$ and multi-variable regression model Estimated $PM_{2.5}$ in Premonsoon (March 2020)

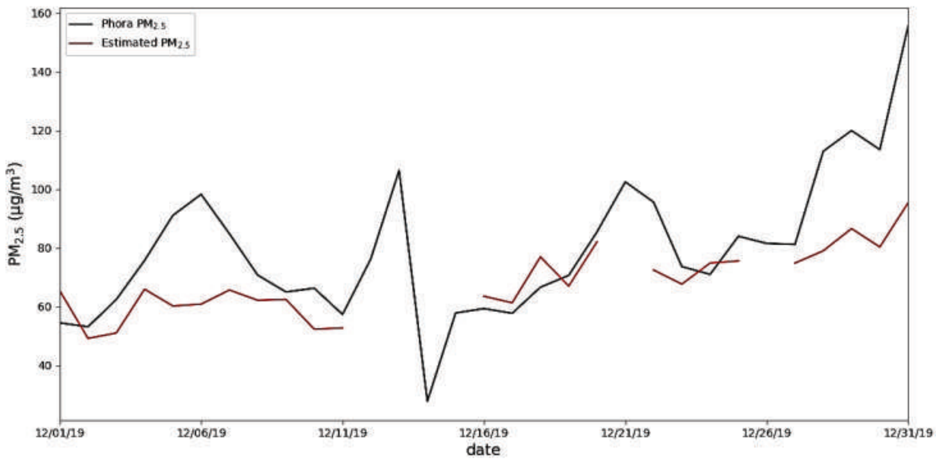

Figure 13: Comparison of Observed $PM_{2.5}$ and multi-variable regression model Estimated $PM_{2.5}$ in Winter (December 2019)

Similarly, Figure 12 and Figure 13 show the relationship between observed $PM_{2.5}$ and single variable regression model estimated $PM_{2.5}$ in winter and pre-monsoon season respectively. Here we can see the gaps in both figures which is the result of missing AOD in our model equations due to the cloudy days. To minimize the error caused by missing AOD during statistical analysis, masking is used in Python which helps to handle the missing or unwanted data.

In summary, the multivariable regression model gives better results in estimating particulate matter than the single-variable regression model. Here in the winter season correlation coefficients are quite low compared to the pre-monsoon season, it is due to the higher quality of pixels present during the extraction of AOD in the pre-monsoon season due to the availability of more clear days. During the estimation of PM, other meteorological variables also play an important role along with the AOD.

Conclusion

The present study estimates the ground-level particulate matter concentration using satellite-based MODIS AOD and derives the relation between particulate matter and AOD. AOD has been used as an input to a single variable regression model and AOD along with other meteorological factors (RH, wind speed, temperature, and PBLH) are used as an input to multivariable regression model developing model equations. MODIS Aqua and Terra retrieved AOD measurements and were employed to derive the correlation coefficient between $PM_{2.5}$ concentrations and AOD during December 2019 and March 2020. The AOD retrievals demonstrate geographical and seasonal variations in their relation to $PM_{2.5}$. Here two regression models were employed to estimate the particulate matter in two seasons (winter and pre-monsoon). A good correlation coefficient was observed in the pre-monsoon season using a multivariate Regression model which generated a higher coefficient of determination ($R^2 = 0.47$ in the winter season and $R^2 = 0.73$ in the pre-monsoon season). While the single variable regression model had a lower coefficient of determination ($R^2 = 0.13$ in the winter season and $R^2 = 0.45$ in the pre-monsoon season). So, the multivariable regression model can derive good relation between particulate matter and AOD. Comparing the seasonal results of each regression model pre-monsoon season has good results compared to the winter season. After comparing with ground station $PM_{2.5}$ concentrations, it can be concluded that $PM_{2.5}$ concentrations predicted by the multivariable regression model nearly followed a similar trend as $PM_{2.5}$ concentrations measured by ground stations. The multivariable Regression model generated the best performance among the two models. So, multivariable regression models can be valuable to conduct research related to air pollution and public health perspectives soon to estimate PM from satellite AOD.

Acknowledgement

Firstly, we would like to express our sincere gratitude to the Department of Environmental Science and Engineering, Kathmandu University for his overwhelming enthusiasm, continuous support, and supervision throughout our research. His ideas, knowledge, and efforts are heavily embedded in this research project. Above all, our deepest gratitude to our parents and family members for their unremitting support and encouragement throughout life.

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Journal of Environment Sciences (2023), **Volume IX**, 13-25
https://doi.org/10.3126/jes.v9i1.56474

Sidewalk Landscape Structure to enhance Pedestrian Thermal Comfort in Kathmandu Metropolitan City

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Abstract

The thermal comfort of pedestrians in the outdoor spaces of urban areas has deteriorated due to the urban densification. The street being a major outdoor space that can promote physical activity, and especially with the emerging concept of walkable cities, thermal comfort in streets should be given utmost importance. Thermal comfort for pedestrians is the absence of any sense of discomfort when interacting with the outdoor thermal environment. This paper aims to evaluate the effectiveness of various landscape measures (trees and pavements) to enhance pedestrian thermal comfort on sidewalks. The study has adopted the quantitative approach and used the simulation and questionnaire survey as methodological tools to meet its objectives. The study was conducted on both sidewalks of Durbarmarg, one of the dense and busy streets of Kathmandu. The microclimatic modeling software ENVI-met 5.03 lite was used for the simulation. The results of the simulation showed that increasing the leaf area density (LAD), tree canopy size and height can reduce the air temperature by 0.2°C and Mean radiant temperature by 4.86°C. Among the various pavement materials in various scenarios for the simulation, the light concrete pavement showed the highest decrease in terms of the air temperature (0.579°C) however the mean radiant temperature was highest (7.22°C) for the same material. Hence, high reflective surfaces reduce the surface /air temperature but it increases the mean radiant temperature and hence they might not be appropriate for the thermal comfort of pedestrians. The paving materials which showed a decrease in both air temperature and mean radiant temperature were porous concrete, flagstone, and brick pavers. The study concludes that proper selection of pavement materials and high leaf area density of trees can enhance the thermal comfort for pedestrians on the sidewalks of Kathmandu.

Keywords: *ENVI-met, Mean Radiant Temperature, Pedestrians, Thermal Sensation*

Introduction

Urban morphology is changing which has led to the phenomenon called Urban Heat Island Effect which elevates city temperatures, degrades urban comfort conditions, and increases cooling energy demand (Faragallah & Ragheb, 2022). In their study of the urban heat island in Kathmandu, Mishra et al. (2019) found an average temperature difference of 5 °C between forested and urban areas in the Kathmandu Valley. The authors also found an annual increase of 0 to 2 °C over the last 18 years. The outdoor environment has major essence in cities because it serves a variety of activities for pedestrians. The comfort level of outdoor spaces has a direct impact on the number of people present outside (Chen & Ng, 2012; Coccolo, et al., 2016; Hass-Klau, 1993; Hakim, et al., 1998). Under the umbrella concept of pedestrian comfort is pedestrian thermal comfort. The rough definition of thermal comfort for pedestrians is the pleasant feeling they have when interacting with the thermal environment surrounding them (Kasim, Shahidan, & Yusof, 2018). ASHRAE (1989) has defined human thermal comfort as a condition of mind that expresses satisfaction with the thermal environment, which is determined by various environmental and individual variables.

Outdoor thermal comfort is mainly related to thermo-physiology, i.e. physiology and heat balance of the human body (Hoppe, 2002) that is directly affected by meteorological conditions like wind velocity and direction, air temperature, and humidity. There are various parameters for outdoor thermal comfort. They can be categorized into subjective and objective. The subjective parameter consists of behavioral and psychological aspects whereas the objective parameter consists of air temperature, mean radiant temperature, metabolic heat, wind, humidity, and clothing insulation. Mean radiant temperature is an important parameter in assessing human comfort outdoors. While air temperature is a measure of cooling (or heating) by contact with air, mean radiant temperature is a measure of cooling (or heating) by exchange of radiant heat with all objects in the area (Sensible House, 2010).

Thermal comfort is particularly important in streets because they have a high potential to promote physical activity like walking and other outdoor activities (Kim, Lee, & Kim, 2018). Sidewalks run parallel to the streets and provide pedestrians mobility and access to buildings, parks, and so on. There are 3 zones on the sidewalks: the clear zone, the service zone, and the transition zone (Santos, Caccia, Samios, & Ferreira, 2019). Green spaces of properly designed landscapes are one of the most important bioclimatic design elements for outdoor thermal comfort (Georgi & Dimitriou, 2010). Trees provide direct shade by intercepting sunlight through their canopy (Sun et al., 2021). The different characteristics of vegetation like the foliage shape and dimensions, the height of the trunk, and leaf area density (LAD) have an impact on outdoor thermal comfort (Perini, Chokhachian, & Auer, 2018). LAD determines the airflow through the foliage (low or high). LAD affects plants' evapotranspiration, which results in reduced air temperatures and increased air humidity.

Paving materials also have a strong effect on the microclimate of the street and represent one of the major contributors to the urban heat island effect (Faragallah & Ragheb, 2022). Streets are traditionally constructed with an impermeable layer, it creates its microclimate due to the solar radiation reflected/absorbed by street surfaces, orientation, and geometry (Shishegar, 2013). The microclimate of streets affects the comfort of pedestrians walking. Walking is the most natural way of transportation in most of the cities including Kathmandu. Walking for short distances could be one of the promising strategies to reduce Vehicle miles traveled (VMT), transport-related energy consumption, and associated environmental impacts (Ewing, et al., 2020). Walkability has been cited by many urban planners as the factor that makes a city sustainable. One of the ways to promote walkability is to improve outdoor thermal comfort for pedestrians.

The current urbanization and motorization in Kathmandu do not provide a safe and pleasant environment for walking. Most streets do not even have sidewalks, and those that do exist are either poorly maintained or occupied by parked vehicles and street vendors (Regmi, 2019). Many street improvement projects carried out under the Municipal Infrastructure Improvement Project (MIIP), Kathmandu Sustainable Urban Transport Project (KSUTP) have focused on vehicular movement and drivers' convenience rather than pedestrian comfort, convenience, and safety (Shrestha, 2011). Sidewalks were widened and built considering the durability of paving materials, but without considering the thermal impact on the microclimate of the street. Most of the trees along the streets are planted indiscriminately and only for beautification, without considering their impact on the microclimate of the street. No significant studies have been done to improve the thermal environment of the sidewalks of Kathmandu. Therefore, the study aims to investigate the existing structure of the sidewalk landscape (mainly trees and pavements) considering the microclimate of the selected street section in Kathmandu and to propose the necessary landscape interventions (trees and pavements) that will improve the thermal environment and the thermal comfort of the pedestrians.

Materials and Methods

Study Area

The selected case study area, Durbarmarg (informally known as Kings' Way), is located in the metropolis of Kathmandu (27.712611N, 85.317972E). and is a very dense and lively street in Kathmandu. It leads to the royal palace of Narayanhiti. Durbar Marg was built in 1961 by the then Crown Prince Birendra Bir Bikram Shah Dev.

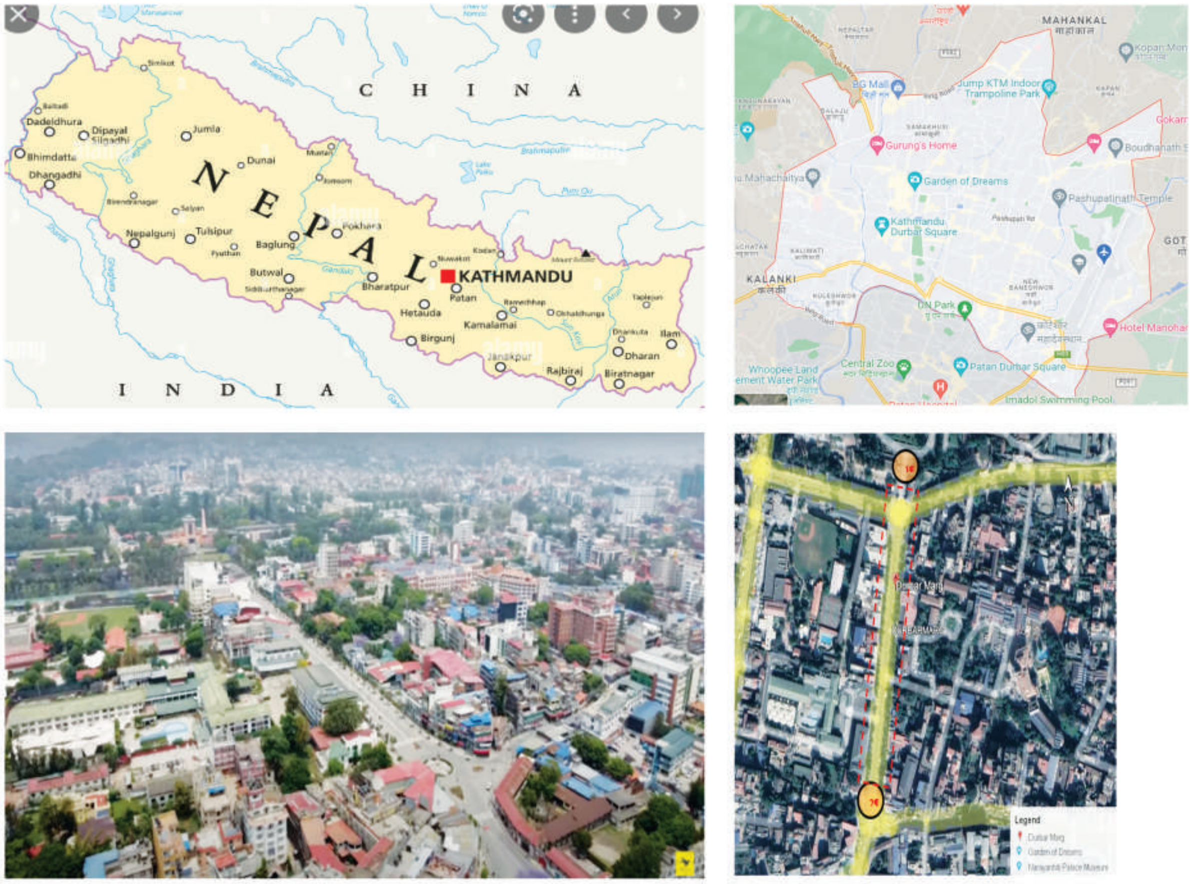

Figure 1: Site map Source: Google maps and Saurav Agrawal (Kathmandu Kingsway-A Drone film 4K) for the bird view picture (bottom left)

Figure 2 shows the blow-up plan of Durbarmarg: the selected street section. The stretch is about 300 m long. The pedestrian flows on the street are immense. For simplicity, the sidewalks are referred to as east-facing sidewalk and west-facing sidewalk. The east-facing sidewalk has street furniture while the west-facing sidewalk has no street furniture.

The number of pedestrians passing the street at a certain point was recorded at different times of the day and on both sidewalks. It was found that pedestrian flow was greater on east-facing Sidewalk than west facing sidewalk. On June 27 at 4:30 p.m., approximately 36 people passed in one minute. The width of the sidewalks, trees height and canopy

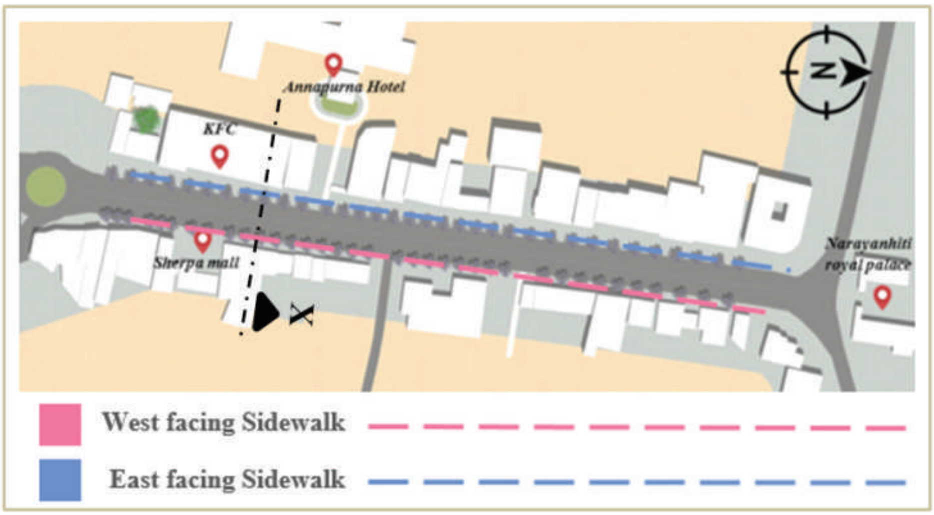

Figure 2: Blow up plan of the Selected Street Section: Durbarmarg

size were also measured. The planted street tree is Jacaranda Mimosifolia and the width of the sidewalks varies within the building frontage and the different sections of the sidewalks. Most of the pavement material is concrete.

The microclimate of the selected street section was also studied. The climatic parameters air temperature, relative humidity was measured with KOBO RH/T data logger (MX2302 and MX2304) for 12 days starting from June 29, 2022 to July 10, 2022 on both sides of sidewalks. The device was calibrated with device on DHM (Department of Hydrology and Meteorology) (See Appendix B) and it was placed on site as shown in the figure 3.

Questionnaire Survey

The thermal comfort survey was done to gain a perception of the thermal environment on both sidewalks of the selected street section for almost 7 days in favorable climatic conditions. A random sample of 36 pedestrians was taken for the survey. The number of people surveyed on east-facing sidewalk and west-facing sidewalk were 21(58%) and 15 (42%) respectively. The main target for this survey were pedestrians however people who spent their most time outdoors in the street like the vendors and guards were also surveyed. The respondents were 83% pedestrians, 11% security guards and 6% vendors.

The questionnaire was divided into 5 parts where first part was to be filled by the surveyor by observation. The rest of the parts consisted of demogrpahic details, purpose of visit, thermal sensation and preference for microclimate (See Appendix A). Kobo Toolbox was used for the analysis of the survey data.

Simulation with ENVI-met software

ENVI-met 5.03 was used to simulate the outdoor comfort of the sidewalks. Envi-met was chosen for the simulation because it has several advantages. The modeling system simulates the dynamics of microclimate within a daily cycle. Different vegetation forms can be generated in the model. ENVI-met considers the physiological processes of evapotranspiration and photosynthesis rather

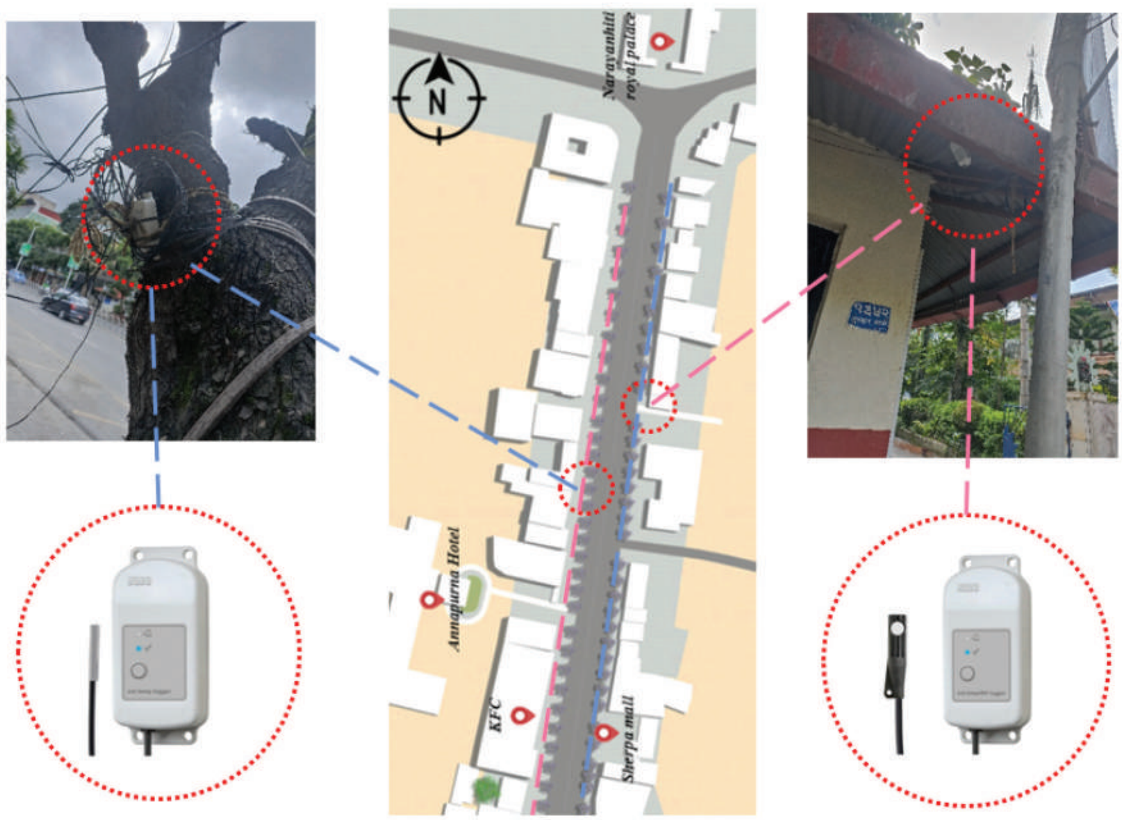

Figure 3: Placement of Hobo data loggers on East facing Sidewalk (left) and West facing Sidewalk (right) respectively.

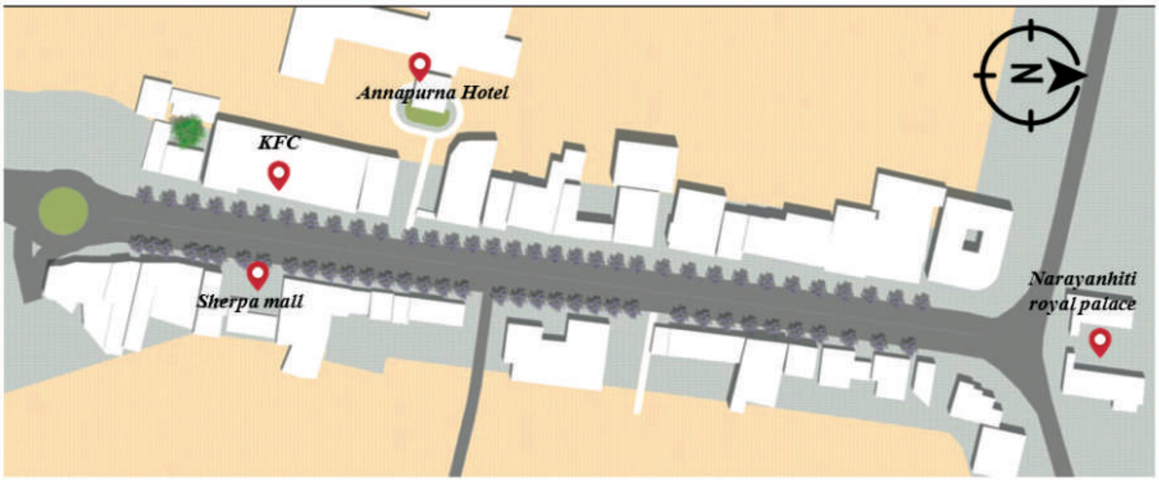

Figure 4: Part of the street section taken for simulation

than vegetation as a porous barrier to wind and solar radiation. A limited number of inputs are required to run the model with a large number of outputs. ENVI-met can calculate Tmrt (mean radiant temperature), the most important parameter in thermal comfort calculations.

A stretch of 150m (See fig.5) was selected for the simulation since the lite/free version of software has limited domain size of 50 X50 X30. The model size in domain is 38 X 50 X 15 with dx 3 m dy 3m and dy 3m. The north is tilted 8 degree towards left with the grid north. The model location is set as 27.712611N, 85.317972E.

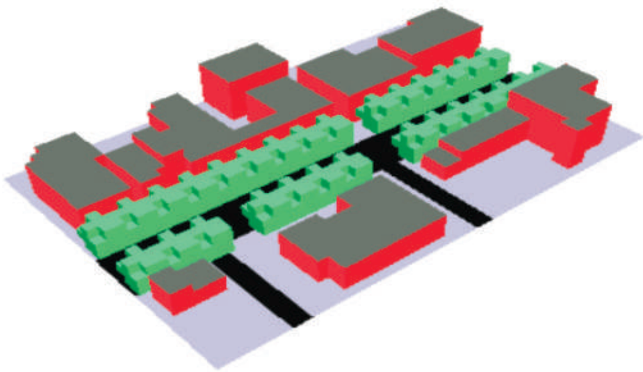

Figure 5: 3D model of Base Case Scenario

Simulation day meteorological Conditions

The simulation day was chosen as 7/7/2022 (one of the hottest day during the 12 days of measurement). The simulation was done for 12 hours starting from 7 am in the morning for the same day. For the simulation, simple forcing of the data has been done using hourly temperature and relative humidity data. The maximum temperature for the day was 33°C and minimum was 22.14°C at 1 pm and 3 am respectively. The input data for the simulation are shown in figure 7 and Table 1.

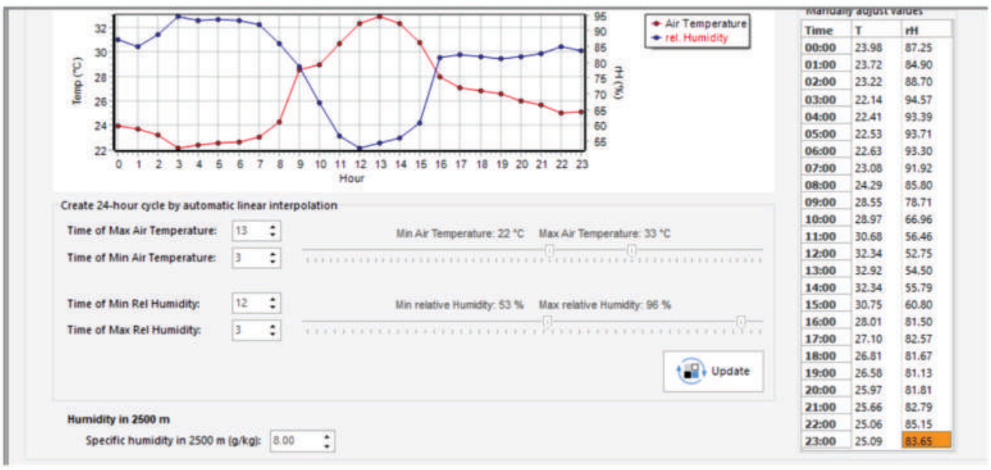

Figure 6: Meteorological conditions for simple forcing

Table 1: Input data in Envi-met for simple forcing

Time of max temp	Time of min. temperature	Time of max Relative Humidity	Time of min Relative humidity	Wind Speed	Wind direction
13:00	3:00	3:00	12:00	2.34 m/s	270

The wind speed data for the particular day was taken from department of hydrology and Meteorology as there was no device available to measure the wind at the selected site. The average wind speed for the day was 2.34 m/s.

Validation of ENVI-met results

For the validation of the ENVI-met results, the hourly temperature and relative humidity from the time 8 am to 7 pm was compared with the results obtained for the base case scenario from the ENVI-met 5.03 results as shown in the figure 8.

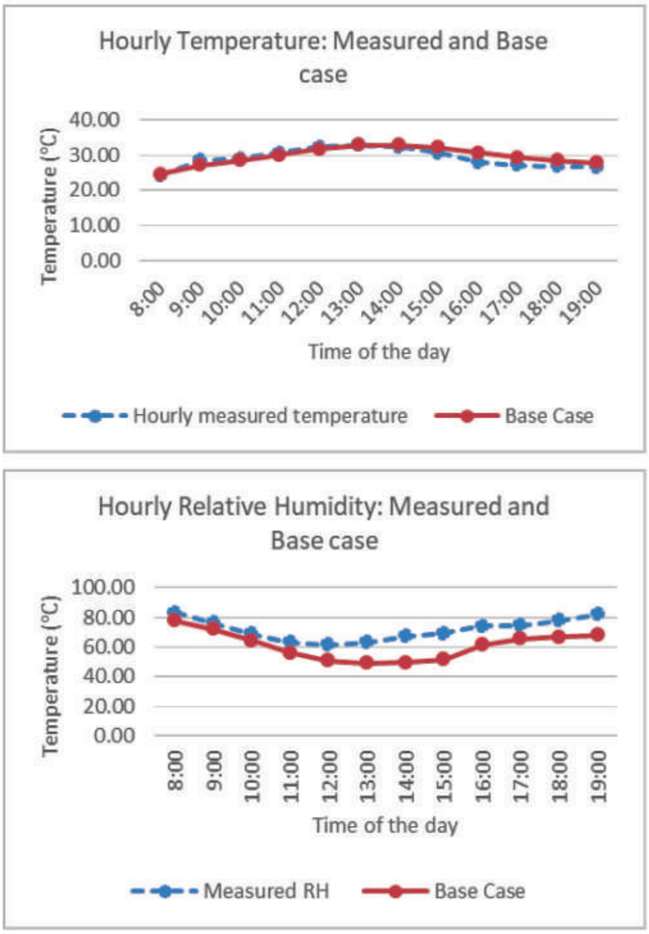

Figure 7: Hourly temperature and relative humidity measured from the device and base case scenario

The average temperature difference between the hourly temperatures: measured and base case throughout the day is 0.55! and the average relative humidity difference between the hourly relative humidity: measured and base case throughout the day is 10%. The discrepancy could be because vegetation other than street trees was not considered in the simulation, the devices were placed on the sidewalks, and the difference in microclimate could also play a role, since the climate data were obtained from the nearest station (Lazimpat), while the devices were placed exactly on site.

Results and Discussion

Thermal comfort varies with time of day. The authors assumed that there was some relationship between time of visit and thermal comfort in summer. However, 19 (54.28%) of the respondents visited the street between 10 am and 2 pm, the time when temperatures are highest. Since most of the respondents visited this street for work reasons, it seems that a visit during the day is reasonable.

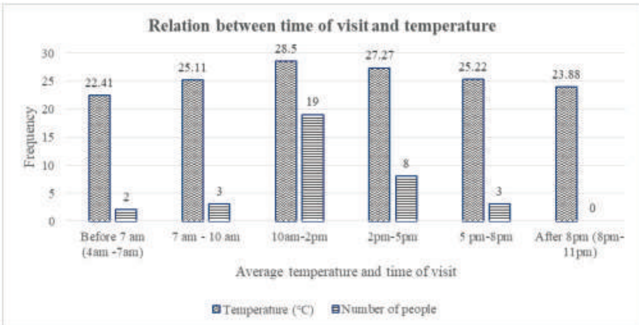

Figure 8: Relation between time of visit and temperature

36% of respondents preferred both sidewalks, while 39% of respondents preferred an east-facing sidewalk, with the remaining 25% preferring a west-facing sidewalk. Also, as mentioned earlier, there were more people on the east-facing sidewalk than on the west-facing sidewalk. Since there was no significant difference in air temperature on the east and west facing sidewalks, as shown in the figure 10, the greater number of people on the east facing sidewalk could be due to the presence of street furniture and the number of restaurants on the east facing sidewalk. Overall, the east-facing sidewalk appeared to be more lively than the west-facing sidewalk.

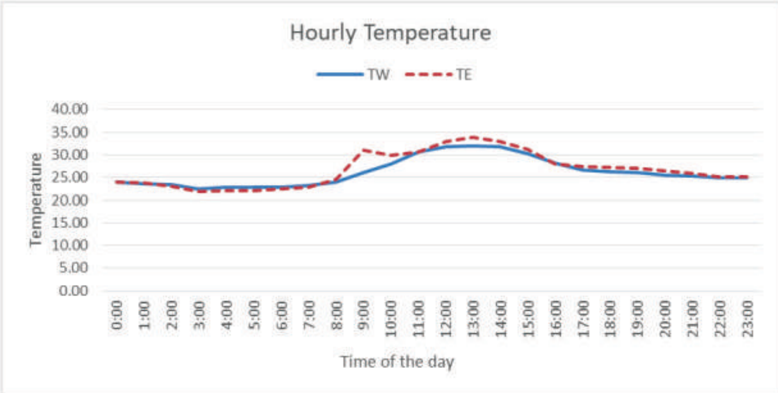

Figure 9: Hourly temperature of east-facing and west-facing Sidewalks.

The activity mapping was also done during the survey. The figure 11 shows the different location of survey within the selected street section with the pedestrians involved in various activities.

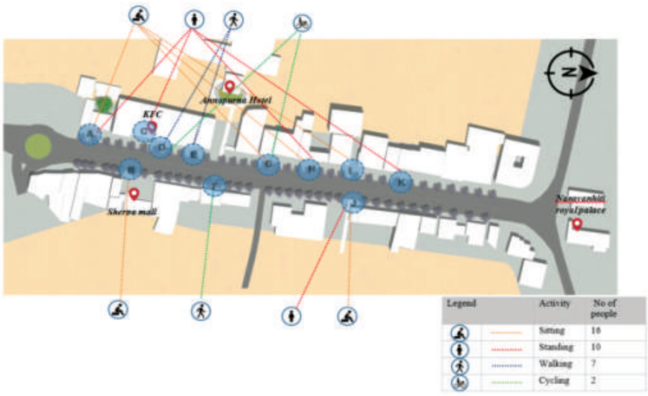

Figure 10: Location of the survey within the site with the pedestrians involved in various activities

Thermal comfort is different in different parts of the street because the microclimate is different in different parts of the street. As shown in figure 12, 41.67% of respondents chose a particular place to sit/stand/walk because it is covered with trees, and 25% of respondents chose a place because the building provides shade. Thus, the physical characteristics of the street play an important role in improving thermal comfort.

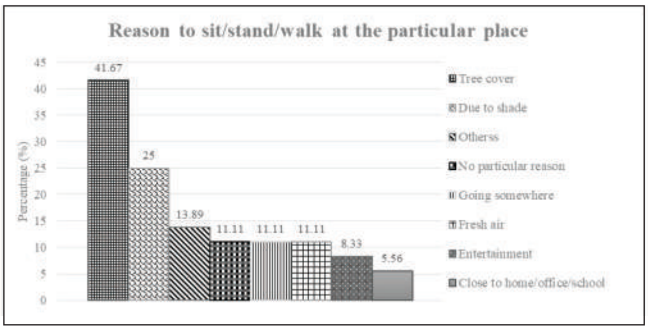

Figure 11: Reason to sit/stand/walk at the particular place

Sidewalk pavement also have a strong influence on the street microclimate and are one of the main contributors to the urban heat island effect (Faragallah & Ragheb, 2022). The paver materials vary within the building frontage and the different sections of the sidewalks. However, the majority of the sidewalks are made of concrete. Respondents were asked whether or not they felt the heat on the sidewalk. The majority of respondents (approximately 63.89%) felt the heat from the sidewalk, as shown in Figure 13.

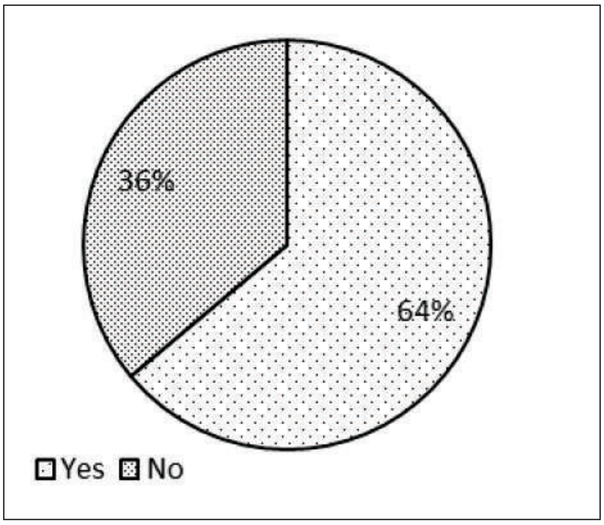

Figure 12: Heat from the pavement

Respondents were asked about their thermal sensation, skin condition, and preference for microclimate at the time of the survey. 13 (36.11%) out of 36 respondents felt hot, 2 (5.56%) felt very hot, 10 (27.78%) felt warm, while the rest of the respondents had a neutral thermal sensation. The thermal sensation votes are shown in Figure 14. 38.89% of the respondents had sweaty skin during the survey

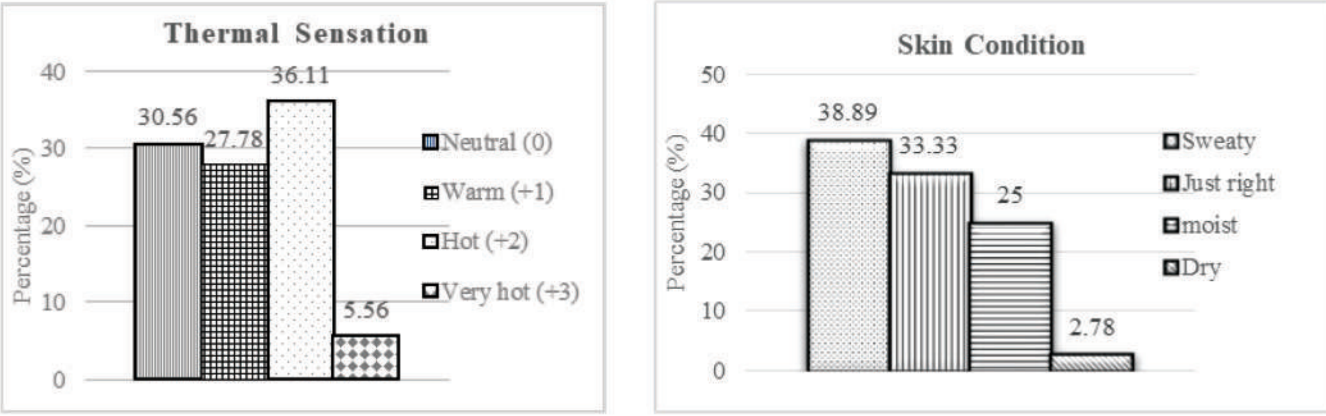

Figure 13: Thermal Sensation Votes and Skin Condition

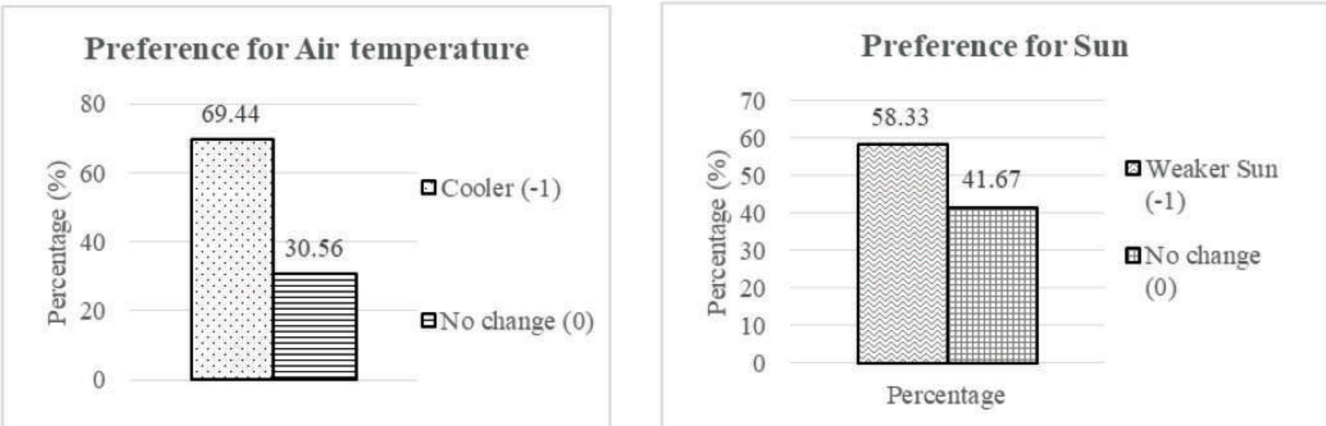

Figure 14: Preference for air temperature and Sun

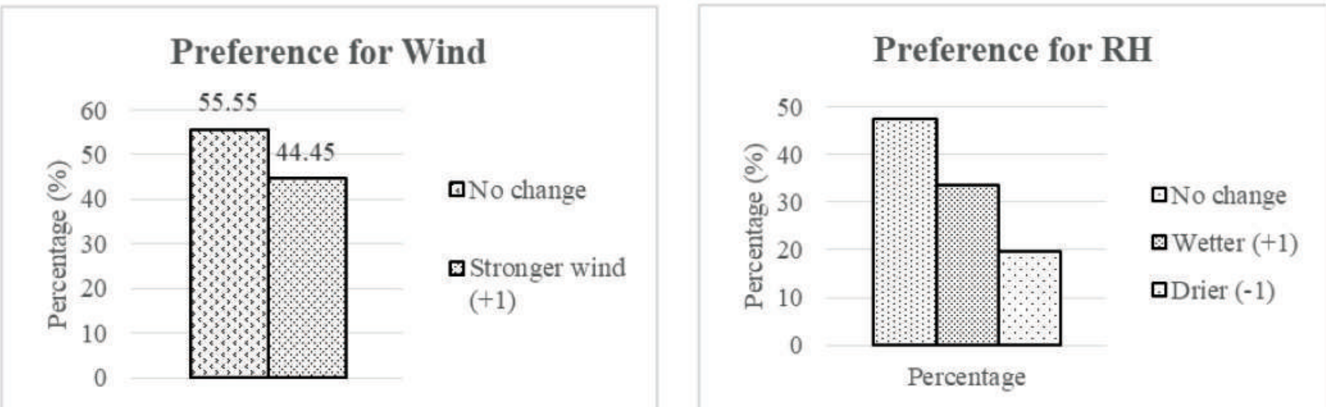

Figure 15: Preference for wind and Relative Humidity

In addition to that, 69.44% of people preferred cooler air temperature, the rest was satisfied with the air temperature. Similarly, 58.33% preferred weaker sunlight for thermal comfort. The majority of respondents preferred stronger wind (55.55%), and for relative humidity, 47.22% preferred no change in Relative Humidity. Since the majority of respondents had either a hot or warm thermal sensation and preferred a change in microclimate, it can be concluded that the thermal environment of the selected street section is not comfortable for pedestrians.

Simulation results

Different scenarios were created by changing the parameters like the orientation, no. of planting strips, spacing between trees, leaf area density and the pavement materials. The summary of scenarios is presented in the table 2.

Table 2: Summary of Different Scenarios for Simulation

S.N	Scenarios	Trees	Pavement
1	BC: Base Case Scenario	Low LAD trees (9m X 10m)	Concrete pavement dirty/used
2.	O1: Orientation changed to EW	Same as base case	Same as base case
3.	V1: Low Leaf Area Density trees(LAD) changed to High LAD	High LAD trees (9m X 10m)	Same as base case
5.	V2: Trees Canopy (13m) and height (15m) changed.	High LAD trees (13m X 15m)	Same as base case
6.	V3: Median with trees introduced in between road (3m X5m)	High LAD trees (9m X 10m)	Same as base case
7	P1: Pavement material same as BC	No trees	Same as base case
8	P2:Pavement material changed	No trees	Light coloured concrete
9	P3:Pavement material changed	No trees	Dark coloured Concrete
10	P4: Pavement material changed	No trees	Interlocking concrete blocks
11	P5: Pavement material changed	No trees	Porous concrete
12	P6: Pavement material changed	No trees	Red brick
13	P7: Pavement material changed	No trees	Flagstone
14	P8: Pavement material changed	No trees	Limestone
15	P9: Pavement material changed	No trees	Coloured Asphalt in road.
16	V1P1: Pavement and vegetation parameter changed.	High LAD trees (9m X 10m)	Pavement same as base case
17	V1P2: Pavement and vegetation parameter changed.	High LAD trees (9m X 10m)	Light color Concrete
18.	V1P5: Pavement and vegetation parameter changed.	High LAD trees (9m X 10m)	Porous Concrete
19.	V1P7: Pavement and vegetation parameter changed.	High LAD trees (9m X 10m)	Flagstone

Comparison of Simulation Scenarios

Different scenarios created so far have been compared in terms of potential air temperature and mean radiant temperature. The figure 17 shows the air temperature and mean radiant temperature difference among the various scenarios considering the orientation and vegetation parameters. When the orientation was changed to EW orientation, potential air temperature increased by average of 0.44°C and mean radiant temperature increased by average of 6°C. It is due to the fact that the EW oriented sidewalks are likely to get long exposure solar radiation than NS oriented sidewalks. The potential air temperature decreased by average 0.074°C when the low LAD trees were changed to high LAD trees (Scenario 1: Base Case to Scenario V1). The potential air temperature decreased by average of 0.197°C when the tree canopy size was increased to 13 m and height was increased to 15m (Base Case to V2). The mean radiant temperature decreased by almost 4.86! in the same case. Similarly, when the trees (3m X5m) were introduced in the median, there was no significant change in the air temperature, however the mean radiant temperature decreased by 3.41°C.

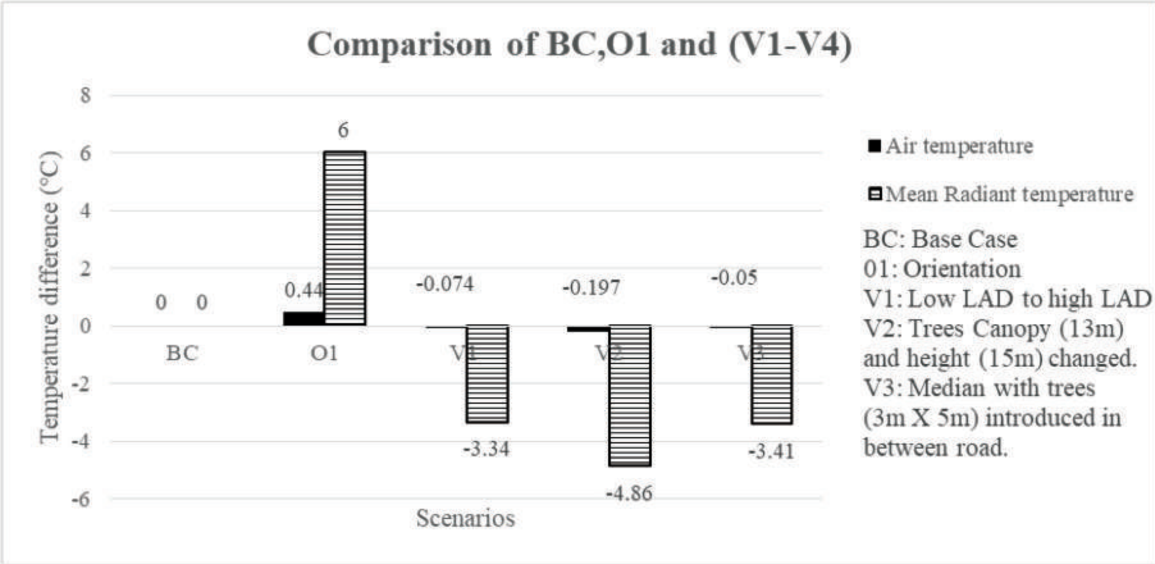

Figure 16: Comparison of Scenarios: BC, O1 (Changing orientation) and (V1-V4)

The figure 18 shows the air temperature and mean radiant temperature difference by changing the pavement materials. Among the various pavement materials in various scenarios for the simulation, the light concrete pavement showed the highest decrease in terms of the air temperature (0.579°C) however the mean radiant temperature was highest (7.22°C) for the same material. This is due to the fact that it has more albedo and hence than reflects more solar radiation than the other pavement materials used in the simulation. The reflected solar radiation is then absorbed by the pedestrians.

Hence the material which decreases the air temperature might also not improve or worsen the thermal comfort for the pedestrians. The materials which showed the decrease in both air temperature and mean radiant temperature were porous concrete, flagstone and brick pavers.

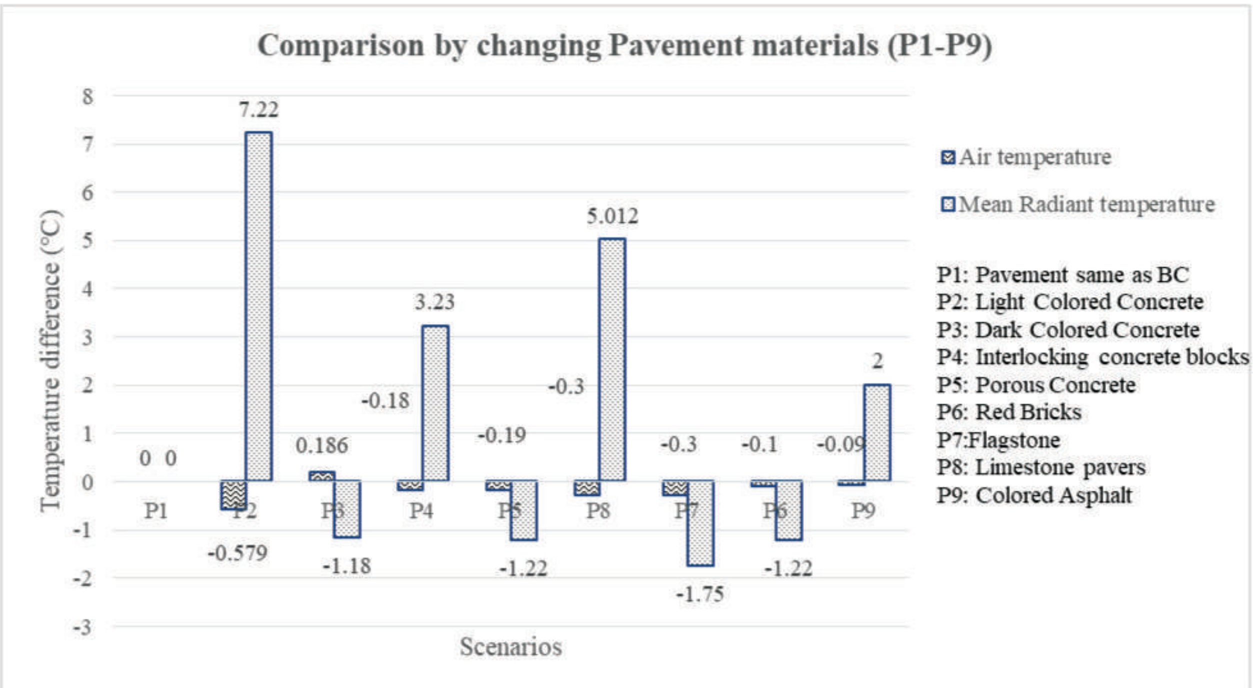

Figure 17: Comparison of Scenarios by changing Pavement materials (P1-P9)

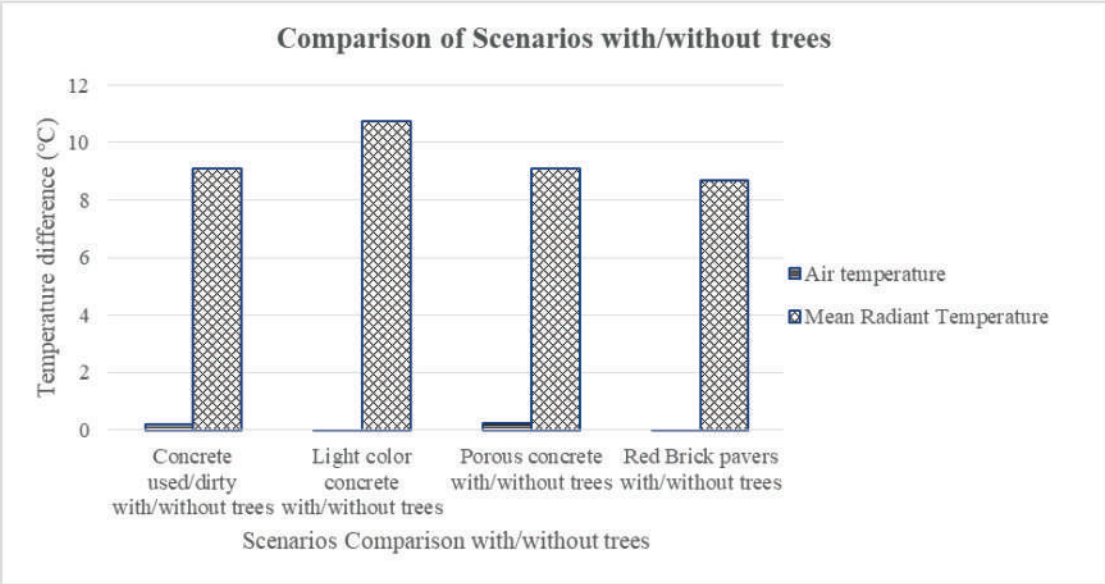

Figure 18: Comparison of Scenarios V1P1, V1P2 (High LAD trees with pavement light color concrete), V1P5 (High LAD trees with pavement porous concrete), V1P6 (High LAD trees with pavement red bricks).

When comparing the scenarios with and without trees (V1P1 and P1, V1P2 and P2, V1P5 and P5, V1P6 and P6), as shown in Figure 45, the potential air temperature difference was found to be highest for porous concrete (0.22°C) and the mean radiant temperature difference for light-colored concrete. Also, the potential air temperature difference with and without trees ranges from 0.045°C to 0.22°C, and the mean radiant temperature difference with and without trees ranges from 8.65°C to 10.71°C. Therefore, the presence of trees on the street has a great influence on the thermal environment and thermal comfort of pedestrians.

Conclusion

The study concludes that the physical characteristics of the sidewalks such as the shade of buildings, the presence of vegetation (trees), orientation and the paver materials affect the thermal environment of the sidewalks. Pedestrians are more prone to thermal stress on EW sidewalks than NW-oriented sidewalks, which is also consistent with the results of other studies (Lin, Cho, & Hsieh, 2021). Among the various vegetation parameters considered, leaf area density is of utmost importance to maintain the thermal comfort. Among the various pavement materials considered, the pervious concrete, brick pavers enhances the thermal comfort for pedestrians. For the high reflective surfaces, the surface /air temperature is reduced but it increases the mean radiant temperature and hence might not be appropriate for the thermal comfort of the pedestrians. This also comply with the findings of other studies (Taleghani & Berardi, 2017; Li, et al., 2012). It can be concluded that certain interventions in sidewalk landscape (trees and pavements) can make significant difference in the microclimate of the street. Hence, the street design guidelines in Kathmandu should also consider the thermal environment of the street/sidewalks while considering the landscape design of the street. Brick pavers, flagstone and porous concrete (evaporative cooling effect) can be used instead of traditional impervious concrete. Trees with high leaf area density can be used to provide the cooling effect in hot climate. Similar studies can be done to enhance pedestrian thermal comfort in Terai region of Nepal. These kind of study /research should be done and will be useful in also creating the public pocket parks within the city to get the maximum thermal benefit.

The results of questionnaire survey show that the sidewalks were not comfortable in terms of thermal comfort. However, the sample size of the survey should be increased to get more accuracy. Further research is needed as the study was conducted in a typical street section and only during the few summer days. In temperate climatic regions like

Kathmandu, the study is also important in winter. However, in this study, the thermal comfort of pedestrians was investigated and evaluated only in summer. Various parameters like the street aspect ratio, tree species and other landscape feature like water bodies can be considered for the further studies.

Acknowledgement

The authors would like to thank all survey participants for their valuable time and the Department of Architecture, Institute of Engineering, Pulchowk Campus for the opportunity to conduct this study. Special thanks to Assistant Professor Dr. Dibas Shrestha, Central Department of Hydrology and Meteorology, Tribhuvan University for providing the data loggers for the measurements.

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Appendix A

S.N	Date-Time	Parameters	Hobo MX 2304	DHM	Diff .RH	Diff. Temp.
1	06/23/2022 15:15:00	T (°C)	28.87	28.72		0.15
		RH(%)		38.46	3.54	
2	06/23/2022 15:20:00	T	28.87	28.84		0.03
		RH		38.07	3.93	
3	06/23/2022 15:25:00	T	29.00	28.93		0.07
		RH		37.72	3.28	
4	06/23/2022 15:30:00	T	29.13	28.99		0.14
		RH		37.26	3.74	
5	06/23/2022 15:35:00	T	29.13	29.13		0.00
		RH		37.05	2.95	
6	06/23/2022 15:40:00	T	29.30	29.19		0.11
		RH		36.94	3.06	
7	06/23/2022 15:45:00	T	29.34	29.06		0.28
		RH		37.28	2.72	
8	06/23/2022 15:50:00	T	29.21	28.87		0.34
		RH		37.4	1.6	
9	06/23/2022 15:55:00	T	29.08	28.87		0.21
		RH		37.7	2.3	
10	06/23/2022 16:00:00	T	29.17	28.97		0.20
		RH		37.08	1.92	
11	06/23/2022 16:05:00	T	29.34	29.08		0.26
		RH		36.58	2.42	
12	06/23/2022 16:10:00	T	29.56	28.99		0.57
		RH		36.95	1.05	
	Average difference				**2.71**	**0.20**

Journal of Environment Sciences (2023), **Volume IX**, 26-33
https://doi.org/10.3126/jes.v9i1.56475

Floristic Composition, Diversity and Carbon Stock Along Altitudinal Gradient in Hasantar Community Forest, in Nagarjun Municipality, Kathmandu District

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Abstract

This study has attempted to estimate above and below ground biomass along altitudinal gradient and examined the relation between carbon stock and diversity indices. The study area was categorized into three sections based on the elevation interval of 200m ranging from 1300m to 1900m. Vegetation sampling was performed in 33 circular plots, each of $500m^2$ and was selected based on systematic random sampling. Phyto-sociological parameters and above and below ground biomass and total carbon stock were calculated for each section of the study area. Carbon stock showed negative and insignificant relation with species evenness ($r=-0.24$, $P= 0.17$) and positive but insignificant relation with species richness ($r=0.17$, $p=0.34$) and Simpson's index of dominance ($r=0.18$, $P=0.31$). However, humped shaped and statistically insignificant ($P=0.93$) relationship was observed between Shannon diversity index and carbon stock. This research results provide baseline information for the management of Hasantar community forest.

Keywords: *Altitudinal gradient, Carbon stock, Community Forest, Diversity indices, Phyto-sociological parameters*

Introduction

Nepalese forest is manifested by the tropical forest in terai, deciduous and coniferous forests in the subtropical and temperate region and the meadows and grasslands at high altitude. Forests in Nepal along with other wooded land comprise 6.61 million hectare of the total area of the country (DFRS, 2015). Over grazing, forest fire, landslide and bush cutting are major factors of forest disturbance. Forest destruction and degradation leads to the biodiversity loss and climate change in a long run (Gebrewahid and Meressa 2020, Talbot 2010). Forest has a significant role in carbon cycle globally as it acts as both sources and sinks of carbon (Huang et al., 2020).

Community forestry is one of the major participatory forest management practices, was initiated in 1970's with the purpose of people's participation in the protection, management and utilization of the forest resources (Acharya, 2002). By the year 2015, the total carbon stock of Nepalese forest was estimated 176.95 t/ha (DFRS, 2015). Poudel et al. (2022) has stated community forestry plays essential role in enhancing carbon sink as well as limiting deforestation and forest degradation. Study of Rana et al. (2017) has reported the success of community forest in the annual increment of the carbon stocks, although estimation of carbon stock has been studied less in community forest of Nepal (Bohara et al., 2021).

Forest carbon stocks are largely dependent on species composition and forest structure and land use system (Shrestha et al., 2013). Higher the wood plant density, higher will be the biomass carbon storage (Rahayu et al., 2005). Along with supporting ecosystem processes, function and services (Gebrewahid and Meressa, 2020), forests play an essential role in the global carbon cycle (Huang et al., 2020; Midgley et al., 2010). Understanding the relationship between carbon stock and diversity indices, improve environmental benefits of carbon storage and biodiversity conservation (Gebrewahid and Meressa, 2020).

Floristic composition, diversity measures and carbon stock of forest provides the baseline information for the formulation of community forest management and conservation strategy. Diversity indices like species evenness, Shannon-wiener and Simpson's index of dominance enhance the understanding towards the relation between carbon storage and biodiversity measures. Thus, this study has attempted to estimate above and below ground carbon stock along altitudinal gradient and understand the relation between carbon stock and diversity indices.

Materials and Methods

Study Area

The study was carried out in Hasantar Community Forest (hereafter, HCF) in Nagarjung Municipality, Kathmandu District. The study area occupies 55.4 hectare and has been surrounded by Raniban Community Forest in the south and human settlement in other aspects. Geographic location of the study area is located between latitudes of 26.22' and 30.27'N and the longitudes of 80.40' and 88.12'E and elevation ranging from 1300 to 1900 meter above mean sea level. Climate is mild, generally warm and temperate. The study area receives precipitation of about 1505 mm annually in average and an average temperature range from 18^{o}C to 24^{o}C. HCF is Northwest facing natural forest and is dominated by *Schima wallichii* and *Rhododendron arboretum* (Silwal 2019, Gautam, 2019).

Sampling Design: Vegetation sampling was performed based on systematic random sampling approach. In total, thirty-three circular plots of area 500m^2 were laid in three different elevations in the interval of 200m, elevation ranging from 1300m to 1900m *i.e.* Section 1 (1300-1500m), Section 2 (1500-1700m) and Section 3 (1700-1900m). Tree species with DBH greater than 10cm were only considered (Sundriyal and Sharma 1996). Tree height (h) and diameter at breast height (DBH) at 1.3m from the ground of individual tree inside the plot were measured. Fiberglass measuring tape was used to prepare sampling plots. Tree height was measured using clinometer and DBH was measured using DBH tape. Latitude, longitude and altitude of each sampling plots were recorded using Garmin GPS.

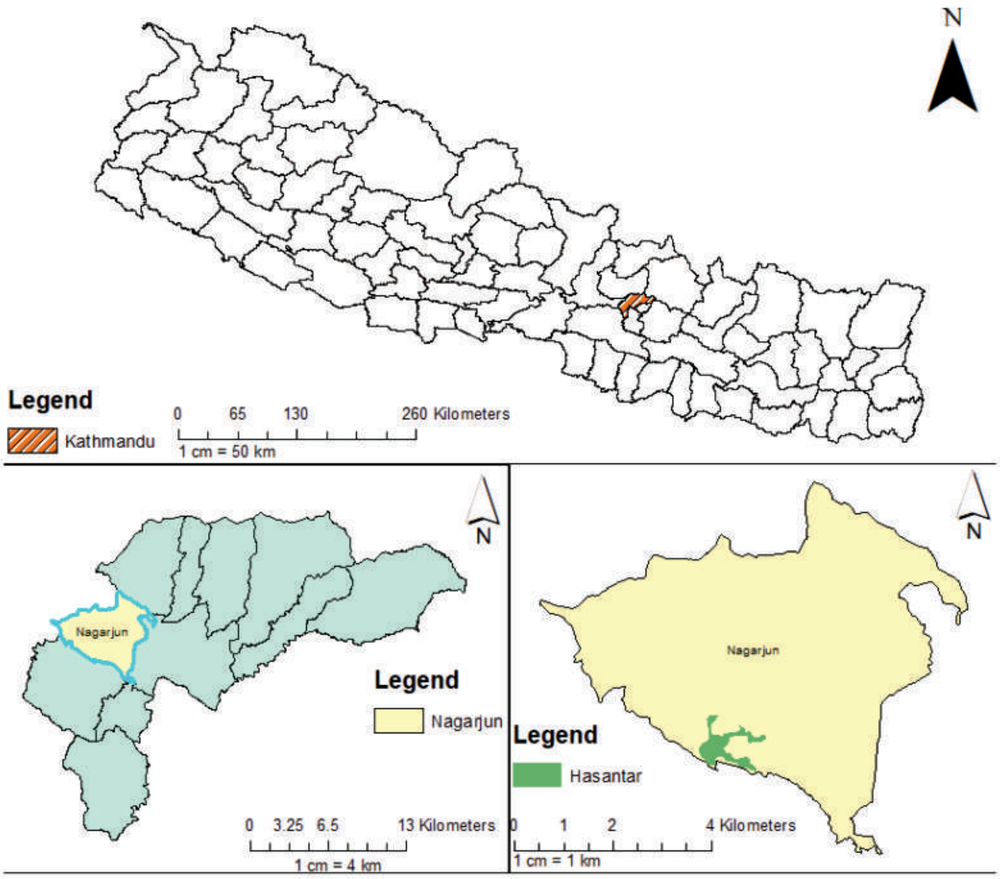

Figure 1: Map of Nepal indicating Nagarjun Municipality. Green color in the Map indicates Hasantar community forest

Data Analysis

Quantitative Vegetation analysis

Vegetation data were tabulated and ecological parameters such as density, frequency and basal area were determined quantitatively (Curtis and McIntosh 1951) in MS Excel 2016. The relative values of density, frequency and basal area summed to obtain Importance value index (IVI) of each tree species. Alpha diversity (species richness, evenness and Shannon diversity index) along altitudinal gradient were determined. Allometric equation (Chave et al. 2005) was used to estimate above ground tree biomass (AGTB).

$$\text{AGTB (t/ha)} = 0.0509 \times \varrho \times D^2 \times h$$

ϱ =wood specific gravity (g/cm³)

D= diameter at breast height (cm) and

h=tree height (m)

Below ground tree biomass (BGTB) was determined based on root to shoot ratio value of 1:5 *i.e.* 20% of AGTB (MacDicken 1997). Further, Total biomass was determined by summing AGTB and BGTB. In order to estimate carbon stock, biomass stock densities was multiplied with default carbon factor *i.e.* 0.47 (Change 2006).

The relationships between carbon stock and diversity measure were examined using Pearson correlation coefficient and represented in scatter plots.

Results and Discussion

Floristic Composition and Diversity Indices

A total of 18 species belonging to 11 families were recorded in 33 sampling plots (Figure 2). Fabaceae (4 species) was dominant family followed by Ericaceae, Myricaceae, Rosaceae and Theaceae (2 species each). Seven species (*Quercus lanata*, *Lyonia ovalifolia*, *Myrsine capitellata*, *Schima wallichii*, *Eurya acuminate*, *Choerspondias axillaris*, and *Engelhardia spicata*) were common in all sites. *Bauhinia variegate*, *Castanopsis indica*, *Myri*ca *esculenta, pyrus pashia*, *Morus alba*, *Ziziphus incurve* were recorded only in section 1 and section 2. *Rhododendron arboretum* and *Alnus nepalensis* were recorded only in section 2 and section 3. *Pyrus cerasoides* and *Duabanga grandiflora* were present only in section 2 and section 3 respectively.

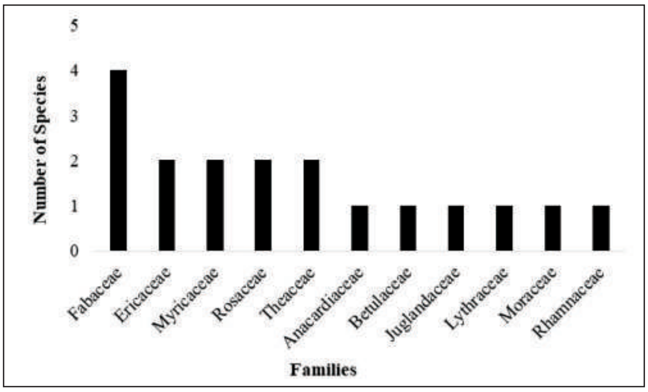

Figure 2: Number of species in different families of vegetation recorded

The study revealed decreasing total density and total basal area of tree species with increasing altitude (Table 1). It might be due to decreasing adaptability of trees at higher altitude (Ghimire et al. 2008). Total density of *Rhododendron arboretum* was found highest (131 ind/ha) followed by *Schima wallichii* (129 ind/ha). Total basal area of *Schima wallichii* was recorded highest (14.68 m^2/ha) followed by *Rhododendron arboretum* (5.16 m^2/ha). In section 3, forest was dominated by *Rhododendron arboretum* having higher density and basal area. However, in section 1, density and basal are of the *Schima wallichii* was noticed higher. Density of *Bauhinia variegate* was recorded higher in section 2 but basal area of *Schima wallichii* was measured higher.

Altitude gradients provide natural climate variations, where key environmental factors such as air temperature, humidity and associated soil properties (pH, temperature, soil depth) affect plant growth and tree distribution, that change significantly within a limited range (Gong et al. 2020, Sundqvist et al. 2013). The enough seedling composition is underpinning for the successful regeneration of natural forest (Nagel et al. 2010, Sinz et al. 2011). In addition, low moisture (Rodríguez-García et al. 2010), low temperature (Pardos et al. 2007) and drought (Padilla and Pugnaire 2007) are not much favorable for the development of seedlings.

Table 1: Phyto-sociological parameters

	Section 1	Section 2	Section 3
Species Richness	14	17	10
Species Evenness	0.73	0.86	0.74
Shannon Diversity Index	1.59	2.02	1.22
Simson's Index of Dominance	0.74	0.81	0.61
Total Density (ind/ha)	807	635	628
Total Basal area (m^2/ha)	14.41	12.05	9.35

Note: ind-individuals, ha-hectare

Species richness (17), and evenness (0.86) was found higher in section 2 and thus Shannon diversity index (2.02) was higher at section 2 (Table 1). Simpson's index of dominance was found ranging between 0.49 to 0.99. In general, tree species richness declines along with increasing elevation (Chikanbanjar et al. 2020, Fosaa 2004). In contrary, this study has represented hump shaped curve instead declining trend. It might be due to consideration of small elevation interval. Along with the altitude, aspects and microclimate influences the distribution of tree species in forest type (Ghimire et al. 2008). Assessment of Panchase protected area has reported similar tree diversity (1.12-2.15) (Chikanbanjar et al. 2020). Giri et al. (2008) has also reported Shannon diversity in the range of 0.88-2.11 of the Nainital catchment area which is alike to this study.

The IVI of the tree species was found ranging from 4.35 to 74.67. Based on IVI, *Schima wallichii* was found to be most important species (74.67) in whole forest followed by *Rhododendron arboreum* (42.72), *Castanopsis indica* (25.13) and *Bauhinia variegate* (25.11). However, *Rhododendron arboretum* was found dominated in section 3 with IVI 94.65. Section 1 and section 2 was dominated by *Schima wallichii* with IVI 67.37 and 85.93 respectively.

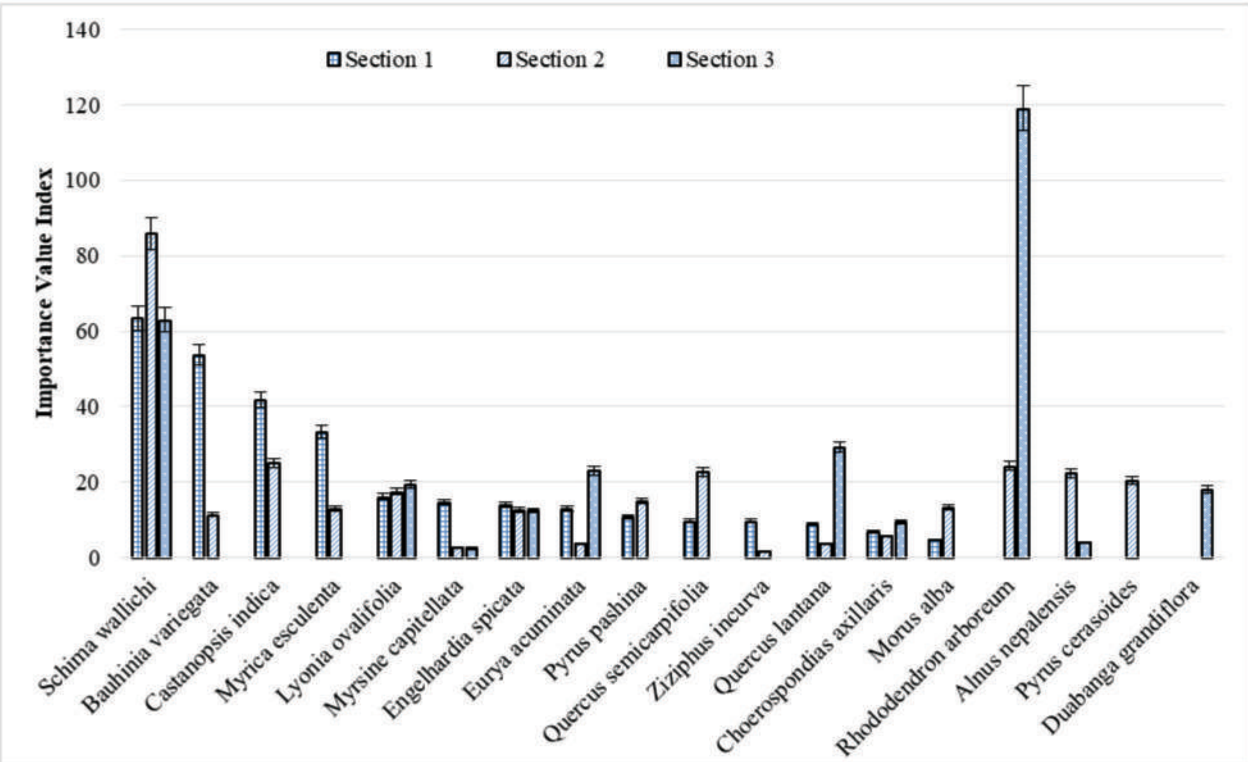

Figure 3: Composition of vegetation along altitudinal gradient. The error bars represent percent error

Carbon Stock of Forest Community

Carbon stock varied with the tree species. *Schima wallichii* comprised 45.08% of the total carbon stock of the HCF followed by *Rhododendron arboretum* (12.32%) and *Duabanga grandiflora* (0.5%) (Figure 4).

The total carbon stock was found higher in Section 1 i.e., 667.7±21.65 with total AGTB (1183±38.39) and total BGTB (236.77±7.67) (Table 2).

Species wise carbon stock found ranging from 7.82–702.29t/ha. Among the recorded species, carbon stock of *Schima wallichii* was found the highest (702.29t/ha) followed by *Rhododendron arboretum* (191.97t/ha) and *Myrica esculenta* (188.08t/ha). The higher carbon stock of *Schima wallichii* might be due to higher density and basal area.

Higher tree density and relative basal area results in higher biomass and thus carbon stock. Shrestha (2016) has also estimated vegetation type, age of the stands, surrounding environment, management activities and other human induced disturbances are key responsible for the variation in carbon stock. Wodajo et al. (2020) reported declining AGTB and BGTB along the increasing altitudinal gradient which might be due to absence of species with large DBH and basal area. Factors comprising soil, humidity, temperature and geomorphological factors determines the dominancy of small size plant in higher elevation (Gedefaw et al. 2014). In addition, higher dependency of adjacent community on the forest products for their livelihood influence carbon pool of the forest (Wodajo et al. 2020). In contrary to biomass of the forest stands decreases with the elevation (Kunwar and Chaudhary 2004), this study has estimated less biomass at Section 2. This might be due to anthropogenic disturbance. Disturbance reduces the growth and productivity of trees, either by damaging their physical structure or by limiting access to resources such as sunlight, water, and nutrients which lead to smaller and less

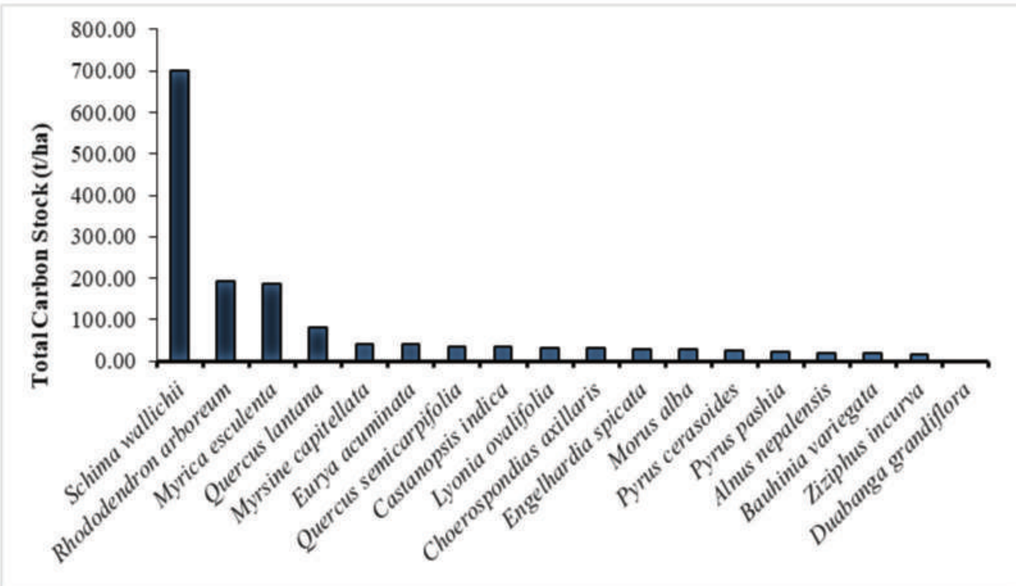

Figure 4: Species wise carbon stock in HCF

Table 2: Carbon stock along different altitudinal gradient

	AGTB±SD (t/ha)	BGTB±SD (t/ha)	TB±SD (t/ha)	Total C±SD (t/ha)
Section 1	1183±38.39	236.77±7.67	1420±46.07	667.7±21.65
Section 2	739.94±35.41	147.98±7.08	887.92±42.49	417.32±19.97
Section 3	753.12±22.12	150.62±4.43	903.75±26.6	424.76±12.51

Note: AGTB-Above ground tree biomass, BGTB- Below ground tree biomass, TB-Total Biomass, C-Carbon, SD-Standard deviation

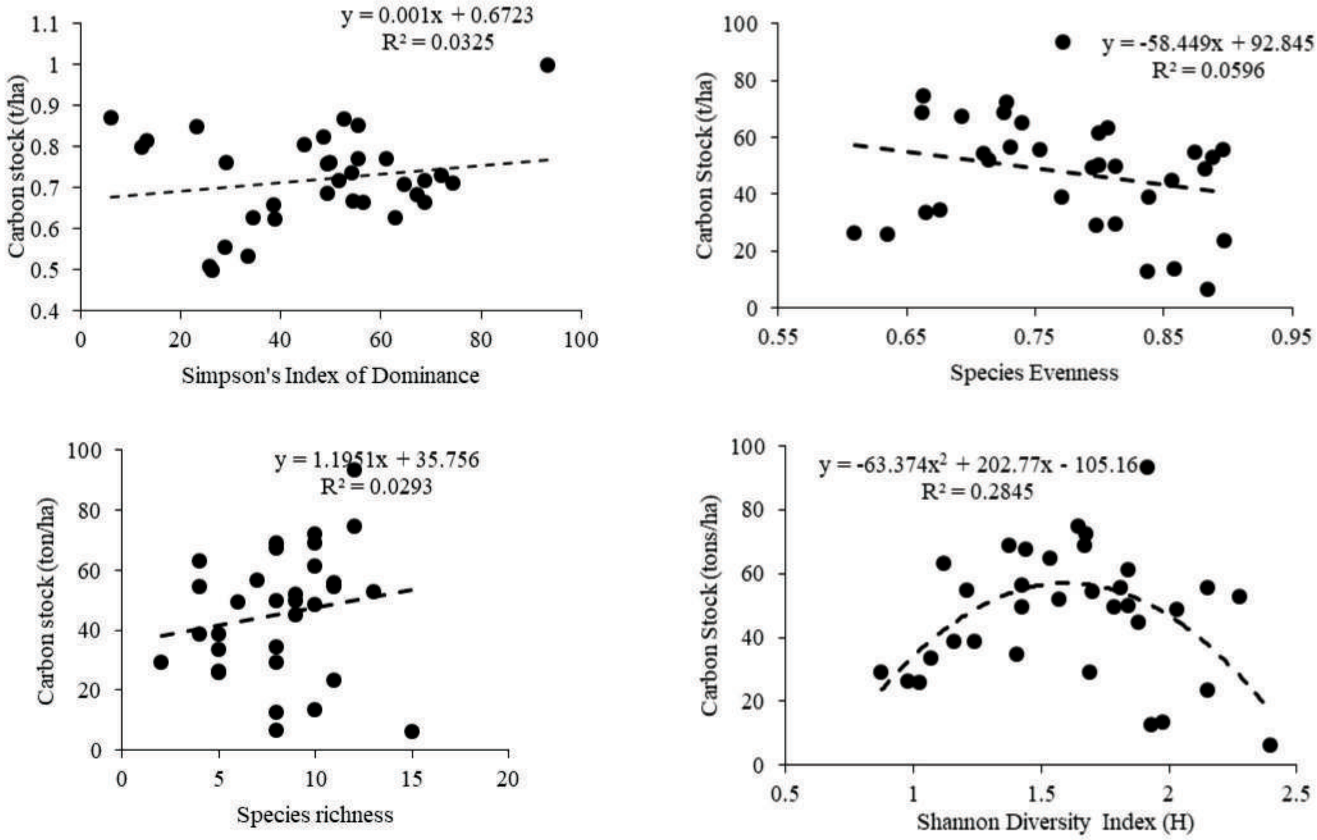

Figure 5: Scatter plot representing correlation between Diversity indices and Carbon stock

productive trees, and ultimately reduce the overall biomass of the forest (Franklin et al. 2002).

Relation between carbon stock and diversity indices

The diversity indices are major determinants for the regulating forest ecosystem's function and services. Results show varied relationship of carbon stock with diversity indices. The relationship between carbon stock and species evenness shows negative but insignificant (r=-0.24, p=0.17). However, positive and insignificant relationship was observed with carbon stock between Simpson's index of dominance (r=0.18, p=0.31) and species richness (r=0.17, p=0.34). Humped shaped but statistically insignificant (p=0.93) relationship was observed between carbon stock and diversity. The result showed the negative relation between carbon stock and species evenness which supports the finding of (Chalcraft et al. 2010), suggested that a few species become more dominant at high biomass, instead of the biomass being distributed evenly among all species. The study conducted by (Ayer et al. 2022) in Kanchanpur district also showed a negative relation between species evenness and carbon stock.

Conclusion

The Hasantar Community Forest is well stocked with mainly dominated by *Schima wallichi* followed by *Rhododendron arboretum*. The findings of this study indicate Shannon diversity and Simpson's index of dominance predominant at mid elevation whereas carbon stock was found high at lower elevation.

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Journal of Environment Sciences (2023), **Volume IX**, 34-43
https://doi.org/10.3126/jes.v9i1.56476

Woody species diversity and assemblage in different forest management stands of central Nepal

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Abstract

Various forest management strategies are in place for the conservation of forest ecosystems across the globe. Nepal is also implementing different forest management and restoration practices and has various impacts on vegetation characteristics. This study aims to compare the richness and diversity of woody plant species, and variability in abundance of woody species assemblages in different forest management stands, viz. restored stands inside Buffer Zone Community Forest (BZCF), natural stands of BZCF and core stands of Parsa National Park. Thirty sampling plots of 30 m × 30 m were laid on each stand, maintaining at least 50 m distance between the plots, where woody plant species having height 1.5 cm was identified and their DBH measured. Species composition was assessed comparing Importance Value Index (IVI) of woody plant species across the forests. Similarly, species diversity and structural diversity across stands were determined using Shannon Diversity index and basal areas of the plant species were calculated. The study showed *Shorea robusta* and *Lagerstroemia parviflora* with highest frequency (>80%) in all the sites, and the species diversity was highest in the core stands inside the national park followed by the natural stands of BZCF, and the restored stands of BZCF. Basal area of overall species and density of *S. robusta* were, however, highest on the restored stands of BZCF, whereas overall density was highest in the natural stands of the BZCF. The study revealed that the forest management practices need improvement in enhancing the plant species diversity of the ecosystems. We recommend to assess the functional attributes of the different forest management stands to evaluate the effectiveness of forest management strategies.

Keywords: *Buffer zone community forest, ecosystem, Restored forest stands, S. robusta*

Introduction

Forests are one of the most crucial natural resources, as they provide habitats for biodiversity, prevent desertification, sequester atmospheric carbon, regulate air, and produce wood (Baskent, 2021). Additionally, status of forests also provides information on forest regeneration and need of varying dimensions of restoration interventions (Chazdon et al., 2022). In rural Nepal, forests are a source of livelihood as people depend on timber, fodder, fuelwood, leaf litter, and other forest products that play a significant role in the livelihoods of communities situated nearby forest areas (Sapkota et al., 2009; Sapkota and Stahl, 2020). However, due to changes in biogeography and habitat, species diversity is not uniform (Whitmore, 1998). Tropical forests, in particular, experience high levels of anthropogenic disturbances due to timber harvesting (Dzulkritil, 2014), which can affect forest structure and composition, as well as its canopies, through top-down effects (Sapkota and Stahl, 2020). The density and size distribution of forests are determined by its structure (Huang et al., 2003), while species diversity and richness are used to assess ecological health (Davari et al., 2011). Various factors, such as environmental conditions, light levels, soil temperature, and air temperature under the canopy, can alter forest structural changes (Lebrija-Trejos et al., 2010).

Forest structure plays a crucial role in affecting different forest components, such as species diversity and composition, functional traits, and functional diversity (Whitfeld, 2014), and disturbances can also change forest structure. In forest habitats, species diversity, genetic flow, and biological interactions are all influenced by forest structure (Jafari et al., 2013). Forest also connotes to number of species, plant composition and tree size (Hui et al., 2019; Nowak et al., 2008). Forest structure provides reflection about habitat and species diversity, development of wildlife and plant species, ecosystem services and biomass production (Pommerening, 2002). Forest structure is also the driver for forest growth and ecological processes, which help to determine the past, present and future scenario of the forest (Hui et al., 2019).

Forest structure and diversity are crucial components in forest management (Jafari et al., 2013). *Shorea robusta* (Sal) is the dominant species in South and Southeast Asia (Whitmore, 1989; Ahmed et al., 2008). Forest management is carried with the main focus on integrating ecological complexity, socio-cultural, political and technological context (Torres-Rojo et al., 2016). It also varies as per the need such as forest conservation context, religious effect, ecosystem services and non-timber forest product (Torres-Rojo et al., 2016). Forest Act (2076) of Nepal has classified forests in terms of management regime government managed forest, forest protected area, community forest, partnership forest, leasehold forest and religious forest. This study focuses on analyzing the diversity, composition, and structure of different forest stands: restored stands inside Buffer Zone Community Forest (BZCF), natural stands of Buffer Zone Community Forest (BZCF) and core forest stands of Parsa National Park of central Nepal. While there are numerous studies on forest management, ecosystem services, invasive species, biomass, and carbon stock (Aryal et al., 2018; Smith et al., 2022; Uprety et al., 2023; Sharma et al., 2023), very few studies have focused on comparative studies on species structure and diversity (Jafari et al., 2013) in different forest management stands This study therefore attempts to fill gap by assessing the patterns of diversity, composition, and structure of the different forest management stands in and around Parsa National Park, Nepal.

Materials and Methods

Study Area

The study was conducted in and around Parsa National Park considering different forest management stands: restored stands inside Buffer Zone Community Forest (BZCF), natural stands of Buffer Zone Community Forest (BZCF) and core forest stands of Parsa National Park (Figure 1). Among the forest stands, BZCFs are managed by the forest user group, while the core forest is managed by the Government of Nepal. The study area lies on the sub-tropical elevation range of 100

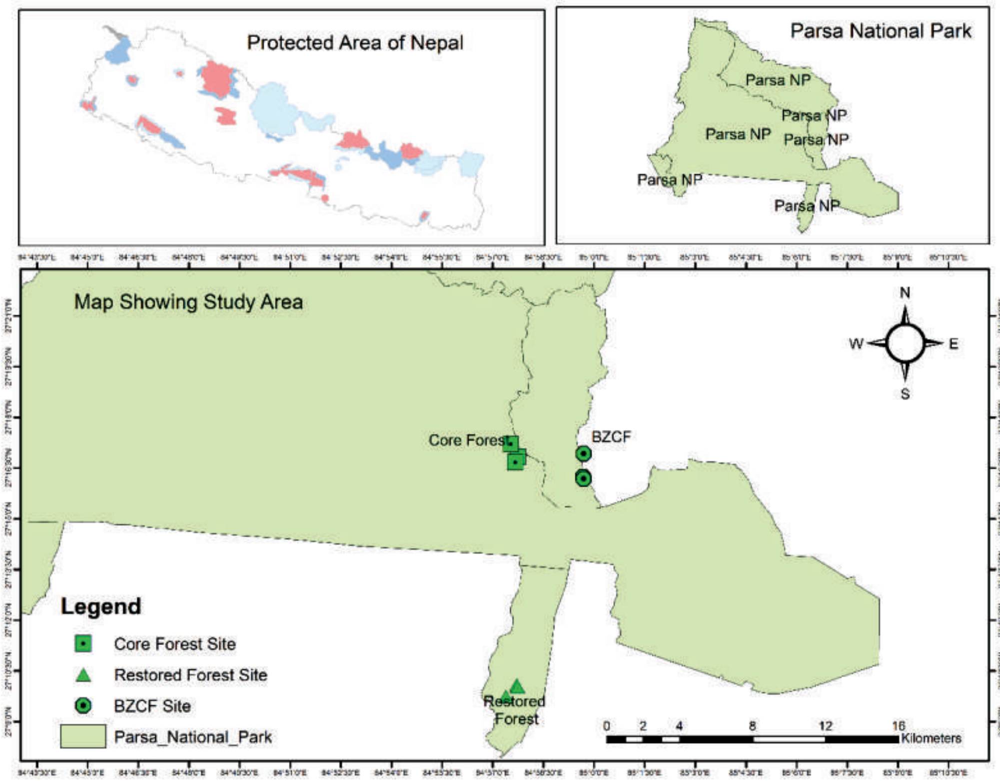

Figure 1: Study area map showing restored stands, natural stands of Buffer Zone Community Forest (BZCF) and core forest stands of Parsa National Park

m to 140 m, and vegetation is dominated by Sal (*Shorea robusta*) species. BZCF forests considered for the study were Radha Krishna BZCF, Janagaran BZCF and Musharni Mai BZCF while Churiya Mai BZCF was selected as the natural BZCF site. The restored stands at BZCFs were restored since about 20 years. Natural stands of BZCF and restored stands of BZCF are near from the human settlement, where human intervention is present. People collect forest resources for their subsistence needs *viz.* fodder, fuel wood, timber, etc. Core forest was inside Parsa National Park, where there is restricted access to the local community for the collection of forest resources.

Methods

Field data was collected on January, 2020. A total of 30 sampling plots for each forest management stands and each plot measuring 30 m x 30 m were established to survey the population structure of woody species in the study area. Tree/shrub was defined as woody species with height e" 1.5 m. In the plot, all the species were identified and their diameter at breast height (DBH) and height were measured. The local name of the species was recorded on site, while the scientific name was sourced from relevant literature. DBH was measured using a DBH tape, and height was estimated by using clinometer.

Data Analysis

This study focuses on analyzing the Shannon Diversity index, species composition, basal area, and species density across the different forest management stands. Species diversity was calculated by using the Shannon Diversity Index as:

$$H' = -\sum \text{pi} \ln \text{pi}$$

The Importance Value Index (IVI) was calculated as the summation of relative frequency, relative density and relative basal area of the species.

Relative frequency (RF %) =

$$\frac{\text{Frequency of a particular species}}{\text{Total frequency of all the species}} \times 100$$

Relative density (RD %) =

$$\frac{\text{Density of the particular species}}{\text{Total density of all the species}} \times 100$$

Relative basal area (RBA %) =

$$\frac{\text{Basal area of the particular species}}{\text{Total basal area of all the species}} \times 100$$

The data were analyzed using R (R Core Team, 2016) and RStudio (RStudio Team, 2015) using the packages “Plotrix” (Lemon, 2006) and “Sciplot” (Morales, 2017) for data handling and descriptive statistics, and “vegan” (Oksanen et al., 2020) for species diversity calculation. Shapiro-Wilk test was used for the normality test and analysis of variance (ANOVA) was used for comparing the mean values of structural attributes under the different management stands. A TukeyHSD test was applied for the pairwise comparisons of the different structural attributes.

Results and Discussion

This study examined structural attributes of different forest management stands in the sub-tropical lowland of Nepal, which consists of the study sites named as- core forest inside the Parsa National Park, natural stands of BZCF, and restored stands of BZCF. The restored stands are under restoration interventions for the past 20 years, while the core forest is protected under the management of Department of National Parks and Wildlife Conservation. The lowland forests are also facing threats from illegal collection and harvesting of forest products, including timber. Biodiversity conservation has emerged as a major concern in forest management over the past few decades, and forest management practices have significantly impacted the forest structure and diversity, as reported by Webb and Sah (2002) and Timilsina and Heinen (2008).

Species Composition

A total of 55 woody plant species were recorded across all sites, of which 15 woody species were common in all the forest management stands. The highest species diversity was observed in the core forest, followed by the natural stands of the BZCF

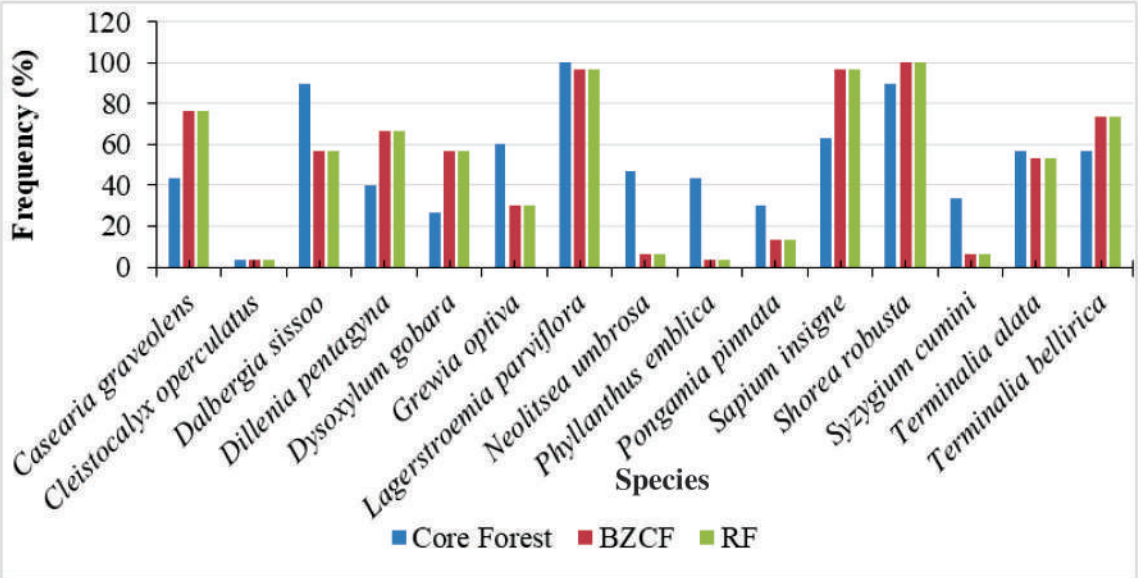

Figure 2: Frequency of 15 most abundant species in the studied forest stands

and the restored stands of the BZCF (Table 1). *S. robusta* and *L. parviflora* were found to have the highest frequency (>80%) in all the sites (Figure 2). Consistent with Terai Forest Inventory carried by DFRS, this study also observed one of the frequent species as *S. robusta* in all the management stands, which is similar with Khadka et al. (2023), Chapagain et al. (2021) and Sapkota et al. (2009).

Previous researchers have found variation was observed in species richness in mixed forests of Nepal. Sharma et al. (2020) found 27 tress species in central Terai Nepal, and Bhatta and Devkota (2020) found 42 species from 20 families in the hilly region of Nepal. The difference in the results might be due to consideration of different ecological zones. Similarly, variations in species richness are also altered by different environmental factors like climate, soil, geographical location, disturbance and management practices (Ram et al., 2004; Das et al., 2017; Bhatta & Devkota, 2020). This study found that the core forest had the highest species richness, consistent with the findings by Chauhan et al. (2010) and Awasti et al. (2020), who also observed higher species richness in their control blocks. Considering IVI, *S. robusta, P. pinnata, L. parviflora, B. ceiba,* and *M. philippensis* were the top three species across all types of forest management stands. The study also found that *S. robusta* had the highest IVI in the restored forest stands of BZCF and the natural stands of BZCF forests, but was comparatively lower in the core forest, which is consistent with findings by Khadka et al. (2023) for the IVI for *S. robusta*. In the core forest of the national park, natural stands of BZCF and the restored stands of the BZCF observed richness were found to be 41, 33, and 24, respectively (Table 1).

The natural forest stands of BZCF and restored forest stands of BZCF showed the highest IVI for

Table 1: Vegetation characteristics of the studied forest stands

Vegetation characteristics	Natural stands of BZCF	Restored stands of BZCF	Core Forest
No. of individuals ha^{-1}	736	489	441
No. of individuals of *Shorea robusta* ha^{-1}	272	381	73
Richness (No. of species observed in the sampling units)	33	24	41
Shannon Diversity Index (average per sampling unit)	1.7	1.1	2.1

Table 2: IVI of 15 most abundant species in the studied forest stands

Species Name	Restored Stands of BZCF				Core Forest				Natural Stands of BZCF			
	RF	RD	RBA	IVI	RF	RD	RBA	IVI	RF	RD	RBA	IVI
Casearia graveolens	9.45	3.48	1.05	13.98	5.53	2.36	2.10	9.99	7.35	2.97	0.93	11.25
Cleistocalyx operculatus	0.79	0.08	0.00	0.86	0.43	0.12	1.00	1.54	0.32	0.05	0.38	0.75
Dalbergia sissoo	1.57	0.61	0.77	2.95	11.49	8.62	3.52	23.63	5.43	1.61	3.42	10.47
Dillenia pentagyna	10.24	3.03	2.68	15.95	5.11	2.36	1.18	8.65	6.39	5.24	1.45	13.08
Dysoxylum gobara	3.94	1.14	2.53	7.61	3.40	4.25	2.00	9.65	5.43	2.82	1.36	9.61
Grewia optiva	2.36	0.68	0.40	3.44	7.66	8.97	2.72	19.35	2.88	0.65	0.18	3.71
Lagerstroemia parviflora	7.87	2.88	0.94	11.69	12.77	25.03	16.10	53.90	9.27	15.21	3.26	27.74
Neolitsea umbrosa	1.57	0.30	0.12	2.00	5.96	2.48	3.08	11.52	0.64	0.15	3.56	4.35
Phyllanthus emblica	2.36	0.38	0.22	2.96	5.53	3.07	1.50	10.10	0.32	0.05	2.10	2.47
Pongamia pinnata	4.72	0.61	4.84	10.17	3.83	1.18	27.84	32.85	1.28	0.25	27.08	28.61
Sapium insigne	1.57	0.38	1.06	3.01	8.09	6.14	8.76	22.98	9.27	9.77	1.37	20.41
Shorea robusta	23.62	77.82	2.21	103.65	11.49	22.55	13.98	48.02	9.58	41.34	1.13	52.06
Syzygium cumini	3.15	0.76	2.03	5.94	4.26	1.18	6.26	11.70	0.64	0.10	8.84	9.58
Terminalia alata	0.79	0.23	1.06	2.08	7.23	4.01	7.70	18.95	5.11	1.81	10.20	17.12
Terminalia bellirica	0.79	0.08	0.11	0.98	7.23	7.67	2.26	17.17	7.03	2.92	0.73	10.68

(RF: Relative Frequency; RD: Relative Density; RBA: Relative Basal Area; IVI: Importance Value Index; Values expressed in %)

S. robusta, while *L. parviflora* had the highest IVI value in the core forest (Table 2). Comparing the IVI of *S. robusta*, restored forest stands have the highest values (103.65%), followed by the natural stands of the BZCF forest (52.06%) and the core forests (48.02%).

Forest Structure

Basal area of tree species was found high in the restored stands of BZCF as compared to other type of forest management stands, since restored stands were managed for conservation of selective species. Likewise, the basal area of *S. robusta* found high in restored stands of BZCF, since there was high *S. robusta* found in the areas. This study found similar result with Whitfeld et al. (2014), who found high basal area in secondary forest like to that of restored forest, but Webb and Sah (2003) determined highest basal area in the natural than any other stands. Basal area may vary with different forest process like succession (Whitfeld et al., 2008), since it is dynamic process and can also vary with stand age, management intervention and regeneration survival.

Total basal area of trees was found 8.99±0.56 m^2/ha, 13.44±1.73 m^2/ha and 16.41±1.12 m^2/ha in natural stands of BZCF, core forest and restored forest stands of BZCF, respectively. There was significant difference in the mean basal area between the core forest and natural stands of BZCF (p=0.03), restored forest stands and natural forest stands of BZCF (p<0.001), but there was no significance difference in mean basal area between restored forest stands and core forest (p=0.21) (Figure 3). While the total basal area of *S. robusta* was found 3.77±0.45 m^2/ha, 3.24±0.56 m^2/ha and 14.24±1.11 m^2/ha in BZCF, core forest and restored forest, respectively. There was no significance difference between core forest and natural stands of BZCF (p=0.87), but significance difference was observed in restored stands and natural stands of BZCF (p<0.001) and restored stands and natural stands of BZCF (p<0.001).

The highest woody species density was found in natural stands of BZCF (735.56±59.11 ind./ha) followed by restored stands of BZCF (489.26±27.35 ind./ha) and the core forest (440.74±20.89 ind./ha), respectively (Figure 4). The TukeyHSD pairwise comparison shows that there was significant difference between core forest and natural stands of BZCF (p<0.001), and restored stands and natural stands of BZCF (p<0.001), but there was no significant difference between restored stands

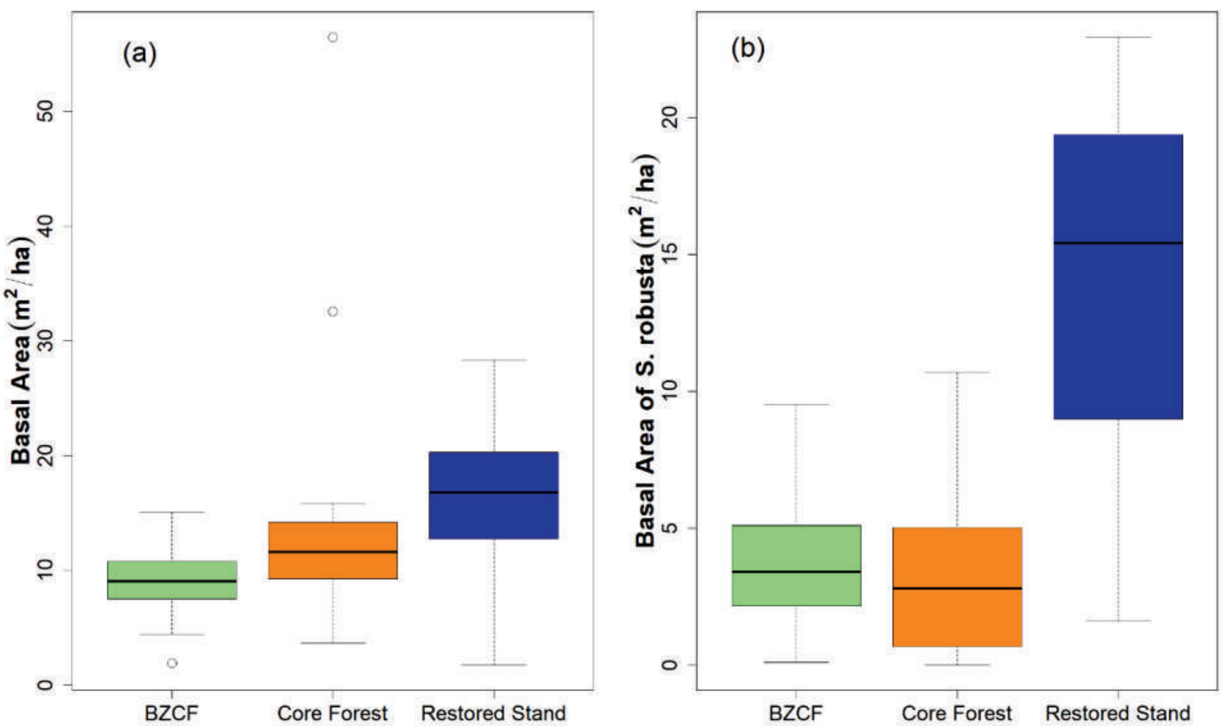

Figure 3: Basal area of overall species (a) and *Shorea robusta* (b)

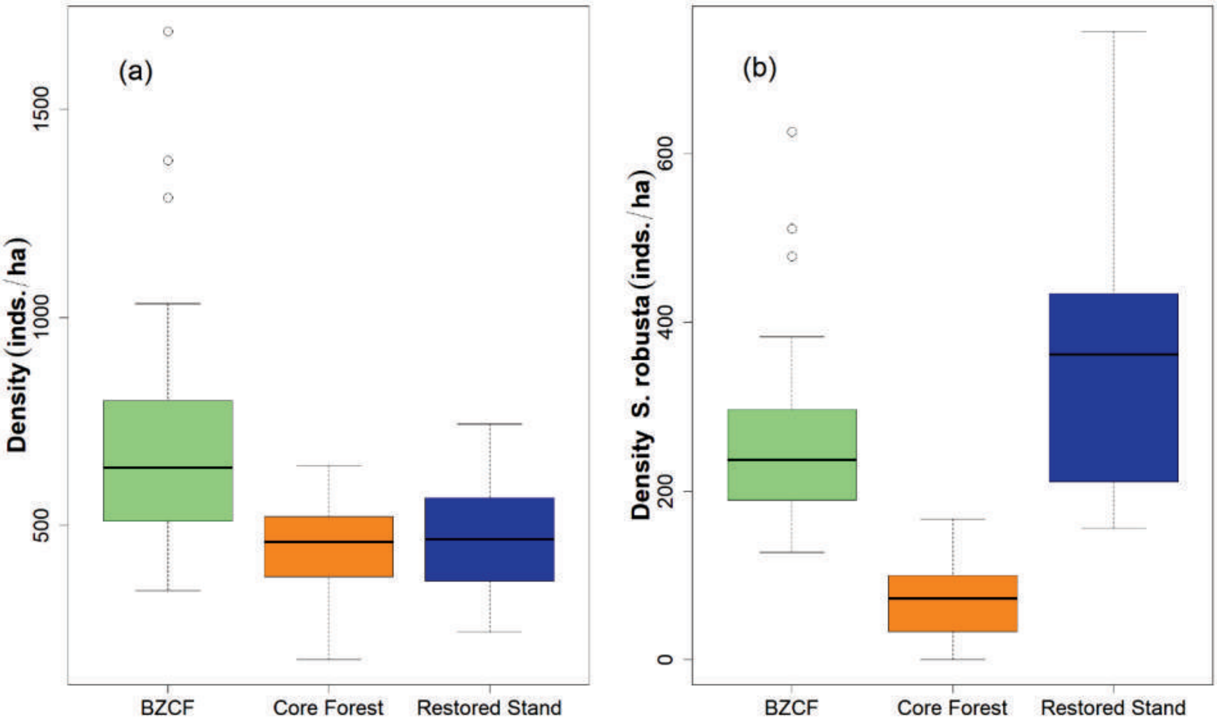

Figure 4: Density of overall species (a) and *Shorea robusta* (b)

and core forest (p=0.66). Similarly, highest *S. robusta* density was found in restored stands of BZCF (380.74±33.92 ind./ha) followed by natural stands of BZCF (272.43±21.89 ind./ha) and the core forest (73.33±8.43 ind./ha), respectively. The TukeyHSD pairwise comparison showed significant difference between all the forest management types. Chapagain et al. (2023) found highest species density in protected areas forest compared to BZCF, with significant difference between the studied sites. Likewise, Pandey et al. (2014) and Paudel and Sah (2015) also found high tree density inside national park as compared to the community forest. Poudyal et al. (2019) shows that selective harvesting support forest parameters, which might be the reason for this high density in the natural stands of BZCF compared to the core forest.

Forest Diversity

The Shannon diversity in natural stands of BZCF, core forest and restored stands of BZCF were 1.70±0.06, 2.12±0.06 and 1.12±0.06, respectively (Figure 5). Tukey HSD test showed significance difference in diversity between different management stands.

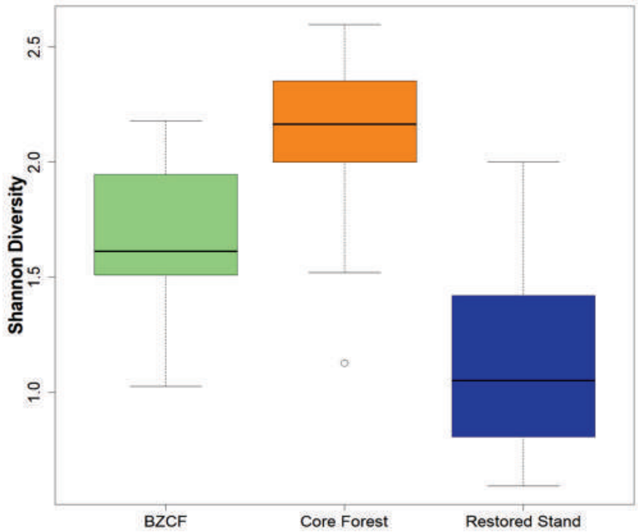

Figure 5: Plot level Shannon diversity of woody species in the studied forest stands

The species richness in core forest compared to other stands was higher which was similar with Awasti et al. (2015) and Chapagain et al. (2021), but they also found high species density in protected areas, while this study found high species densities in the restored stands of BZCF and natural stands of BZCF. Awasti at al. (2015) found low species richness in managed block and high species richness in unmanaged block, which was similar with this study. Whitfeld et al. (2008) found higher species richness on matured forest as compare to others, our study also correlates with their study, though they found more diversity in mature forest. But species diversity and richness were variable with functional habitat, biogeography, traits, grazing, social condition, disturbance and climatic variation (Whitmore, 1988; Tagle et al., 2008; Ratovonama et al., 2013; Jafari et al., 2013). Chapagain et al. (2017) found species richness changes with management practices.

Conclusion

This study has documented the woody species composition and diversity in different forest management stands in the sub-tropical forest ecosystems of Nepal. Our findings showed that the core forest had the highest species diversity, followed by the natural stands of BZCF and the restored stands of BZCF. *S. robusta* and *L. parviflora* with highest frequency (>80%) in all the forest management stands. Basal area of overall species and density of *S. robusta* were highest on the restored forest stands of BZCF, whereas overall species density was highest in the natural stands of the BZCF. Our findings emphasize the importance of considering forest structural attributes as indicators of health and integrity of the forest ecosystems. We recommend to assess the functional attributes of the different forest management stands to evaluate the effectiveness of forest management, and explore the interactions of different biotic and abiotic covariates in the future studies.

Acknowledgement

The authors are thankful to the University Grants Commission, Nepal for awarding with the research grant (Faculty Research Grant, Award No.: FRG-2076/77-S&T-4 received by the corresponding author and the second author of this manuscript). This research is a part for the accomplishment of the research activities of the grant. We would also like to acknowledge the Parsa National Park and the Department of National Parks and Wildlife Conservation, Government of Nepal for providing permission to access the forests. We are thankful to the Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University for providing administrative support for conducting the research.

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Journal of Environment Sciences (2023), **Volume IX**, 44-50
https://doi.org/10.3126/jes.v9i1.56477

Flood Loss Assessment - A Case Study of Dordi Basin, Gandaki, Province

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Abstract

Hydropower plants are a quintessential source of clean and economical energy, serving as the primary preference for renewable energy technologies for many governments owing to their unparalleled ability to deliver dependable baseload power with negligible fluctuation. However, despite their numerous benefits, the construction and operation of these plants pose a significant threat to the population living in the river basin and the equipment involved. The damage caused by flooding can have devastating and long-lasting impacts on the area, leading to severe economic losses and a prolonged period of recovery. In the case of the Dordi Rural Municipality, a study was carried out, which revealed that the Upper Dordi Hydropower Plant Headwork and Super Dordi Hydropower Plant inlet were ravaged by a ruinous flood, which resulted in the loss of twenty million equipment and eleven workers die. The cause of the flood was attributed to the upstream landslide blockage, which eventually led to the sudden bursting of the blockage and subsequent flooding. While the compensation of the workers was provided by the District Administration Office, Lamjung, and Dordi Rural Municipality through their incurrence policy, the study underscores the urgent need to establish a highly frequent flood warning system to alert the hydropower station and the local community. Additionally, the scouring and deposition process in the river channel was observed in detail, and the data analysis indicates no significant relationship between discharge and rainfall, emphasizing the importance of proactive measures to prevent future flooding events.

Keywords: *Channel, Damage, Hazards, Landslide, River*

Introduction

In many river basins with emerging economies, rising energy demands and campaigns to reduce fossil-fuel dependence have prompted the rapid expansion of hydropower (Zarfl et al., 2015; Zhang et al., 2017). Hydropower development, which could increase by over 70% in developing countries in the next few decades (Zarfl et al., 2015; IEA, 2016), is threatening ecosystems in basins with some of the greatest aquatic biodiversity (Winemiller et al., 2016). The basin's hydropower reservoir storage, which may upsurge from ~2% of its mean annual flow in 2008 to ~20% in 2025, is diminishing seasonal flow variability downstream of many dams with an integral powerhouse and large storage reservoirs (Hecht et al., 2019).

Nepal is one of the rich in hydro-resources, with one of the uppermost per capita hydropower potentials in the world. The estimated theoretical power potential is approximately 83,000 MW. However, the economically feasible potential has been evaluated at approximately 43,000 MW (Malla, 2013). Nepal has brilliant high potential for renewable water resources, possessing about 2.27% of the world's freshwater resources (Malla, 2013). Most of the rivers flowing from Nepal Himalayas covers 818,500 ha land area equivalent to 5%, of the total surface area of the country (Bhandari, 1992). The annual average discharge of the Nepalese rivers is about 7124 m^3/s including the total basin area and about 5479 m^3/s excluding the area outside of Nepal (Malla, 2013). River flood occurs when a river overspills its banks; that is when its flow can no longer be contained within its channel.

Flood hazards are worldwide considered one of the most significant natural disasters in terms of human impact and economic losses (Jonkman, 2005). The objective of the study is to assess and performs the impact of river flooding on the Upper Dordi hydropower project. Hydropower systems alter flow conditions in the downstream river reaches regarding both seasonal distribution and seasonal volume.

Materials and Methods

Study Area: Dordi River is a perennial snow-fed river located in Gandaki Basin in the Gandaki Province, Nepal. It is the tributary of the Marsyandi River. In the river channel alltogether four Hydropower Projects (HPP) are ongoing i.e. Himalayan HPP (27 MW), Dordi 1 HPP (10.3 MW), Upper Dordi HPP (21 MW) and Supper Dordi (49.6) the average gradient of Dordi River is 15%. The study was conducted in the Super Dordi HPP and Upper Dordi HPP. It lies in Dordi Rural Municipality, Lamjung District (Figure 1).

Methods

There are two ways of doing research: qualitative and quantitative methods in research (Crotty, 1998). In this study, both qualitative and quantitative methods have been applied. The study area was selected based on the flooding issues occurring every year and the heavy loss and damage faced by hydropower plants in the Dordi River. The field survey was conducted in last early months of 2020. The measurement of the cross-section and width, of the river channel, was carried out every 100 m difference. The thickness of deposition and scoring of the river channel was observed.

Meteorological data, particularly rainfall and temperature of the nearest station Khudi Bazaar (Index No.802), and discharge data (Index 349.6) were collected from the Department of Hydrology and Meteorology, Government of Nepal. The social data was collected from the Dordi Rural Municipality whereas focal group discussions (FGDs), and Key Informant Information (KII) were conducted. Data collected using different tools were first organized into an Excel sheet so they could be systematically analyzed in detail. Economic loss caused by flood is estimated by the cost of

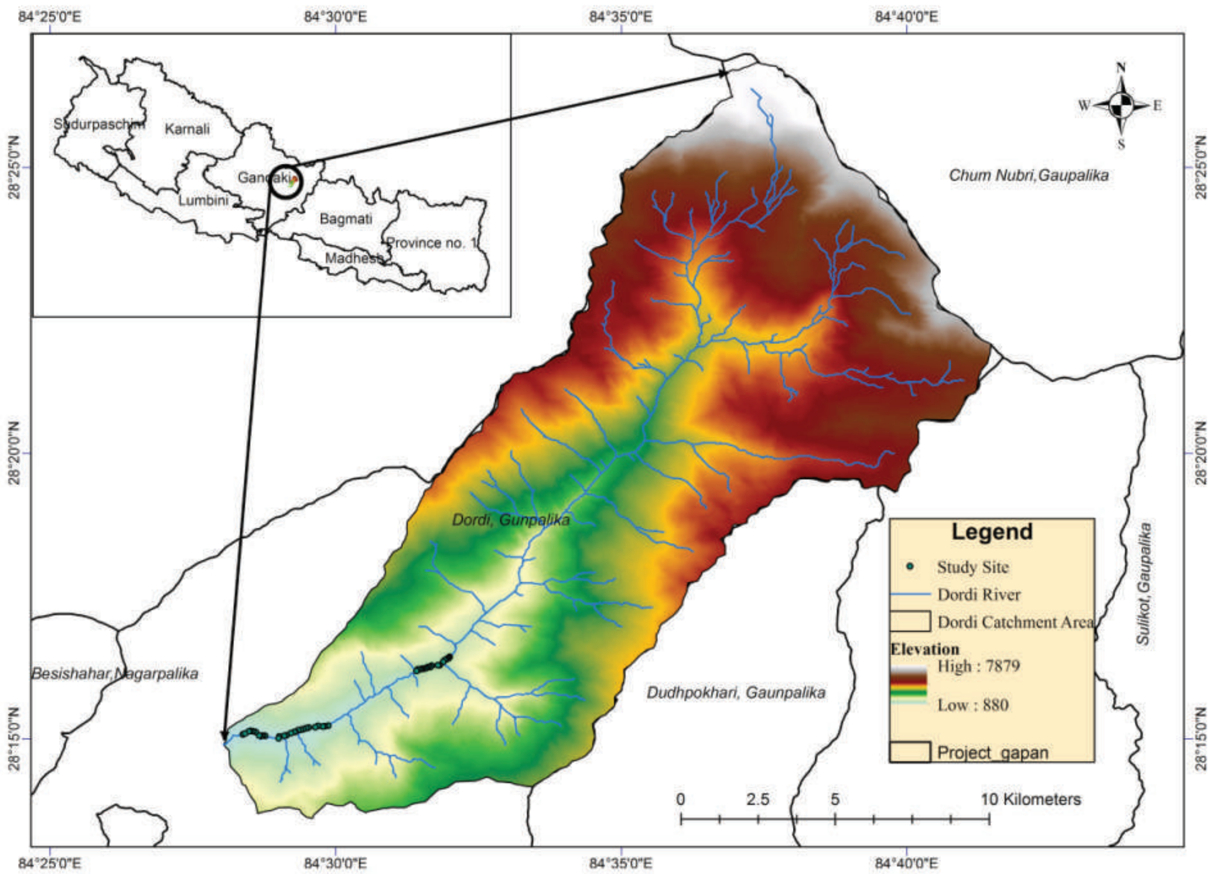

Figure 1: Map showing the Dordi river basin at Lamjung District in Gandaki Province.

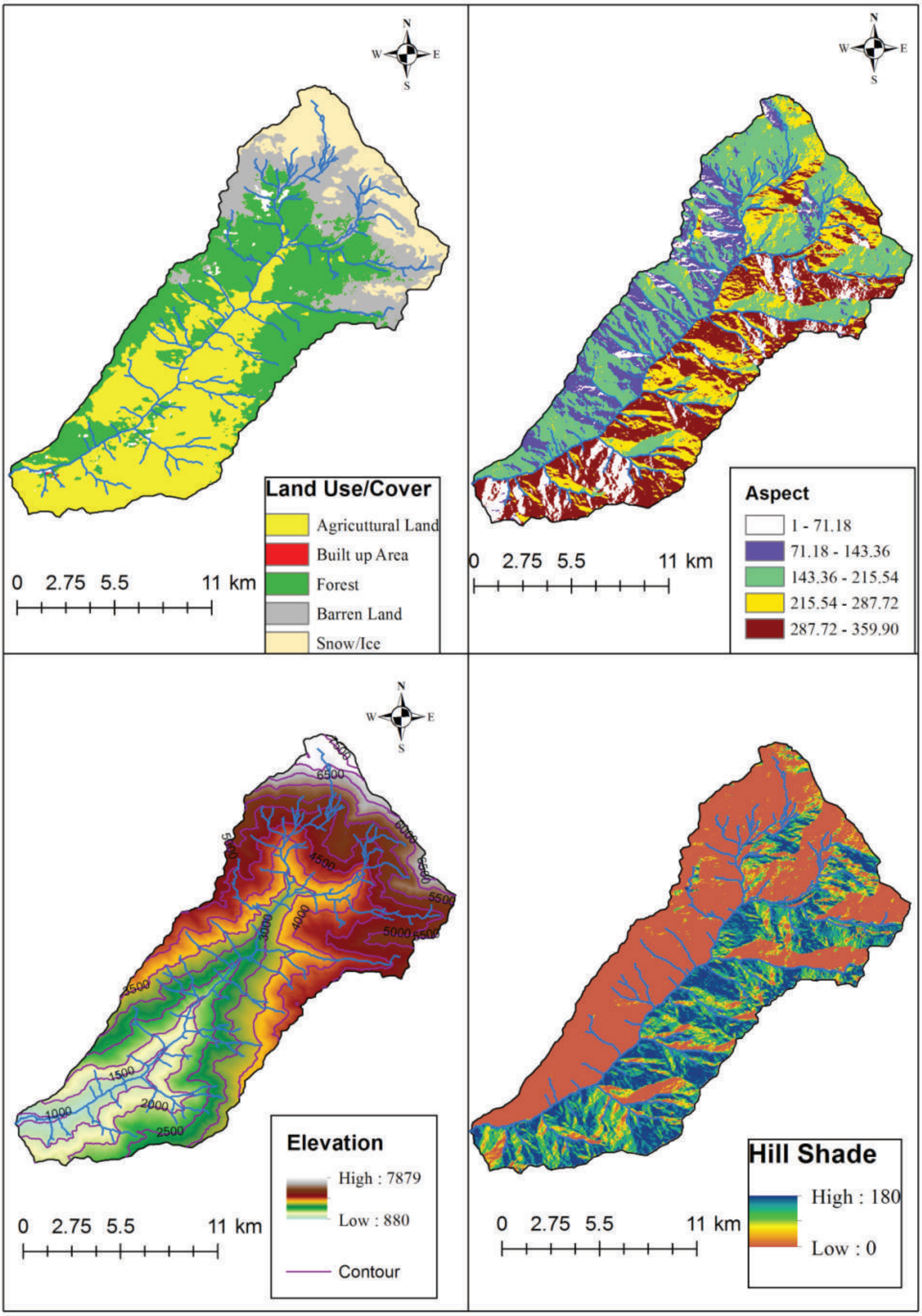

Figure 2: Dordi basin map of land use/cover, aspect, contour, and hill shade.

construction and instrument cost provided by the hydropower company. The data were analyzed by linear regression, bar -diagram, and scatter plot, and compare different variables by using Microsoft Excel 2016, ArcMap 10.2.1, and R studio.

Results and Discussion

Temperature and Rainfall

The average maximum temperature of 1988-2018 shows an increasing trend of 0.043°C/year, whereas the minimum temperature is in decreasing trend by -0.006°C/year. It reveals that those summer months are going hotter while winter months are going colder as shown in Figure 3. Similarly, rainfall data (1988-2018) indicated a decreasing trend. The maximum rainfall was observed in 1996 with a value of 4445.7 mm and the minimum rainfall was in 2014 with a value of 2070.3 mm. The trendline shows a decreasing trend of 15.7 mm per year (Figure 4). In the case of monsoon and winter months are taken while June, July, August, and September have been taken as monsoon months, and January, November, and December are taken as winter months. Monsoon rainfall is in decreasing trend of 14.36 mm per year whereas winter rainfall is slightly in an increasing trend by 0.57 mm per year.

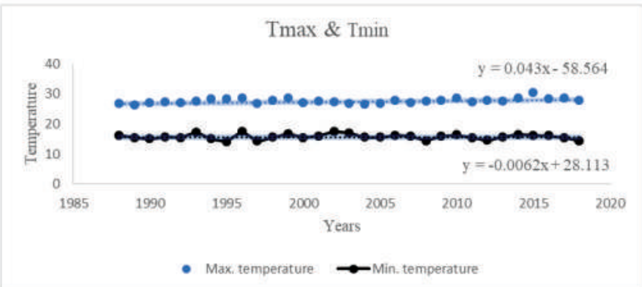

Figure 3: Maximum and minimum temperature trend (1985-2018).

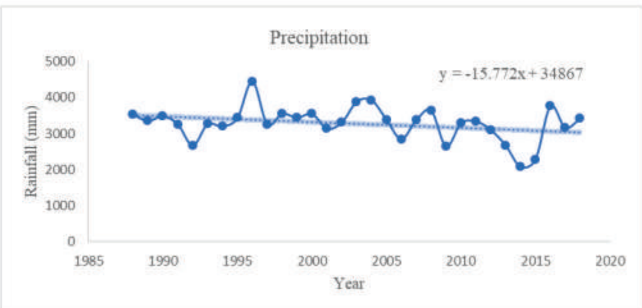

Figure 4: Annual Rainfall of 1985-2018 Dordi Basin.

Rainfall Discharge Relationship

Linear regression was applied to the relationship rainfall between and discharge. R-squared is a statistical measure of how close the data are to the fitted regression. The r-square value was 0.05, which illustrates that there is no relationship between discharge and rainfall. It showed that in heavy rainfall time, there was no high discharge rate. The relationship between the discharge and days shown in hump-shaped that the 25 July 2020 had peak discharge i.e. 338 m3/sec. It showed river was changeable in nature there is no sign of early flooding. Sudden rise discharge of the dordi river May landslide blockage in the upper stream; the burst accidentally and flood occur in the lower region of the hydropower dam construction site.

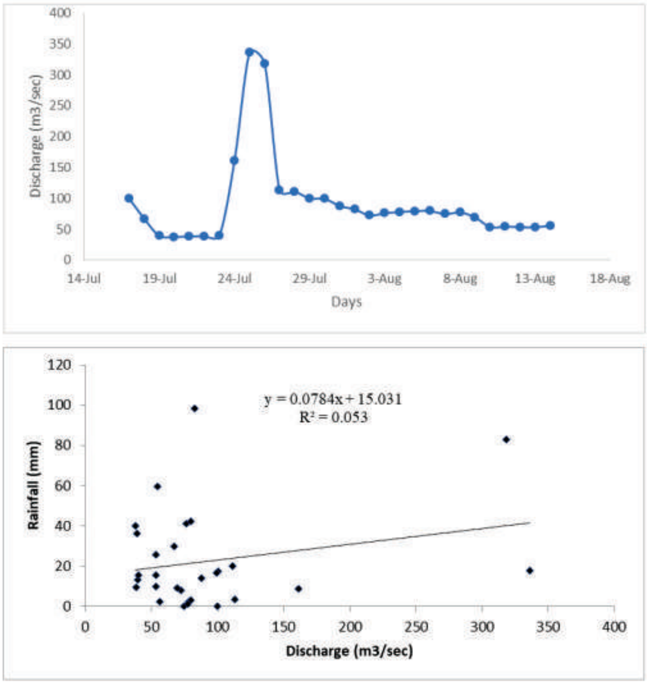

Figure 5: Relationship between (A) Discharge and days (14th July to 18th Aug 2020) (B) Rainfall and Discharge (14th July to 18th Aug 2020)

Channel Morphology

In nature, different river patterns occur but not all river patterns have an alike frequency of occurrence. R squared value of the optimum channel was 0.28 which means independent variables were correlated with the dependent variable. It shows that the optimum channel increases in a 2.32 m in every hundred meters. Cross sections are used to define the shape of the stream and its characteristics, such as roughness, expansion and contraction losses, and ineffective flow areas Channel erosion occurs by two separate processes, entrainment of channel bed sediment (scour) or mass wasting of channel banks, which consequences in channel banks collapsing into the channel bed. Channel scour happens when shear stress, controlled by channel slope and flow depth, exceeds the critical or threshold shear stress required for channel bed sediments to be trained.

The substantial widening of the Dordi channel during the flood of July 2020 was a typical morphological change caused by extreme floods in Mountain Rivers (Fuller, 2008; Krapesch et al., 2011; Nardi and Rinaldi, 2015). However, local conditions exerted a considerable stimulus on the spatial pattern of the river spreading. The alternation of short, channelized ranges where the channel width increased fewer and of longer, unmanaged reaches with the larger width increase markedly amplified downstream differences in active channel width in comparison with the pre-flood situation. Moreover, the largest increase in mean channel width and in the width, variation took place in the stretches in which the river is unconfined and its channel is entirely formed in alluvium. Channel scours are velocity-dependent and are extreme during large streamflow events. Several studies established that erosion in confined channel sections during bulky floods led to major changes in channel configuration (Fuller, 2008; Thompson and Croke, 2013). Several studies demonstrated that erosion in confined channel sections during large floods led to major changes in channel configuration (Fuller, 2008; Thompson and Croke, 2013).

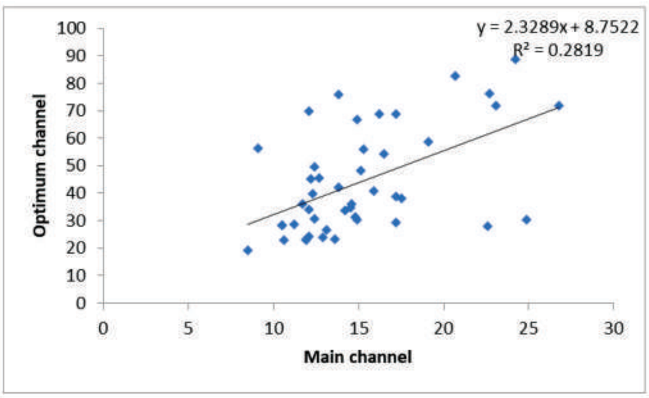

Figure 6: Relationship between an optimum channel and main channel.

Loss Damage

Natural causes of flooding in Nepalese rivers comprise fragile geological conditions, extremities in climates, topographical extremities, and seismic activities. The anthropogenic causes of flooding include socio-economic changes (population growth, poverty, and illiteracy), deforestation, unscientific agricultural practices, Land use changes, and other developmental activities. The real amount of flood damage generated by a specific flood happening is time and again a driving force that stimulates politicians to strengthen flood policy measures usually soon after flood events. It encompasses a wide range of harmful effects on humans, their health, and their belongings, on public infrastructure, cultural heritage, ecological systems, industrial production, and the competitive strength of the affected economy. Some of these damages can be specified in monetary terms, others – the so-called intangibles are usually recorded by non-monetary measures like the number of lives lost or square meters of ecosystems affected by pollution. Flood damage effects can be further categorized into direct and indirect effects. Direct flood damage covers all varieties of harm that relate to the immediate physical contact of flood water to humans, property, and the environment. Nepal is one of the most disasters prone countries to climate change and experiences frequent landslides, debris flows, and floods because of its varied topography and geological characteristics, together with torrential rain during the monsoon season. National estimates in Nepal suggest that flood events have on average killed almost 200 people and caused $35 million worth of damage every year since 1980. Low economic strength, inadequate infrastructure, low-level of social development, lack of institutional capacity, and higher dependency on natural resource makes the country vulnerable to change in a climatic system including variability and extreme events. Figure 7 shows the upper dordi hydropower, headwork construction site seven workers were killed, and five labour missing in the flood, and the estimated cost for reconstruction is $1,980,000. According to focal group informants and public perception in the afternoon, time flooding happened and the working condition of workers at the dam site was swept.

Conclusion

The extreme flood of July 2020 of the Dordi River changes the river morphology, and loss of flood in Super Dordi and Upper Dordi hydropower in Gandaki Province. The river morphology confirmed the ability of high-magnitude floods to considerably broaden the channels of Mountain Rivers. However, the pattern of the river widening reflected the legacy of hydropower as well as human impacts on the Dordi River. It revealed that the abrupt release of water is not due to normal operation at the hydropower stations in the Dordi River, but is due to sudden discharges at the rupture of blockage of the landside. From the analysis there is no relationship between rainfall and discharge, data analysis shows that discharge suddenly upsurges.

Acknowledgement

I would like to thank the Central Department of Environmental Science, Kirtipur for providing an opportunity to conduct this case study, the staff of super dordi hydropower, upper dordi hydropower and local people for providing support in the field.

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Figure 7: Comparative photographs of hydropower site before and after the flood.

Journal of Environment Sciences (2023), **Volume IX**, 51-66
https://doi.org/10.3126/jes.v9i1.56479

Wildlife restoration in Nepal: tracking the conservation translocations in the country

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Abstract

Negative consequences of human impacts on biodiversity are undisputable and inadequate efforts in managing biodiversity have been realized across the globe. The present biodiversity crisis, including burgeoning effects of climate change, therefore, has warranted restoration actions in place. Conservation translocation, one of the effective measures of restoration, involves the individuals of species deliberate movement from one habitat to another, particularly animal species. Nepal has been practicing the conservation translocations for more than four decades. However, details of conservation translocation events and outcomes are not well documented. This article aims to explore the status and issues of conservation translocation in Nepal. . For the purpose, we reviewed seven protected area management plans and nine species conservation action plans available in public domain along with related peer reviewed journal articles. We documented the conservation translocation of Blackbuck, Gharials, Swamp deer, Greater One Horned Rhino, Elongated tortoise, Narrow Headed Soft Shell Turtle, Wild Water Buffalo and Vulture. Adoption of feeble adaptive management framework and ad hoc approach of wildlife translocation has left many rooms for improvement in the translocation strategies of Nepal. This is largely exemplified by the improvement required in Vulture Breeding Center, Swamp deer and Wild water buffalo translocations to Chitwan National Park, and Blackbuck translocation to Bardia National Park. For many species, data and information are limited to evaluate the wildlife restoration outcomes independently.

Keywords: *Reinforcement, Swamp deer, Turtle, Wild water buffalo*

Introduction

Biodiversity engenders critical life support system as it provides ecosystem services - the key to the wellbeing of humans (Wang et al., 2021). Currently facing tremendous extinction threats due to anthropogenic pressures, particularly overexploitation and agricultural activities, impacts of climate change on biodiversity are anticipated to affect many species in the future (Maxwell et al., 2016). As the human population is increasing at an exponential rate, more than eight billion by 2022 and accelerated per capita resource consumption, we can expect increased pressure on natural resources leading to further degradation of the ecosystems and human well-being (Gross, 2023).

Biodiversity in Nepal is facing multitude of challenges. Land use land cover change, urbanization and associated effects in those areas are affecting species and ecosystems that have detrimental consequences for ecosystem services and wellbeing (Aryal et al., 2020; Chaudhary et al., 2016). Infrastructure development is causing habitat degradation even in the ecosystems within the protected areas and the trend is expected to increase in the near future (Sharma et al., 2018). Observed and anticipated impacts from climatic changes in the Himalayas have shown the necessity of researches to ensure climate sensitive conservation planning and implementation (Bhattacharjee et al., 2017). There is a dire need for the evidence based intervention for the conservation of threatened biodiversity in Nepal (Paudel & Heinen, 2015).

In the past, conservation biology was proposed as essential element to revert the loss of biodiversity and associated degradation of ecosystem services

(Young, 2000). However, as of now, unsustainable exploitation and consumption of resources are increasing and impact of climate change is increasing rapidly. For sustainable solutions to the pressing problems in biodiversity conservation, ecological restoration is the key and this has been realized from global commitments made to address environmental and social problems. For example, New York Declaration on Forests (NYDF) adopted in 2014 and refreshed on 2021 aims to restore at least 350 million hectors of forest (https://forestdeclaration.org/about/new-york-declaration-on-forests/) (Forest Declaration, 2021) while United Nations Decades on Ecosystem Restoration 2021-2030 aims "to prevent, halt and reverse the degradation of ecosystems at every continents and every oceans as a means to end poverty, halt climate change and prevent mass extinction" (UNEP & FAO, 2022).

Properly executed restoration activities are important to restore individual species, ecosystem function and ecosystem services (Harrington et al., 2013). Ecological restoration involves the restoration of the ecosystem or components of those and includes integration of several fields. Not only traditional approaches, this has emphasized multi-stakeholder collaboration using newer mechanisms and arrangements from local to global scales (Martin, 2017; Uprety et al., 2012). Ecosystem restoration involves restoration of the species, habitat, population, or landscape or the restoration of the services, including the conservation translocation.

Conservation translocations are the planned movement of the animals from one habitat to another for the purpose of reaching the conservation outcomes (IUCN/SSC, 2013). Various forms of conservation translocations are being practiced throughout the world. They are grouped either as population reintroduction and conservation introduction based on habitat use history of the site. If the release is made on habitat already used by the species at any time in the past or present, it is known as population reintroduction while if they are released to totally new environment they are known as conservation introduction (IUCN/SSC, 2013)., Population reintroduction are grouped into two classes viz. reintroduction and reinforcement and both are commonly practiced (Corlett, 2016). In reintroduction program, animals are released to their native range while in reinforcement program; individuals are released into existing population (IUCN/SSC, 2013). Animal reintroductions are carried out with the objectives of ensuring the survival and reproduction of the species and establishment of the viable population of the species at the end (Shier, 2015). There is possibility of translocation science being the face of the conservation biology as the innovation in the field could be vital to halt the biodiversity loss across the globe (Evans et al., 2023).

Translocation of wildlife is a complex problem with financial, political, ecological and socio-economic opportunities and constraints and the successful execution requires a systematic and structured approach to project planning and implementation (Schwartz & Martin, 2013). Global practices of conservation translocations have provided lessons on some criteria and indicators to consider before, during and after conservation translocations (Soorae, 2021). A clear recipe is possible neither for what species to include nor about where to do interventions. These decisions should be guided by existing and future scenarios of dynamic socio-environmental domains. However, the sciences, both the natural science and social sciences receive due considerations in the decision making. Furthermore, reintroduction process involves a series of the decision making steps and in each phase, there are possibilities for the alternative decisions to be taken which will be vital for the ultimate fate of the whole projects (Panfylova et al., 2019). Our ability to make a rational choice is compromised by human error in judgment, and structural decision-making can act as a tool to address the same (Panfylova et al., 2019). Despite the growth of the conservation translocation as a tool of conservation, analysis of comprehensive of pattern of translocation is not possible due to inadequate regularly updated and accessible database (Novak et al., 2021), which also holds true for Nepal.

Thus, in this review, efforts have been made to analyze the translocation movements in Nepal with the aim of i) analyzing context of conservation translocation planning documents and ii) understanding the execution of the conservation translocation and outcomes after a time span.

Materials and Methods

Study area

Nepal (28.3949° N, 84.1240° E) with an area of 147,516 km2 has wide altitudinal variation ranging from 60 m to 8848 m within the north south stretch of nearly 193 km resulting in five major physiographic regions (Tarai, Siwalik, Hill, Middle Mountain and High Mountain, Figure 1). Each of these physiographic regions has diverse climatic condition. Furthermore, Himalaya is formed by the collision of Indian Plate and Eurasian Plate and Nepal is a part of the Himalaya. Nepal is also located at the junction of two biogeographic realms Palaeartic in the North and Indo-Malayan in the South (GoN/MoFSC, 2014). These factors result in 118 ecosystem types in Nepal, 75 vegetation types, and 35 forest types in Nepal (DNPWC & BCN, 2018). Furthermore, within less than 1% of total land area of world, Nepal has around 2.7% flowering plant species, 4.5% of mammal species, 9% of bird species, 2.6% of butterfly and moth species of the world (DNPWC & BCN, 2018). Nepal is a home to 212 species of mammals (Amin et al., 2018), 57 species of amphibians and 143 species of reptiles (Rai et al., 2022). Nepal has established a wide range of protected areas that includes 12 national parks, six conservation areas, one hunting reserve and a wildlife reserve, and there are buffer zones in the periphery of 12 national parks.

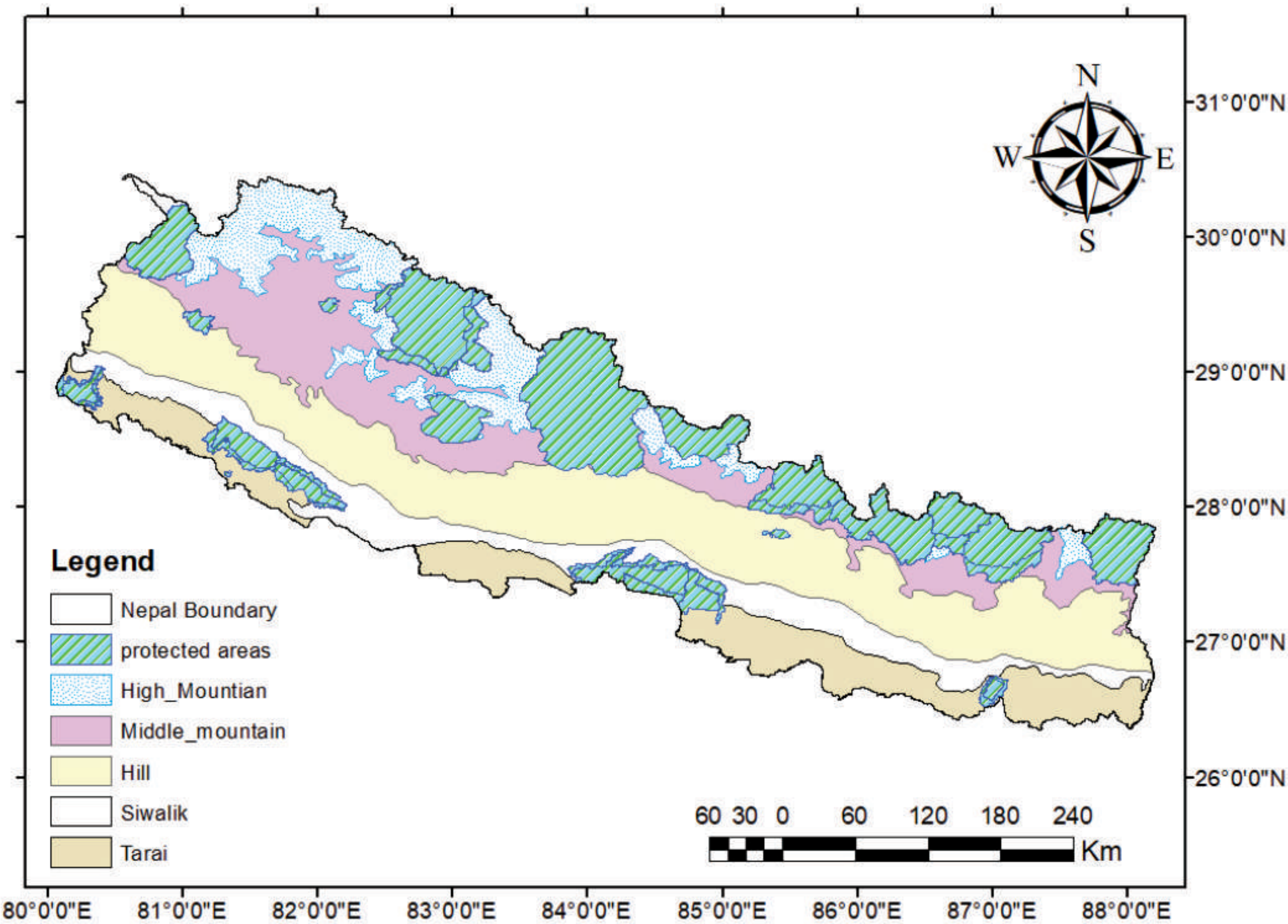


Figure 1: Map of Nepal showing the physiographic region and protected areas.

Methods

This study is primarily based on the review of species conservation action plans, management plans of the protected areas and government reports that are available on the website of Department of National Parks and Wildlife Reserve (DNPWC) and websites of the protected areas. Government of Nepal periodically updates the management plans of protected areas and species conservation action plans with revisions. Thus, whenever there were more than two reports or documents on the online archives, only the recent ones were reviewed to explore the provisions related to conservation translocation. Data on the conservation translocation that has been carried out till date were compiled from published government reports and data visualization was done using ggplot2 (Wickham, 2016) in R (R Core Team, 2021) implemented in RStudio (RStudio Team, 2022) . Since we have not used specific testing methods and techniques to reach a conclusion, the results should be taken as simple interpretation of the basic status rather than cause - effects as well as do's and don'ts.

Results and Discussion

Conservation translocations in Nepal have largely been response of conservation authorities towards degraded habitats and declining populations, chiefly of large vertebrates, in lowlands. Reintroductions have been long suggested to address the issues of faunal collapse that have occurred in the Tarai regions including the protected areas (Heinen & Yonzon, 1994) and some efforts have been made (Acharya *et al*., 2017; Thapa et al., 2013). In this article, we attempt to compile information on state of wildlife translocations in Nepal by exploring existing protected area management plans, species conservation action plans and selected cases.

Conservation translocation in conservation plans

Conservation translocation in Nepal has been identified as an important management tool by both the protected area management plans and species conservation action plans. Management plans of seven protected areas mention about the translocation (Table 1). Greater One Horned Rhinoceros (rhino hereafter), Swamp deer, Gaur, Wild Water Buffalo and Blackbuck are the primary mammals that are prioritized for translocation in protected areas of Tarai, while Swamp francolin is the only bird listed by the protected area management plans in Tarai Region for translocation. Blue sheep translocation is stated by management plans of Lamtang NP and Sagarmatha NP. All seven PA Management Plans have focused on inter park translocation except Chitwan National Park prioritizing intra park translocation so as to conserve and reduce mortality of Rhino.

Table 1: Provision of Conservation Translocation in Protected Area Management Plans

SN	Management Plan	Translocation related focus	Translocation related provisions	Source
1	Management Plan of Bardia National Park and its Buffer Zone (FY 2079/80-2083/84 BS)	Study	Conduct feasibility study in the source site and release site for translocation of Rhino	(BNP, 2022)
		Translocation	Translocate additional 50 individuals of Rhino to BNP from Chitwan National Park, 50 individuals of Swamp Deer to establish viable population and 50 individuals of Gaur from Chitwan-Parsa Complex to sustain alternative viable population in western Nepal.	
2	Lamtang National Park and its Buffer	Study	Conduct the feasibility study to translocate Blue sheep to LNP as a way to supplement the prey base of Snow	(LNP, 2020)

	Zone Management Plan (FY 2077/78 – 2081/82 BS)		Leopard	
3	Snow Leopard and Ecosystem Management Plan (2017-2026)	Study	Conduct Feasibility Study to assess reintroduction potentiality of prey base of Snow Leopard	(MoFSC, 2017)
4	Banke National Park and its Buffer Zone Management Plan (FY 2075/76-2079/80 BS)	Translocation	Translocate Blackbuck to BaNP	(BaNP, 2018)
5	Koshi Tappu Wildlife Reserve and Its Buffer zone management plan (FY 2074/75-2078/79 BS)	Study	Conduct feasibility studies for translocation of rhino and swamp deer, tiger and large carnivores including leopard. Conduct feasibility study in other PAs to translocate Swamp francolin (*Francolin gularis*) and Wild Water Buffalo. Study the failure of Gharial Release in the Past.	(KTWR, 2018)
		Translocation	Proposes a strategy to translocate and introduce new breed of Wild Water Buffalo from Assam India	
6	Management Plan of Krishnasar Conservation Area (BS 2074/75-2078/79)	Study	Status study of the translocated population and identifying sites suitable for further translocations as research priority.	(KrCA, 2017)
		Translocation	Translocate Blackbuck to other protected areas with similar habitat.	
7	Sagarmatha National Park and its Buffer Zone Management Plan 2016-2020	Study	Conduct feasibility study to translocate blue sheep to supplement prey species of Snow Leopard.	(GoN/MoFSC/DNPWC/SNP, 2016)
		Translocation	Translocation of blue sheep to SNP as a mitigation measure for human-wildlife conflict.	
8	Chitwan National Park and its Buffer Zone Management Plan 2013-2017	Study	Conduct feasibility study to translocate rhino to other parts of CNP. Explore the possibility of reintroducing Wild water buffalo to CNP. Initiate the feasibility study to translocate Gaur to BNP from CNP.	(GoN/MoFSC/DNPWC/CNP, 2013)
		Translocation	Remains open to translocate rhino from the high density areas to other PAs Proposes to reintroduce a sizeable population of swamp deer in Sukhibhar area of CNP	

Most of the provisions in the species conservation action plans are analogous to the plan mentioned in the protected area management plans (Table 1 and Table 2). However, some of provisions are novel in species conservation action plans *viz.* Dolphin translocation management plan is in place not included in PA management plans.

Translocation of the species is a complex issue which demands the prediction and execution of conservation translocations based on state of the art science and refinements of translocation techniques (Evans et al., 2023). The casual factors of the rarity are species specific, meaning we need to customize the reintroduction success criteria to incorporate the differences (Haskins, 2015). However, the provisions mentioned in most of the species conservation action plans of Nepal are too generic confined to listing the activities- study or translocation actions.

For instances, though the genetic study on Cheer pheasant is almost nonexistent in case of Nepal, the species conservation action plan has recommended the translocation of some individuals between the populations to address genetic depression (DNPWC & DFSC, 2018). Similarly, translocation of blue sheep to Lamtang National Park and Sagarmatha National Park has been prioritized by the PA management plans (Table 1), however the Snow Leopard Conservation Action Plan for Nepal (2017 – 2021) remains silent on same (DNPWC, 2017a) and the blue sheep translocation is purposed for enriching prey availability of Snow Leopard. Conservation translocation does not necessarily results in enhancement of the species populations, they can add challenges such as reduced genetic fitness, transmission of diseases and so on (Berger Tal et al., 2020; Peters et al., 2020) which are not adequately addressed by the action plans.

Table 2: Issues of Conservation Translocation in Species Conservation Action Plans

SN	Species Action Plan	Translocation related focus	Translocation related provisions	Source
1	Dolphin Conservation Action Plan 2021-2025	Translocation	Identifies the essentiality of either immigration from India or translocation for maintaining the viable population of Gangatic Dolphin even for the largest population of Koshi	(DNPWC & DoFSC, 2021)
2	Gaur Conservation Action Plan for Nepal 2020-2024	Study	Proposes to conduct habitat suitability and translocation possibility of Gaur in BaNP, BNP, KTWR, and Trijuga forest of Udayapur district	(DNPWC, 2020a)
		Translocation	Proposes to translocate Gaur to KTWR and Triyuga Forest to create meta population in eastern Nepal	
3	Wild Water Buffalo (*Bubalus arnee*) Conservation Action Plan for Nepal(2020-2024)	Study	Proposes to undertake assessment and lesson learning of translocation of Wild Water Buffalo to CNP	(DNPWC, 2020b)
		Translocation	Proposes to translocate additional 25 Wild Water Buffalo to CNP to increase the herd size Identifies the potentiality of translocation of Wild Water Buffalo to BNP on basis of success of translocation to CNP	
4	Pheasant Conservation Action Plan for Nepal (2019-2023)	Study	Recognizes the problem of Genetic Depression in case of Cheer Pheasants of Nepal and proposes to conduct genetic study	(DNPWC & DFSC, 2018)

		Translocation	Identifies the translocations of some individuals from one population to other to address issues of genetic depression	
5	Gharial Conservation Action Plan for Nepal (2018-2022)	Upgrading	Identifies the needs to systemization ex-situ conservation with development of Gharial husbandry and management guideline, release protocol and sharing best practices. Identifies the necessities to develop capacity of human resources	(DNPWC, 2018)
6	The Greater One-horned Rhinoceros Conservation Action Plan for Nepal (2017-2021)	Study	Aims to assess the habitat suitability for Rhino at KTWR	(DNPWC, 2017b)
		Translocation	Proposes to translocate at least 10 rhino to SuNP and 15 rhino to BNP to support meta-population network	
			Proposes intra park translocation of Rhino from high density region of park to low density region as a means of increasing population	
7	Site Specific Conservation Action Plan for Blackbuck in Shuklaphanta Wildlife Reserve, Nepal 2016-2020	Study	Remains open to collaborate between Shuklaphanta Wildlife Reserve and research and academic institutions to conduct research and monitoring related to blackbuck translocation Conduct feasibility study to establish another population in other Pas	(DNPWC, 2016a)
8	Tiger Conservation Action Plan for Nepal (2016-2020)	Translocation	Identifies swamp deer and wild water buffalo as ecosystems and identifies their reintroduction to the CNP as a means to maintain the grassland and wetland in the Park	(DNPWC, 2016b)
9	Vulture Conservation Action Plan for Nepal (2015—2019)	Reintroduction	Aims to use captive breeding and reintroduction as complementary measures to in-situ conservation interventions to prevent the extinction of species of vulture in Nepal	(DNPWC, 2015)
		Planning	Identifies the need of translocation plan and building and infrastructure for the future release of captive breed vulture	

Conservation translocation practice in Nepal

Conservation translocation in Nepal is predominated by the population reintroduction and both forms of population reintroduction i.e. reintroduction and reinforcement are in practice. Gharial breeding (in CNP and BNP) and releases in Narayani, Rapti and Babai; turtles released in areas of CNP, Swamp deer translocation to BNP and Vulture breeding and release program represent the examples of conservation reinforcement. In the meantime, Swamp deer translocation to CNP, Rhino translocation to ShNP and BNP, Gharial release to Koshi and Kaligandaki Rivers, Blackbuck translocation to Hirapur Phanta of Shuklaphanta and Bagaura Phanta of BNP, and wild water buffalo translocation to CNP represents the example of reintroduction.

Gharial breeding and release

Gharial population throughout the range in 1940s was estimated to be 5000 – 10000 individuals that were reported to decline to less than 200 individuals in 1970s (Whitaker, 2007). The decline is attributed to a diverse array of anthropogenic interferences such as exploitation, changes in riverine habitat quality and infrastructure being a few among many (Lang et al., 2019). To halt the species declines, Government of Nepal initiated a Gharial Conservation Program (Gharial Conservation Breeding Center – GCBC) in Chitwan National Park (Maskey et al., 2006). GCBC protects the nesting habitat of Gharial, collects the eggs from nests, hatches those eggs and carries out in-situ releases (Maskey et al., 2006). Up to 2022, altogether, 1692 Gharials that have been hatched and reared at the Gharial Breeding center have been released in different river systems of Nepal (Figure 2a). Most of the releases (82.21%) have been done at Rapti and Narayani Rivers of Central Nepal (Figure 2b.) and 57.44% of the release have been done at Rapti River alone. Furthermore, a male Gharial was captured from the Babai River and was released to the Rapti River in 2017 (CNP, 2018).

The population of the Gharial has been increasing gradually in the rivers of Nepal with the reported population of 198 individuals in 2016 (GoN/MoFE/DNPWC, 2022). Though, abundance is a poor measure of the reintroduction success (Shier, 2015), recovery of the population of species which was once presumed to follow the path of extinction (Whitaker, 2007) should be taken as positive sign. However, in one year of release 50% of the released population is reported to disappear, indicating the low success of reintroduction (Ballouard et al., 2010). Furthermore, the population of the Gharials is heavily female skewed in case of Chitwan Population compared to that of Bardia (Bashyal et al., 2021). As the sex in the Gharials, particularly during the population monitoring are determined by visual observation of ghara, amateurs usually cannot differentiate between the sub-adult male and female, which could be one of the reasons for reported bias in male female ratio (Bashyal et al., 2021). Still, the male biased population in CNP was reported to add challenge in conservation of Gharials with reported decline of reproductive success. To address the issue, a male Gharial was captured at Babai, and was released to Rapti River (CNP, 2018).

Blackbuck conservation

There is over 45 year long history of Blackbuck translocation in Nepal. A total of 52 individuals were translocated from Khairapur and Central

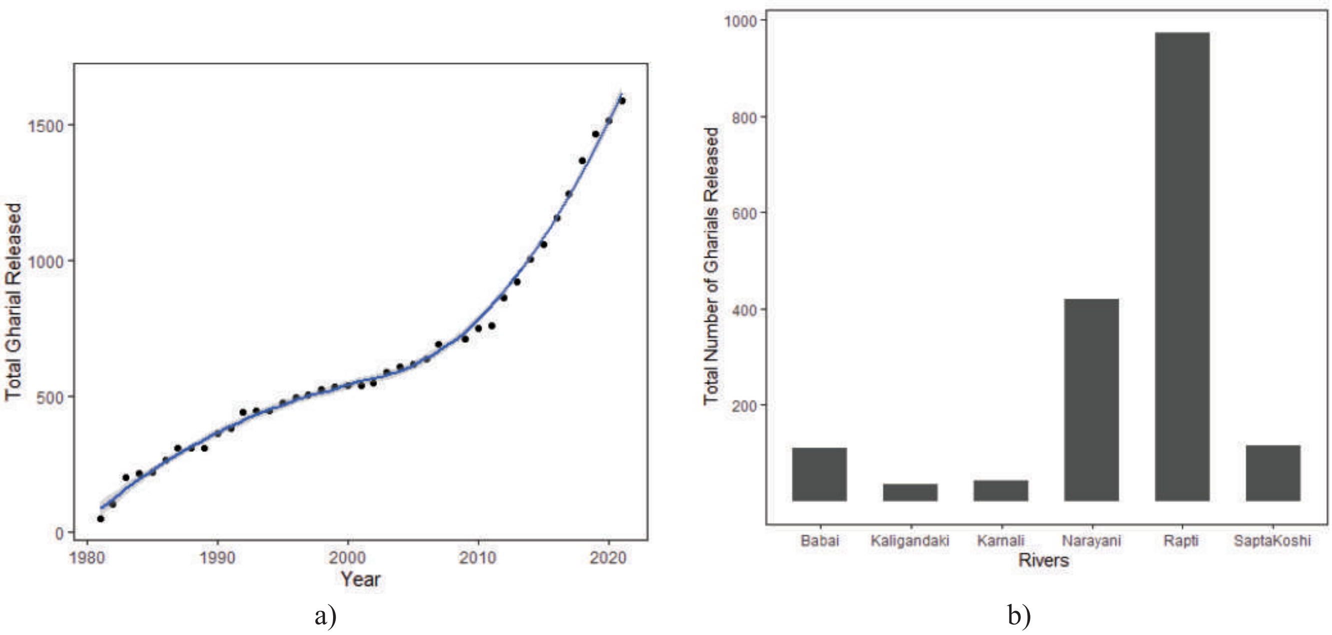


Figure 2: Gharials released in different rivers of Nepal a) Cumulative number of Gharials released b) river wise number of gharials released (Source: (CNP, 2022))

Zoo in three different incidents (Table 3) (Bist et al., 2021; DNPWC, 2016a). Blackbuck usually prefers the habitat with the short grasses however, Bhaugara Phanta were dominated by tall grassland, thus unsuitable habitat and predation resulted in extirpation of the species (DNPWC, 2016a). Habitat quality is the most important factors in translocation and without high quality habitat the success of translocation are low regardless of the number of the animals released and preparatory works carried out (Griffith et al., 1989).

Starting from 2012, efforts are being made to establish the second population of Blackbuck in Hirapur Phanta of Shuklaphanta National Park and 28 individuals were translocated (Table 3) and are now kept at enclosure. The site specific plan aims to expand the area of the enclosure to 40 ha from 17 ha current (the then) areas (DNPWC, 2016a) and later release the species to open space when the herd size reaches 100 and this abundance based decision could be counter-productive. Population size is a poor indicator of the extinction risk, particularly in case of the reintroduction program (Shier, 2015). Furthermore, the individuals kept in closed conditions such as zoos are supposed to have evolved under the relaxed selection pressure and are more adapted to the ex-situ habitat conditions (Lacy, 2013). That adaptation could be a maladaptation to the conditions of natural environment. As the source population of blackbuck for Hirapur Phanta is either the zoos or another closed population from Khairapur, those individuals could potentially have poor defense mechanism against natural predators and other factors due to contemporary evolution. Pre-release training of the captive breeding animals are suggested to ensure they can adapt to the new environment (Yang et al., 2018). Concerned authority should plan the training of the blackbuck in the aspects such as defense against predators, before completely releasing them in natural habitats.

Greater One Horned Rhinoceros (Rhino) translocation

Rhino translocation was initiated in Nepal in 1986 by translocating 13 individuals from CNP to Karnali Flood Plains of BNP and continued till 2017. During the period, a total of 100 Rhino have been translocated to BNP and ShNP (Figure 3a). The reintroduced rhino population declined during the Maiost insurgency period (1996-2006) particularly due to poaching. A total of 36 rhinoceros were killed between 1999/00 and 2004/05 (DNPWC, 2006; M. Khadka & Thapaliya, 2007). In 2007 census, only 31 Rhino were recorded from BNP, nearly one third of 83 individuals translocated to the park between 1986 and 2003 (DNPWC, 2009). The population is recovering gradually (Figure 3b), and surpassed half the number, 38 in BNP and 17 in ShNP (GoN/MoFE/DNPWC, 2022), translocated from CNP.

Habitat management and protection measures are essential to maintain the rhino population in CNP. To protect this species, there is dire need to establish the metapopulation network through translocation of rhinos in other protected areas of Nepal (Sinha et al., 2011; Subedi et al., 2017). Population viability analysis (PVA) also supports this idea, which indicates that rhino populations of BNP are prone to local extirpation if they are exposed

Table 3: Chronological records of Blackbuck translocation in Nepal

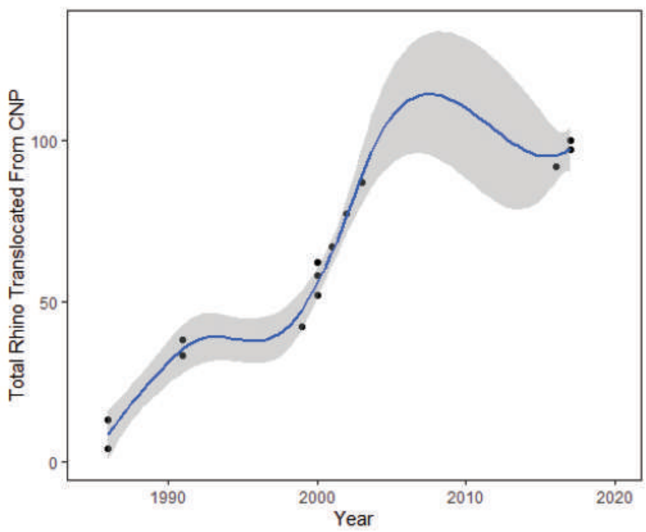
Year	From	To	Animals Translocated
1977	Khairapur	Baghaura Phanta, BNP	8
1987	Khairapur	Baghaura Phanta, BNP	17
1987	Central Zoo, Jawalakhel	Baghaura Phanta, BNP	27
	Sub total		**52**
2012	Mini Zoo, Nepalgunj	Hirapur, ShNP (then SWR)	22
2012	Central Zoo, Jawalakhel	Hirapur, ShNP (then SWR)	6
2015	Khairapur	Hirapur, ShNP	14
	Sub total		**42**
	Total		**94**

Source: (DNPWC, 2016a; GoN/MoFSC/DNPWC, 2017) to poaching pressure while translocation of 3 individuals regularly for 30 years can establish self-sufficient population (Kafley et al., 2015) justifying translocation needs. Chitwan populations were found to be stable and have potential to become source population in both PVA and population and habitat suitability analysis (PVHA) though the degree of contribution differed between the two studies. PAV indicated that CNP can supplement 10 to 15 individuals every three year (Kafley et al., 2015) if properly managed, Chitwan can supplement eight males and five females annually to establish other population (Subedi et al., 2017).

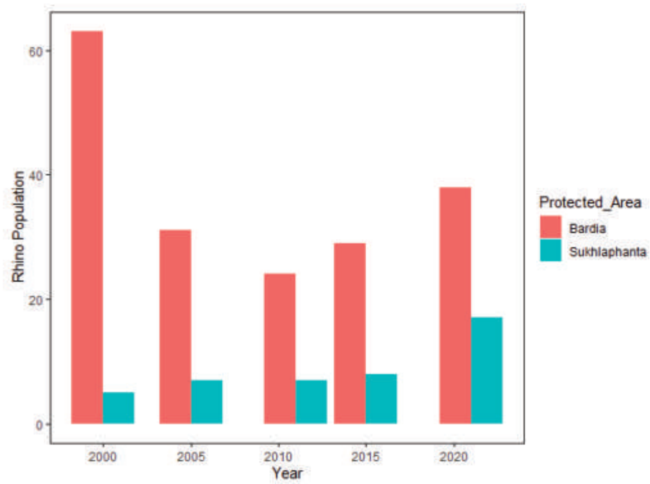
Wild Water buffalo

As majority of the area in KTWR is prone to the peak floods and buffer zone of the reserve is devoid of natural forests, Wild Water Buffalos are forced to seek refuge in the cropland during floods (Heinen & Paudel, 2015). Furthermore, resuming the risk of an unforeseeable future catastrophe, recommendations were made to establish the second population of the Wild Water Buffalo outside KTWR, and CNP was suggested as a suitable habitat based on the evidence of being the past home of the species, a better protected national park, and the firm availability of the suitable habitats (Heinen & Kandel, 2006). Furthermore, 8.92 Square Kilometer of Babai Flood Plains of BNP was identified as suitable site for the species, based on geospatial and vegetation based habitat suitability (Thapa et al., 2020). Biological feasibility, social feasibility, regulatory compliance and resources availability are crucial for successful animal translocation (IUCN/SSC, 2013). However, most researches done to guide conservation rely heavily on geospatial tools and partial analysis of vegetation which are insufficient to cover full range of biological feasibility.

Fifteen wild water buffalos, 12 from KTWR and three from the Central Zoo and were translocated to the 30 ha enclosure in Padampur area of CNP in 2017, of which four females died in the same fiscal year that includes all three from Central Zoo (CNP, 2018; GoN/MoFSC/DNPWC, 2018). In the span of 5 years, the translocated population gave birth to six calves and showed hope for establishment of reintroduced population. Later on, all of the Arna translocated died and the population is zero at present (GoN/MoFE/DNPWC, 2022) and the causes are believed to be management issues. Poor planning, lack of resources and ignorance to the avoidable issues have been the cause of the reintroduction failure in the past (Haskins, 2015) and recent Arna translocation outcomes conform to this.



a)



b)

Figure 3: a) Cumulative number of Rhino translocate to Bardia NP and Shuklaphanta NP b) Population of Rhinoceros in BNP and ShNP at different year (Source: (GoN/MoFE/DNPWC, 2019))

Swamp Deer

Five individuals of Swamp deer (2 male and 3 female) were translocated to BNP in 2016 while seven (7) individuals (5 female and 2 male) were translocated to CNP in 2017 (Table 4). In CNP, Swamp deer were kept in the enclosure made at Padampur. However, all the individuals died (Heinen et al., 2019) within one year of translocation. Bardia National Park Management Plan has planned to translocate at least 50 individuals from Shuklaphanta NP to establish the viable population (BNP, 2022). Decision choices in reintroduction programs is usually difficult to make owing the uncertainty about the population dynamics and ecology of the individuals in novel habitat conditions and this can be addressed by active adaptive management whereby the process is iterated and a balance is maintained between learning and management (Runge, 2013).

Turtle/Tortoise

In CNP and BNP, Turtle Conservation Center has been established within the premises of the Gharial Conservation Center in 1999 (CNP, 2016). Five species of turtles are maintained at the conservation center that includes Elongated tortoise (Indotestudo elongata), Tricarinate Hill Turtle (Melanochelys tricarinata), Flapshell Turtle (Lessimys punctata), Peacock Soft Shell Turtle (Nilssonia hurum) and Black Pond Turtle (Melanochelys trijuga) (CNP, 2018). However, TCC is more utilized as for exhibition center rather than conservation center. Two ad hoc cases of the turtle reintroduction have been carried out from Turtle Conservation Center. Five individuals of elongated tortoise were released on May 22, 2014 by making soft enclosure (B. Khadka, 2014) and information on success of that release is not known. In 2020, the team deployed for locating the nest of the Gharials found three nest of Narrow headed Soft-shell turtle (Chitra indica) with the clutch size of 120, 197 and 197 from which 83, 134 and 158 eggs were successfully hatched after the average of 54 days and later released to Rapti River (Khadka et al., 2022).

Vulture breeding and release

Vulture Breeding Center was established at Kasara of CNP by keeping the 14 chicks from the Hemja Village Development committee in the first year and 30 and 20 vulture chicks collected in second and third year respectively from different parts of Palpa, Rupendehi, Dang and Kapilvastu districts (Paudel, 2014). Even in natural condition, the

Table 4: Translocation of Swamp deer from Shuklaphanta to BNP and CNP

SN	Date	From	To	Details	Source
1	May 30, 2016 to June 5, 2016	ShNP	BNP	5 (2 male, 3 female)	(GoN/MoFSC/DNPWC, 2017)
2	April 26, 2017 to May 4, 2017	ShNP	CNP	7 (5 female, 2 male)	(GoN/MoFSC/DNPWC, 2018)

Table 5: Details of the Vulture Egg laid, chicks hatched, survived and released to wild

Year	Eggs Laid	Chicks hatched	Chicks Survived	Vulture Released to wild	Remarks
2008					Establishment of Vulture Breeding Center
2012	4	0	0		
2014	11	1	1		First Egg hatched
2015	8	0			
2016	15	9	8		One chicks died after hatching
2017	21	6	6	6	
2018	20	2	2	12	
2019	19	0		13	
2020	14	0		8	
2021	12	0		10	
2022				10	
Total	**109**	**17**	**16**	**49**	

Source: (CNP, 2013, 2019, 2020, 2022; GoN/MoFE/DNPWC, 2018; GoN/MoFSC/DNPWC, 2013)

White Rupmed Vultures (WRV) was reported to have breeding success in excess of 50% (Baral & Gautam, 2007). Thus, we can say that Breeding center failed miserably as the breeding success was reported to be lower than in the natural environment.

Conclusion

Anthropogenic influence and associated drivers have changed the dynamics of ecosystems compromising the ability to provide the ecosystem services. Thus, in addition to restoration of habitat, restoration of species is equally necessary and conservation translocation support as a means to restore the species in indigenous or naïve habitat. Nepal has introduced conservation translocation as management tools in both protected area management plans and species conservation action plans. Some of these documents though prepared under the leadership of Department of National Park and Wildlife Conservation, lack coherence even for the same species. This indicates the possibility of the ad hoc decisions while formulating the plans. Furthermore, most of those provisions are simple statements and promises without due consideration to the ecology and conservation biology of the species. Conservation translocation have been carried out for some reptiles, birds and mammals in an attempt to either augment the existing population or reestablish the additional sub-population as an insurance against the stochastic extinction. Conservation translocations are vital for the successful conservation of species in protected areas or other native habitats that are mostly surrounded by the anthropogenic landscapes. Conservation translocation, in this context, should be carried out with strong foundation integrating species, population and ecosystem dimensions. Restoration sites potentially differ from native conditions of source populations, therefore translocation should be practiced on the basis of adaptive management framework and continuous interventions follow up to achieve the success.

Acknowledgement

This review work reach to the current state with the direct and indirect support of the great deal of people and institutions. Thus, the authors would like to acknowledge all of them. Some of the honorable mentions are Department of Environmental Science, Padma Kanya Multiple Campus, Tribhuvan University (TU); Environment Protection and Study Center (ENPROSC); Department of Environmental Science, GoldenGate International Collage (GGIC), TU; and associated persons for logistic support. Furthermore we would like to express our gratitude to the anonymous reviewers for their valuable comments which were crucial for improving the quality of the manuscript.

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Journal of Environment Sciences (2023), **Volume IX**, 67-73
https://doi.org/10.3126/jes.v9i1.56482

Impacts of Earthquake and Earthquake-induced Disasters on Community Forests in Nepal

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Abstract

Managing the commons is a challenging issue during crisis such as earthquakes. We considered four community forests, two from Gorkha and one from each of Dolakha and Sindupalchowk districts that were major earthquake affected areas. The study made use of ecological and socioeconomic survey techniques to assess the impacts of earthquake on community forests and management status of those forests. We calculated density of seedling, sapling and tree species and diameter size distribution of trees. We also analysed the forest status changes before and after the earthquake events and distribution of timber and fire wood in the community forest user groups. Seedling, sapling and adult trees number wise regeneration status of trees was good in all the studied forest whereas DBH size class diagram were bell shaped indicating unsustainable regeneration. Most of the respondents reported poor forest management after the earthquake and wood distribution has drastically increased after the earthquake 2015. From this study it is recommended that community forest management practices should be resilient to disasters and prepare alternative solutions to lower the pressure on forest products so as to maintain sustainable regeneration of forest trees and regular supplies of resources in future.

Keywords: *Commons, Community Forest, Earthquake, Trees*

Introduction

Natural resources management is a challenging problem (Ullah et al., 2021). Commons means public property, most of the natural resources is commons and these commons face more risk during the crisis. In developing countries like Nepal community forest is always at the risk as it has played or can play an important role in addressing poverty of the households (Singh et al., 2021). The critical role of community forestry in environmental protection in general and in fostering social and economic development in particular in Nepal's rural areas has already drawn some attention (Chhetri & Jackson, 1995; Lamichhane et al 2021; Malla, 2000).

Poverty of the people is the result of the state failure. The socio-economic disparity is the long term impact of top down policy or lack of decentralization and devolution (Torado & Smith, 2005). Nepal has been suffering vast socio-economic disparity and the cumulative impact is experienced as a form of political violence (CHRGJ, 2006). Socio-economic disparity and inequality is a global problem but the magnitude of disparity is very high in Nepal compared to other under-developed countries of the world. The unequal distribution of resources or inappropriate sharing of benefit is a major cause of discrepancy by which almost all of the socio-economic conflicts have been emerged (Sen, 2004). Forest resource is one of the means of living for rural livelihoods (Baidhya, et al., 2021; Niraula, 2005), so the reasonable distribution of forest resource can play a crucial role in poverty reduction in rural community (Pokharel, 1997). Although there are many positive implications of the community forestry, the past decades of implementation has not addressed poverty alleviation and equity in benefit sharing effectively. However, the implementation of community forestry is failing to address these second generation issues (Kanel & Kandel, 2004).

While trends towards resource degradation have been arrested and in much case forest covers are reported to be improved, the livelihoods of the local forest dependent communities have not improved as expected. In worst cases, in fact, the implementation of CF policy has inflicted added costs to the poor, such as reduced access to forest products and forced allocation of household resources for communal forest management with insecurity over the benefits.

Mega-earthquakes of April 25 (7.8 in Richter Scale) and May 12 with epicentre in and around Barpak of Gorkha and Sindhupalchok, Nepal heavily destroyed lives and property of the people. The earthquake has been a terrible calamity for Nepal as they affected almost half of its districts, including hard-to-reach isolated mountainous areas. Over 8, 790 people lost their lives and more than 22, 300 people were injured (NPC, 2015). The scale of destruction remained immense. Nature itself suffered massively due the earthquake and aftershocks following the major earthquake. There are no concrete accounts of the impacts and scale of the disasters on community forests. This is massively important as millions of people of the affected areas depend directly on natural resources for their subsistence. The people of the areas are some of the poorest and most-disadvantaged groups far from the reach of the mainstream economical and developmental endeavours.

A comprehensive assessment of the damages and losses caused by the earthquake was undertaken as the first step towards recovery planning. However, the assessment virtually neglected to assess the impacts on the natural resources especially the forests. It is especially important as the resources required for reconstruction of the damaged infrastructures heavily involves harvesting of the forest products. And it is not difficult to trace the sources of the resources being non-other than community forests. It is therefore, imperative to study the impacts of such harvesting on future sustainability of the resources. On top of this it is also important to assess the situation of the access to resources of the poor and disadvantaged groups in the times of crisis and also the management and governance in times of crisis. The information thus derived will be helpful in managing resources sustainably in the future disaster scenarios as Nepal is prone to several categories of natural disasters.

Materials and Methods

Gorkha, Sindhupalchok and Dolakha (Figure 1) are the epicenter of 2015 Gorkha Earthquake and vicinity. Gorkha is a district of Gandaki Province. This district looks like ladder, which varies from Mahabharat region to High Himalaya. It is bordered by Dhading District (Budhi Gandaki River) in east; Tanahun, Lamjung, Manang, (Chepe River) in west, Tibet of China in North and Tanahun and Chitwan District in South. Gorkha District has an area of 3610 km^2, which is fourth biggest district among 77 district of Nepal. Gorkha district varies from 228 meter to 2500 meter above mean sea level. These are the nearest community forest to the epicentre of earthquake 2015 in Gorkha. Milijuli community forest's area is 144 hectare and Tasarpakha Community forest's area is 93.18 hectare. Both forests lie in Warpak village.

Sindhupalchowk district, a part of Bagmati Zone is one of the seventy-seven districts of Nepal located in a central development region. The district with Chautara as its headquarter, covers an area of 2542 km^2 and has a population of 2,87, 798 (CBS, 2011). It extends between the latitudes 27^0 27' and 28^0 13' North and longitudes 85^0 27' and 85^0 06' East (CBS, 2011). Maitar-Kawase Community Forest (MKCF) was selected from Sindhupalchowk district.

Dolakha district, with Charikot as its district headquarter, covers an area of 2,191 km^2 and has a population of 1,86,557 (CBS 2011) Mixed forest types of *Quercus*, *Rhododendron*, *Schima-Castanopsis* and *Shorea* are found in both community forest. Maithan-Harisiddhi Community Forest (MHCF) was selected from Dolakha

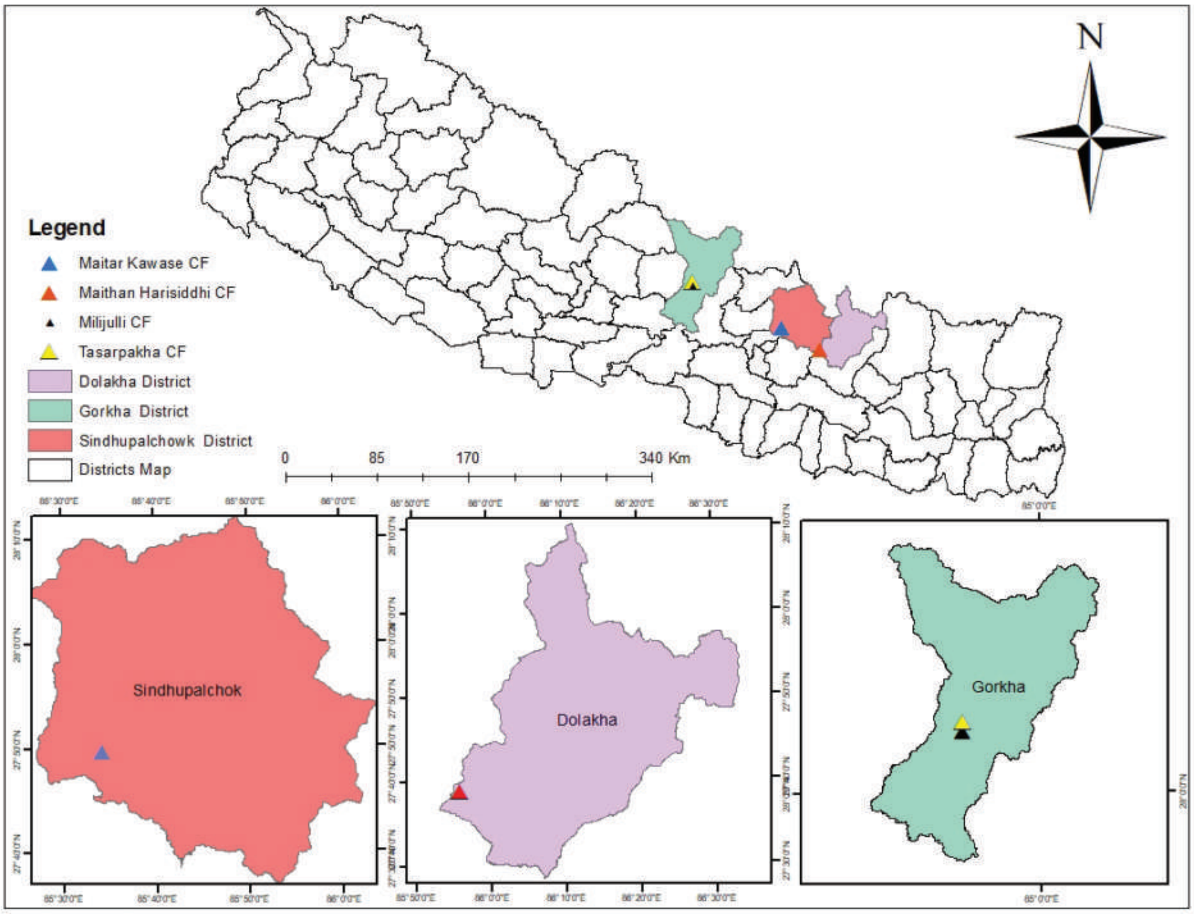

Figure 1: Map showing locations of studied community forests

Data Collection

Ecological survey was conducted using square plots of 20m x 20m in which saplings were measured in 25 m^2 plots on two opposite corners and seedlings were sampled in four 1 m^2 plots at four corners of tree plot following Kent (2012). A total of 60 plots, 15 plots in each of the studied community forest were sampled for the study. The total surveyed area was 2.4 hectare equal to 0.5% of the total area. Individuals of tree species were divided into three growth stages: trees (DBH≥5 cm), saplings (DBH<5 cm, height > 1.3 m) and seedling (height < 1.3 cm). All the trees on the sample plots were measured for their height (m) using clinometer and DBH (cm) using diameter tape. The seedlings and saplings were counted and identified in the field for each plot. Canopy cover was visually estimated by averaging values obtained for four corners and the centre of each plot. The local names of the species were recorded in the plot when their scientific names were not known immediately. The local names were later tallied with Shrestha (1998) to identify the species.

We surveyed 90 households 45 in MHCF/MKCF and 45 in MHCF/ MKCF. We compiled the records of wood- timber distributions from MHF and MKF only as we could not get the records from other forest user groups. Therefore we used only these two forests data for wood distributions trend analysis.

Data Analysis

Impact of earthquake was seen through the analysis of regeneration status of trees (seedling, sapling and adult count, DBH size class diagram), increase and decrease perception of forest management, wood distribution trend and governance.

Density of Adults, Saplings and Seedlings were determined for regeneration trees assessment.

$$\text{Density (Number/hectare)} = \frac{\text{Total number of individual of species in all plot}}{\text{Total number of plot sample x size of quadrat}} \times (10000)$$

Table 1: Structural Parameters of studied Community Forests

Variables	T CF	MCF	MHCF	MKCF
Adult (ind./ha)	456	550	527	1345
Sapling (ind/ha)	1867	1950	700	1413
Seedling (ind/ha)	15417	27083	8010	26450
Canopy (%)	51	50.44	50	75
Tree species richness	9	12	5	7
Dominant sp.	*Engelhardtia spicata*	*Shorea robusta*	*Pinus roxburghii*	*Shorea robusta*

The DBH of adults were grouped into different size keeping 5cm class interval and DBH size class diagram of each studied forests were made separately to see the population structures.

The information about local wood distribution is shown in a graph with regression line fitted to the data. Local people responses on management status of forest before and after 2015 Gorkha Earthquake are given in percentage (%) and presented in bar graphs.

Results and Discussion

We recorded more number of seedlings followed by saplings and adults respectively in the studied forests. Among the four sites the tree richness was most in MCF 12 followed by TCF 9, MKCF 7 and MHCF 5 respectively. The MCF and MKCF forests were dominated by *Shorea robusta* whereas, TCF was dominated by *Engelhardtia spicata* and MHCF was dominated by *Pinus roxburghii*. The average canopy cover of TCF, MCF, MHCF and MKCF were 51%, 50.44%, 50%, and 75 % in respectively (Table 1).

We found hump shaped DBH size class diagram for the adults of four studied CFs. More trees were in DBH size class 20-25cm in TCF and MCF. In MHCF, more trees were in DBH size class 15cm-20cm and 35-40cm in in MKCF (Figure 2)..

Perception of Local People CF Management

Perceptions of local people on community forest management were not so positive after the earthquake and subsequent resource distribution experience. Before earthquake, the perceptions looked more positive. The negative perception after the earthquake was highest in MHCH and lowest in TCF (Figure 3).

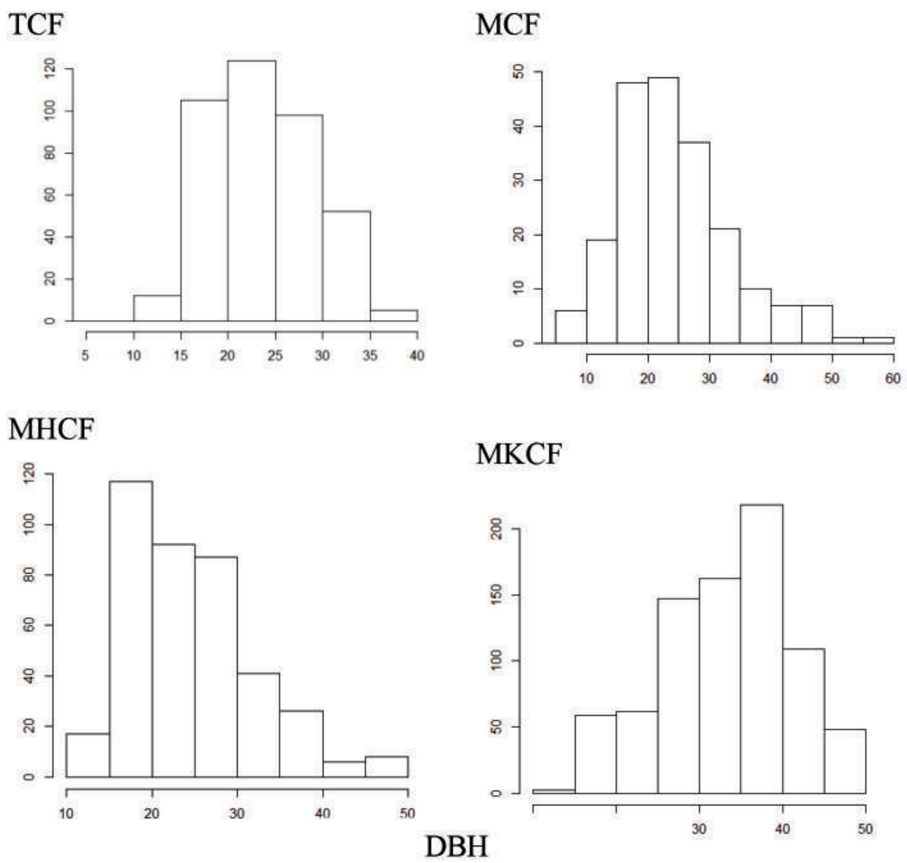

Figure 2: DBH size class diagram of tree in different forest.

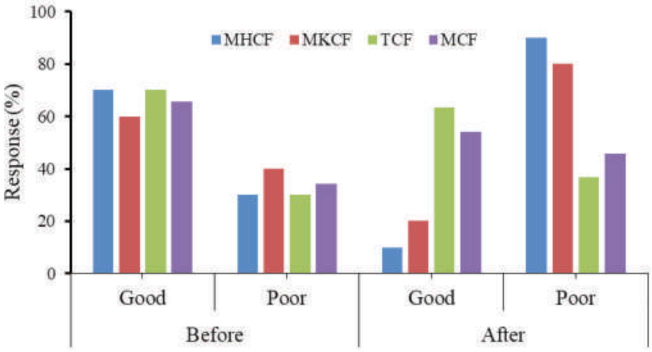

Figure 3: Perception of users on CF management before and after the earthquake

Resources Distribution

The average wood distribution trend was in increasing trend both in MHF and MKF since 2010 to 2017.The polynomial equation showed good fit with $R^2 = 0.8723$ and 0.9192 respectively. The average wood distribution trend was increasing more than before earthquake. The average amount distribution of wood per year in MHF was 252 cubic feet per from 2010 to 2015 whereas after 2015 the wood distribution was 600 cubic foot per year which is above 100% in compare to average wood distribution from 2010 to 2014. Similarly average distribution of wood in MKF was 261.67cubic foot per year till 2015 but after it increased to 2300 cubic foot per year (Figure 4).

Regeneration of trees is a major attribute to show forest structure and composition. The number of seedling - sapling presence is more than tree number indicating fair regeneration in the studied community forest (Shankar, 2001). The species richness is low in all the three forests as the two forests were *Shorea robusta* dominated forest and one with the dominance of *Pinus roxburghii* and *Shorea robusta* dominated forest is species poor forest (Stainton, 1972).

Shorea robusta is one of the most common species in the studied forests. The number of sapling development from seedling similar to other studies in *Shorea robusta* forest (Mishra & Garkoti 2014). The forest will be sustainable if the seedlings and sapling are protected and conserved in a long run.

The DBH size class diagram showed bell shaped distribution indicating that the forest is not continuously regenerating (Shrestha, 2005). This type of structure might be due to the cutting of trees to make temporary houses as post disaster recovery activities (Liu et al., 2021) and also to supply firewood.Clear disturbances was seen in low DBH size classes (5cm-15cm).The disturbances seen in smaller adult tree size class might be due to the easy wood preference of people during rapid construction of temporary houses

Local perception on community forest management was rather low after the earthquake. This could be the reason that the human interest and potential goes towards getting the most basic things during post disaster conditions so that issues of forest protection and management can't be realized as important. At this phase the resettlement of people was the common and basic need in Nepal (Rieger,

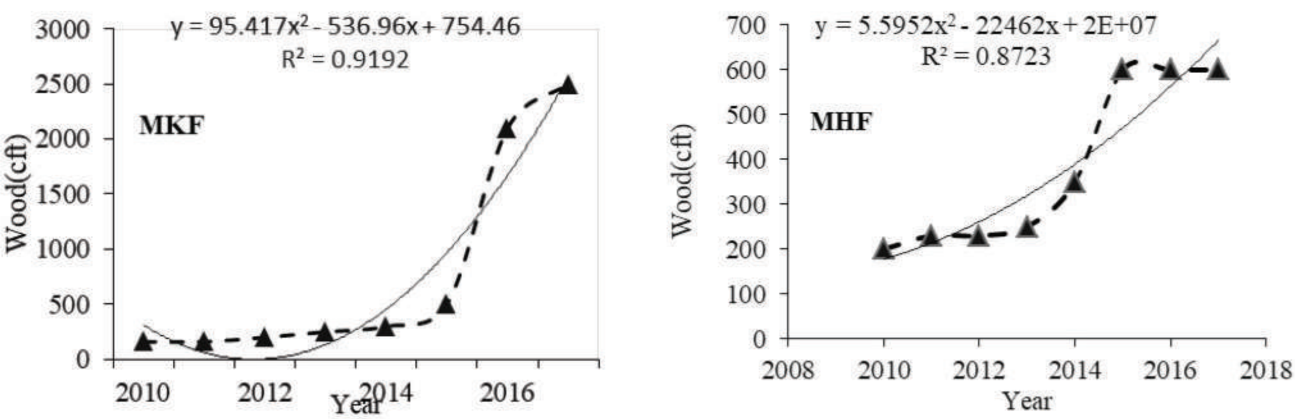

Figure 4: The distribution of wood in MHF and MKF. The markers represent the annual amount of wood distribution. The polynomial line represent non-linear trend in consumption.

2021). Before earthquake, the perception towards forest management was highly positive meaning the users were satisfied with the forest management activities. This shifted to negative perception after the earthquake indicating the users' dissatisfaction with the activities of the user groups in managing forest resources. The resource distribution, in terms of timber and wood, showed rise of wood distribution after 2015 in the studied forest as wood and timber resources are essential for reconstruction work and for livelihood recovery in different places of Nepal (Gentle et al., 2020). This increase wood consumption might create pressure on wood and lead to shortage of wood (Paudel et al., 2015). If tree cutting is unregulated and protection measures are not put in place, the sustainability of the forests and thereby, the resource supplies are highly compromised to the users.

Conclusion

The research revealed good regeneration status of forests in all the four study sites in terms of seedlings and saplings but unsustainable state of tree sizes due to tree cuttings for wood supplies aftermath of 2015 Gorkha earthquake. The CFs under consideration are habitats for important and valuable tree species such as *Shorea robusta*. Resource use pattern in terms of timber in two CFs for which the data were available showed an increasing trend of uses after the earthquake. This might be because of the increased demand for reconstruction and might also be due to mismanagement of resource in times of crisis. The users didn't report serious negative attitudes but were not happy towards CF management practices after earthquake. Locals suggested the need of a careful further investigation viewing potential negative attitude towards management practices could be detrimental in resource management in the long run.

Acknowledgement

We would like to thank members of the four study community forest users group for their cooperation and support in field. We would also like to thank the district forest Offices of Dolakha, Sindhupalchowk and Gorkha for their support in this study. Dr Man Kumar Dhamala passed before the works were completed. Therefore, this work is dedicated to his contribution and we are deeply affected by his absence.

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Journal of Environment Sciences (2023), **Volume IX**, 74-81
https://doi.org/10.3126/jes.v9i1.56484

Land use land cover change and its implication on water fowl diversity: A case study of Taudaha Lake, Kathmandu, Nepal

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Abstract

The wetlands of Nepal are well known for unusually rich biodiversity. Taudaha is famous for winter migrant water fowls as far as from Siberian. The natural form of Taudaha has been neglected and it is surrounded by concrete homes instead of trees and paddy field. Land use change is often regarded as one of the main reasons for habitat degradation and subsequent decrease in migratory birds' population. This article aims to quantify the land use change scenario in and around the lake area using GIS tool. Google images from February 2004 and April 2022 were obtained from "Google Earth Pro" software and used to prepare the land use map by using "QGIS 3.12" software. The cultivated land covered about 73.42% of the total study area followed by settlement (8.61%), vegetation (8.02%) and the lake (9.95%) itself in 2004. But 18 years later, in the year 2022, Taudaha is gradually surrounded by urban areas. The cultivated land has been changed to be settlement areas. The cultivated land has decreased for construction of houses, hotels and resorts. Human activities in hotels and resorts near the lake area have caused distraction to migratory birds visiting the lake. This is causing degradation of habitat of the migratory bird species. Literatures showed the declining number of migratory bird species visiting the lake areas during winter.

Keywords: *Land use change, GIS, Migratory bird, Urbanization*

Introduction

"Land-use change" is any way in which humans modify the natural landscape. Some of these changes are permanent destruction, such as urban expansion. Other changes, such as cropland abandonment and forest restoration, may attempt to repair previous damage. About three-quarters of the Earth's land surface has been altered by humans within the last millennium (Winkler et al., 2021). Land use change has affected almost a third (32%) of the global land area in just six decades (1960-2019) (Winkler et al., 2021).

Nepal has undergone significant land cover changes, with forests, wetlands, and permanent ice/snow decreasing while croplands, artificial surfaces, and bare lands increasing between 1990 and 2015. Factors such as climate changes, population growth, urbanization, and government policies have driven these changes, with higher intensities observed in the Eastern and Central Development Regions (Li et al., 2017). Spatiotemporal changes in land use/land cover (LULC) in Nepal's Bagmati River Basin from 1988 to 2018, reveal significant increases in urban areas by 247.5%, barren land by 109.5%, and shrub land by 32.4%, while forest cover declined by 6.2%, cultivated land decreased by 4.1%, water bodies reduced by 30.3%, sand areas diminished by 29.2%, and grass cover declined by 10.6% (Risal et al., 2021).

As growing human populations place additional burdens on land due to increased needs for food, energy, natural resources, economic development, and space, pressure increases to convert natural habitats for other uses. Land use change reduces the size of habitats and ecosystems and therefore leads to biodiversity loss and loss of ecosystem services. The loss of ecosystem services leads to economic damage, which can be interpreted as the lost value of biodiversity and damage to human well-being and health (Galgani et al., 2021). Globally, the continuous intensification of industrialization and urbanization has led to a significant reduction in wetlands and land cover due to newly constructed lands. Although cities account for less than 3% of the land area on Earth, the loss of native habitats resulting from urbanization has become an important cause of decreasing biodiversity (Galgani et al., 2021). Kathmandu Valley, Nepal is undergoing rapid urbanization and it can be categorized into urban, sub-urban and rural areas. A study showed that the species richness and diversity of birds declined from rural to urban areas and showed significant variation along urban–rural gradients (Katuwal, 2018).

Birds, as a large and widely distributed group of animals, are sensitive to changes in habitats and human disturbance. They have high mobility and habitat selectivity and are therefore often selected as biological indicators of habitat and ecosystem changes (Xu et al., 2022). Species with a narrow range and specialized habitats such as wetland ecosystems are at higher risk. The Koshi Tappu Wildlife Reserve serves as a habitat for numerous species that are globally threatened. These species predominantly rely on swamp and marshes, forests, grasslands, and freshwater ecosystems as important habitats. Analyzing the changes over the past 34 years, it is evident that these ecosystems have undergone significant transformations, which are particularly crucial for globally important species. Among the ecosystems, the forested ecosystem has experienced the most substantial loss over the past 34 years, followed by wetland ecosystems like marshes/swamps and rivers/streams (Chettri et al., 2013). The study examining the transformations in Nepal's wetland areas, particularly the Ghodaghodi Lake Complex, using remote sensing, climate and population data analysis, reveals an increase in surrounding population, changes in land cover, temperature rise, and decreased rainfall, with anthropogenic pressure and climate variability identified as factors contributing to ecological degradation. (Lamsal et al., 2019)

Wetlands are among the most productive ecosystem in the world. The wetlands of Nepal are well known for unusually rich biodiversity. Taudaha Lake serves as a stopover site in Kathmandu for long-distance winter migratory water birds, with their arrival and departure times influenced by the weather system, as decreasing temperatures from October attract the birds to the lake and increasing temperatures from March prompt their departure, with the highest population observed in January (Khatri et al, 2023). Water geese from Tibet, China, Korea, Mongolia and Central Asia migrate south across the mountains to spend the winter in Nepal. Some waterfowl such as Common Coot (*Fulica atra*), the Great Cormorant (*Phalacrocorax carbo*), the Common Teal (*Anas crecca*), the Eurasian Wigeon (*Anas penelope*), the Gadwall (*Anas strepera*) and the Mallard (*Anas platyrhynchos*) etc travel south through the Kathmandu Valley and live in Taudaha (Nepal, 2022) in winter. The natural form of Taudaha has been altered by concrete homes surrounding the lake instead of trees and Paddy field. A significant number of restaurants are opened and ever-increasing visitor population and their activities is deteriorating natural environment gradually around the Taudaha lake area.

A study from September 2007 to April 2008 recorded 40 species of birds out of which 21 were winter migrants, two were summer migrants and 17 were residents (Shah, 2016). Most recent bird count by BCN in Taudaha Lake in 2022 recorded 21 water birds of 19 species at Taudaha (Nepal, 2022). Water bird count at Taudaha has gone down in 2022 both in terms of the number of species and individuals (Nepal, 2022). There are plenty of researches about the lake, most of which deals about the water quality and biodiversity of the lake (Paudel et al., 2022; Shrestha B., 2022) but the information regarding land use change in and around the lake is very scarce. Land use change is often regarded as one of the main reasons for habitat degradation and subsequent decrease in migratory birds' population (Khatri et al, 2023; Nepal, 2022). The main objectives of the article are to map out the land use and land cover change in and around Taudaha Lake during the period of 2004 till 2022 using Google earth image, quantify the change in land use during this period and review the implication of urbanization on water fowl diversity in Taudaha Lake area.

Materials and Methods

Study Area

Taudaha Lake is situated in Kirtipur Municipality-6, Kathmandu district, Bagmati province, Nepal. Geographically it lies at 27º 38' 72 55.5''N and 85º 16' 54.8'' E with altitude of 1291 m on the way to Dakshinkali Temple about 7 km South from Balkhu of Kathmandu. The area of the lake is about 4.6 ha with maximum depth of 6.8 m. The Lake is mainly fed by rainfall and irrigation canals coming from the nearby paddy fields. The climatic condition of Taudaha Lake resembles with the Kathmandu city. The average annual temperature varies form 10°c to 26°c. The lake shows subtropical climate with three distinct seasons as summer, rainy and winter. Kathmandu Valley was once a huge lake. It is believed that the Taudaha Lake is formed when the stagnant water in the valley was released out through Chobhar gorge. Taudaha is about 210 meters long and 180 meters wide. In Newari language, 'Tah Dah' means 'big pond'. Later, it is considered to be 'Taudaha' by aberration of 'Tah Dah'. It is also one of the most important religious places in Kirtipur. It is believed that the Taudaha is home to Karkotak Naag and people celebrate Nagpanchami in the name of Karkat Nag Raja and Nag Rani, once a year. Figure 1a and 1b presents the Location map of Taudaha Lake and a photograph of the Taudaha Lake taken in January 2022 respectively.

Methodology

Land use change mapping

This research is mainly based on the analysis of Google imagery using GIS tools. Google images from 1st January 2004 and 3rd November 2022 were obtained from "Google Earth Pro" software and used to prepare the land use map by using "QGIS 3.12" software. A polygon has been created by enclosing the four points having following geographic co-ordinates [27º 39 2.78N, 85º 16 40.00E], [27º 39 5.31 N, 85º 17' 12.56"E], [27º 38' 41.92" N, 85º 16' 41.54"E] and [27º 38' 44.38"N, 85º 17' 13.36"E] in both images for this study. Figure 2a and 2b shows the Google Imagery of the study area in the year 2004 and 2022. The polygon is created such that the lake lies on the center of the polygon. The area of the polygon is 46.43 hectare**.** The images were geo-referenced and screen digitized using "QGIS 3.12" software in order to create the features and assigned the respective land cover attribute to the respective features. The features are categorized in four classes as Settlement, Agricultural, Vegetation and Lake. Lastly the area covered by these four features are calculated for both years and a comparison is made to draw the conclusion. Methodology adopted for Land use change mapping in this study is presented in figure 3.

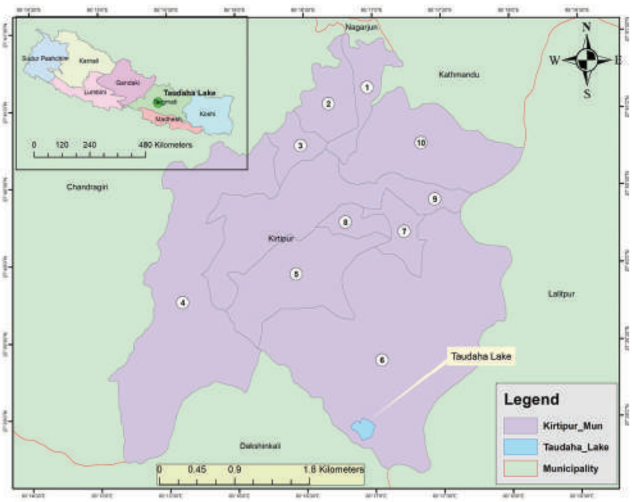

Figure 1a: Location Map of Taudaha Lake

Figure 1b: Photograph of the Taudaha Lake taken in January, 2022

Figure 2a: Google Imagery of Taudaha Lake and its surrounding area in the year 2004

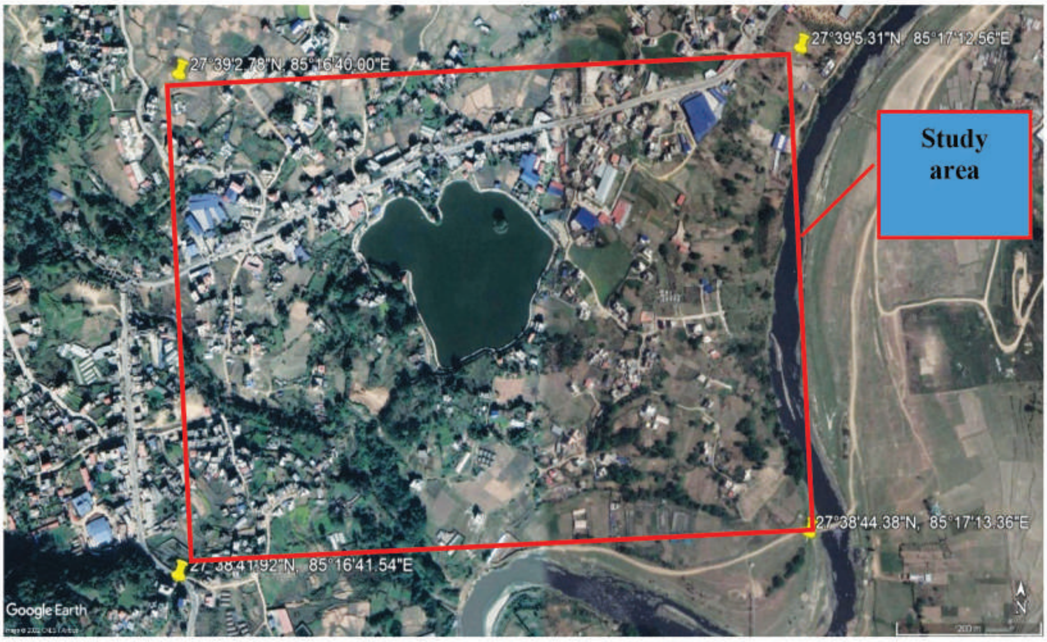

Figure 2b: Google Imagery of Taudaha Lake and its surrounding area in the year 2022

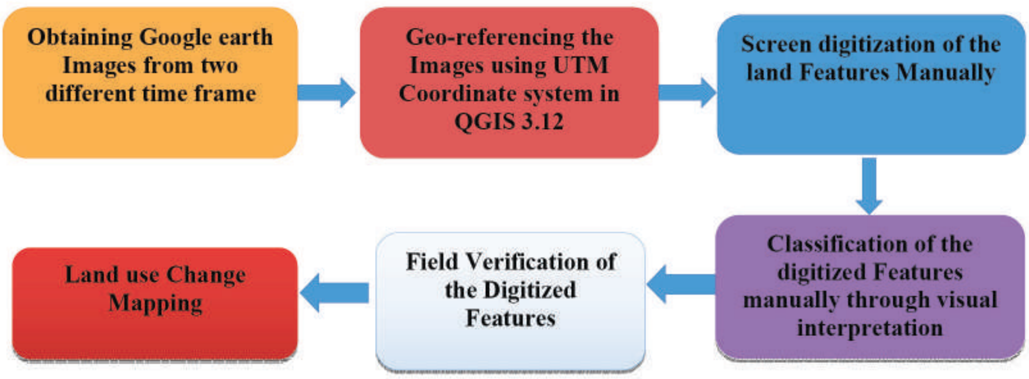

Figure 3: Methodology adopted for Land use change mapping

Impact of land use change on water fowls

To study the land use change and its implication on wetland, various scientific papers related to land use change and wetland were reviewed and analyzed qualitatively in the paper.

Results and Discussion

Figure 4a and 4b present the Land use map of Taudaha Lake and its surrounding area in the year 2004 and 2022 respectively and the result has been presented in table 1. The total area considered under this study is 46.43 ha. In the year 2004,Taudaha Lake is mostly surrounded by cultivated land, mostly paddy field. The cultivated land covered about 73.42% of the total study area followed by Settlement (8.61%), Vegetation (8.02%) and the lake (9.95%) itself in 2004. But 18 years later, in the year 2022, the Taudaha is gradually surrounded by urban areas. The cultivated land has been changed to be settlement areas. The area of the cultivated land decreased by 25.58% whiles the settlement area increased by 22.48% during that period. Vegetation cover around the Taudaha Lake is found to be increased by 3.02%. The reason behind this is that some cultivated areas are turned uncultivated and some are changed into private park/ resort for commercial purposes. In 2004, the settlement areas were mainly

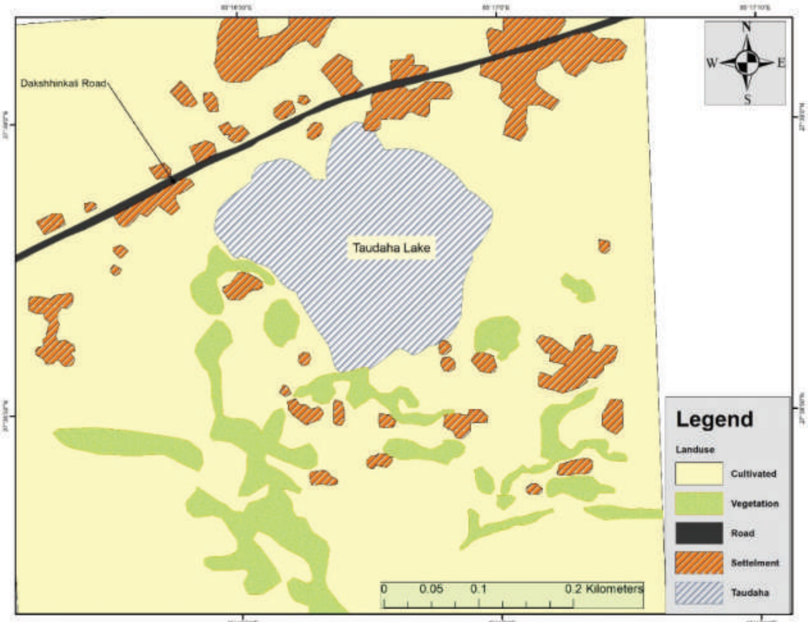

Figure 4a: Landuse map of Taudaha Lake and its surrounding area in the year 2004

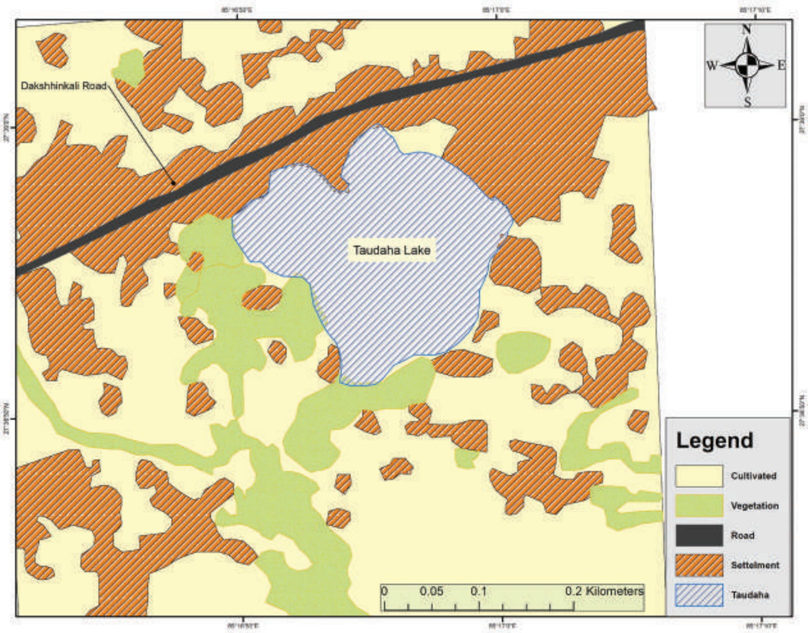

Figure 4b: Landuse map of Taudaha Lake and its surrounding area in the year 2022

Table 1: Land use Change of Taudaha Lake and its surrounding area

Landuse	2004		2022		% Change
	Area (Ha)	%	Area (Ha)	%	
Cultivated	34.09	73.42	22.21	47.84	-25.58
Vegetation	3.72	8.02	5.12	11.03	3.02
Settlement	4.00	8.61	14.43	31.09	22.48
Taudaha	4.62	9.95	4.66	10.04	0.09
Grand Total	**46.43**	**100.00**	**46.43**	**100.00**	

concentrated along the Dakshinkali Highway on the northern side but currently the lake is surrounded by settlements from all sides of the Lake.

Taudaha lake is recognized as popular destination for migratory water fowls such as the Common Coot (*Fulica atra*), the Great Cormorant (*Phalacrocorax carbo*), the Common Teal (*Anas crecca*), the Eurasian Wigeon (*Anas penelope*), the Gadwall (*Anas strepera*) and the Mallard (*Anas platyrhynchos)*. The Bar-headed Goose (*Anser indicus*), the Ruddy Shelduck (*Tadorna ferruginea*), the Spot-billed Duck (*Anas poecilorhyncha*), the Northern Shoveler (*Anas clypeata*), the Northern Pintal (*Anas acuta*), the Common Pochard (*Aythya ferina*), the Red-crested Pochard (*Rhodonessa rufina*), the Tufted Duck (*Aythya fuligula*), the Furruginous pochard (*Aythya nyroca*), the Black-headed Gull (*Chroicocephalus ridibundus*), and the Lesser Black-backed Gull (*Larus fuscus*) have also been reported over the years in Taudaha Lake, especially in winter (Shah., 2016; Nepal, 2022). Urbanization and rapid development activities near the lakeside and Taudaha beautification process are attributed to the continuous decline in the number of water birds visiting the Taudaha Lake area in winter (Nepal, 2022; Shrestha, 2022). For instance, in 2007 the census reported 40 species (Shah,, 2016), 28 species in 2014, 23 species in 2015, 21 species in 2016, 23 species in 2017, 20 species in 2018, 23 species in 2019, 17 species in 2020 and 2021 respectively (Nepal, 2022).

Khatri et al., (2023) also reported 10 migratory water bird species observed at Taudaha Lake in 2020 which is lower compared to previous years. The total population of water birds recorded was found to be 210 which is almost 120% lower than the count in 2007/8 and 30% lower than in 2014-15. Previously abundant water bird species like Gadwall, Common Teal, and Mallard have experienced a rapid decline in their populations. Moreover, Falcated Duck (*Mareca falcatae*), Tufted Duck (*Aythya fuligula*), and Garganey (*Spatula querquedula*) have not been sighted at the lake since 2003, 2008, and 2011, respectively. This absence could be attributed to increased disturbances caused by people, such as playing loud music, ongoing concrete construction activities, insufficient vegetation in and around the lake, and changes in land use near the lake's periphery (Khatri et al., 2023). Figure 5a shows Migratory birds (Great Cormorant) resting on a tree located in the middle of Taudaha lake and figure 5b shows the ever growing urban areas along the bank of the Lake.

Parajuli, (2022) pointed out that the majority of the species found in the wetland of Hetauda were discovered to be at risk due to the loss and deterioration of their natural habitats. The main

Figure 5a: Migratory birds (Great Cormorant) resting on a tree located in the middle of Taudaha lake in January 2022.

Figure 5b: Recently opened hotel and resorts on western side of the Lake along Dakshinkali highway.

concerns identified in the research include the fragmentation and degradation of habitats, as well as pollution and sewage stemming from industrial zones and urban regions. Effect of urbanization on wetland bird was studied in seven river wetlands around Chaohu Lake, China with satellite remote sensing image data from the same period. It was found that the water bird diversity index declined exponentially with increases in the intensity of urbanization. The changes in the land use patterns around river wetlands associated with urbanization resulted in the loss of food resources and habitats (Xu et al., 2022).

Now a days bathing and washing in the Taudaha lake has been banned. Similarly it is restricted to dispose sewage into the Lake. Recent research on the hydrochemistry and water quality of Taudaha Lake demonstrates that the water is suitable for supporting aquatic life as well as domestic and irrigation purposes. The slightly alkaline pH and moderate dissolved oxygen (DO) level suggest that the lake water has been minimally affected by organic pollutants originating from human activities (Paudel et al., 2022). Hence it can be concluded that lake water is not a root cause of declining migratory bird population in the Lake.

There were no hotels and resorts along the bank of Taudaha lake and the tourist activities were also nil. Currently there are more than 15 hotels and restaurants surrounding the lake from all sides. The lake is now one of the hotspots for tourists in Kathmandu valley and Tourist activities have been increased drastically. Nearby hotels often play loud music and sounds for their entertainment in the restaurants. The use of colorful lights on the trees in which birds' shelter has forced some birds like cormorants take refuge in nearby network towers. The line of restaurants and use of powerful sound equipment around Taudaha Lake may causes ear damage, an increase in stress response, changes in forage or call responses, and even a flight reaction (Nepal, 2022). Noise pollution can alter bird communities by forcing some birds to abandon the area (Tang, 2022). Artificial light itself can have countless negative influences on different aspects of birds, such as sleep, digestive efficiency, and circadian rhythm. Light pollution not only affects the physiology of urban birds but also poses a significant threat to migratory birds, as the challenges of migration make them more vulnerable to its effects, leading to disrupted migration patterns, attraction to artificial lights, and abandonment of resource-rich areas, ultimately impacting the success of their journeys. (Tang, 2022). The number and concentration of migratory species decrease as built infrastructure expands. Certain birds, like the Eurasian blackbird and house sparrow, exhibit a decline in their migratory patterns because urban areas provide sufficient food resources to sustain them during the winter season. Resident species have the tendency to occupy high-quality nesting locations in cities prior to the arrival of migratory species. This leads to the exclusion of migrants from urban areas through competitive interactions (Patankar, et al., 2021).

Conclusion

It can be concluded from this research that the Taudaha lake and its surrounding area is experiencing rapid urbanization. The cultivated land is decreasing day by day for construction of houses, hotels and resorts. Human activities in hotels and resorts near the Lake area are the cause of distraction to migratory birds visiting the lake. This is causing degradation of habitat of the migratory bird species. Various measures, such as acoustic barriers and tree planting can be implemented to mitigate noise pollution and promote environmental sustainability. The concerned authority should implement strict regulation to control the excessive human interventions in and around the lake in order to preserve Taudaha lake as a natural habitat for migratory bird.

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Journal of Environment Sciences (2023), **Volume IX**, 82-93
https://doi.org/10.3126/jes.v9i1.56483

Estimation of soil erosion using the Revised Universal Soil Loss Equation (RUSLE) in Relation to Landslides in Mid-hills of Nepal

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Abstract

An attempt has been made in this research to assess soil erosion and its spatial distribution by the revised universal soil loss equation (RUSLE) model at Rangun Khola Watershed, western Nepal. The erosion factors were acquired from multiple sources (Satellite images, ALOSPALSAR DEM, SOTER soil database, Esri 2020 land cover map, rainfall database of DHM) and an integrated analysis was carried out in raster format of GIS. A landslide inventory was generated on the basis of satellite images and past literature to validate soil erosion intensity in the area. The result map of the RUSLE model was categorized into six levels based on the erosion severity, and 9.06 % of the area was found to be under extremely severe soil erosion risk (> 80 ton ha^{-1}year^{-1}) indicating urgent consequences. The frequency ratios for each level of potential erosion susceptible to landside exhibited a linear relationship depicting reasonable and satisfactory level of agreement between the landslide event/location data and the erosion map that validates the model result. The result of this study will be helpful to detect the sensitive zones presenting a priority of protection and offer valuable information that aids decision-makers and user agencies in creating adequate conservation planning programs to stop soil erosion and maintain the natural balance.

Keywords: *Soil erosion, Landslides, RUSLE, Mid-hills*

Introduction

Land degradation is one of the major global issues that affect agricultural output and natural resource availability (Gomiero, 2016). Among the many forms of land degradation (soil truncation, loss of fertility, slope instability), soil erosion is the most significant phenomenon and is greatly influenced by land use and management practices (Abdulkareem et al., 2019). Erosion reduces the ability of the soil to hold water and support plant growth, thereby reducing its ability to support agro-biodiversity (Pimentel, 2006). It is also believed that, as a result of the erosion over the past four decades, 30% of the world's arable land has lost its fertility (Hossain et al., 2020).

In recent years, climate change impacts have accelerated the rate of erosion and related consequences (Eekhout & De Vente, 2020). Accelerated erosion can degrade the quality of land resources, leading to major environmental catastrophes (such as deposition, drought, and floods), impairing regional sustainability through detrimental ecological and social effects and having a significant impact on human survival and economic development (Lin et al., 2012). Soil erosion is a severe environmental concern in Nepal as well, with an estimated 25 ton ha^{-1} yr^{-1} national mean annual soil loss (Koirala et al., 2019). The rate and severity of the erosion also vary in different physiographic regions of the country, and approximately 45.5% of land erodes from the water in steeper areas of the hilly region (Chalise et al., 2019). Thus, studying soil erosion is crucial for scientifically predicting and controlling soil erosion as well as exploiting land resources(Koirala et al., 2019; Pan & Wen, 2014).

In the Rangun Khola watershed of western Nepal, environmental hazards like landslides contribute to a higher rate of erosion and vice versa in the monsoon seasons (Bhandari et al., 2021). There have been a number of landslide events recorded over the last decades, leading to erosion (Pathak & Devkota, 2022a). In this watershed, the natural elements, particularly the weather elements, are highly erosive (Dhital, 2015). Because of the high intensity of monsoon rainfall over short periods of time, the erosivity of rain and run-off are major drivers of soil loosening, slope weakening, and finally mass movements of solid and semi-solid materials such as soil creep, landslips, and landslides (Bhandari et al., 2021; Koirala et al., 2019; Pathak & Devkota, 2022b). Like many of the hilly areas that are on the way of being developed, this watershed is also in the growing phase of development. There are numerous such developmental activities such as the construction of roads and other linear infrastructure are found to be associated with higher amounts of erosion and associated hazards (Chalise et al., 2019). With the ongoing developmental activities and some other development projects in the pipeline for future developments, the risk of soil erosion and landslide events (Bhandari et al., 2021; Pathak & Devkota, 2022a). As a result, the Rangun Khola watershed can be assumed to be under constant pressure for various agricultural and urban developments. In such a scenario, the quantitative information on soil erosion at the watershed scale is extremely useful in planning for soil conservation, erosion control, and watershed management(Pan & Wen, 2014).

There are several models for analyzing soil erosion, but the most often used is the Universal Soil Loss Equation (USLE), which is an empirical model assessing long-term averages of sheet and rill erosion based on plot data gathered in the eastern United States (Morgan et al., 1998). Other models used to assess soil loss include the Erosion/Productivity Impact Calculator (Williams, 1990), the European Soil Erosion Model (Morgan et al., 1998), and the Water Erosion Prediction Project (Flanagan & Nearing, 1995). The Revised Universal Soil Loss Equation (RUSLE) was created as a result of substantial improvements to the USLE as well as its database in order to more correctly assess soil erosion (Renard et al., 2017).

The RUSLE with GIS is employed in this research to assess the soil erosion potential, which is one of the major environmental problems in the Rangun Khola watershed. Along with this association, another equally significant and related environmental concern landslides, was carried out, which directly impacts and is influenced by soil erosion. It is anticipated that the findings of the study would give planners and decision-makers crucial information they may use to develop effective land management plans in the watershed.

Materials and Methods

Study area

This study was carried out in Rangun watershed situated in Sudurpaschim province, western Nepal covering the area of 48,939 hectare (489.39 sq. km) (Fig. 1). It is one of the major watershed of the Mahakali River Basin, which is an international boundary between Nepal and India(Pathak et al., 2020).The altitude range between 258 to 2,500 m asl, forming the steep slope susceptible to soil erosion. Numbers of landslide events from very past can be observed in the due to natural topographic setting along with the anthropic activities such as, land use and cover change, deforestation, terrace farming on steep slopes and rapid developmental activities (Bhandari et al., 2021; Pathak & Devkota, 2022b).

The average annual temperature ranges between 10°C to 25p C, and annual average rainfall in the watershed is about 1,346.6 mm, which concentrates in June-September mainly in and causes massive erosion each year (Bhandari et al., 2021). Along with various percentages of pasture land and sporadic patches of trees, bushes, and shrubs, the two main crops that make up the majority of the land use are forest and arable. Mudstones, shale, sandstones, siltstones, and conglomerates make up the majority of the rock types (Bhandari et al., 2021). Several instabilities can be observed within the different geological formations white to milky white calcareous quartzite, dolomitic limestone, shales and fine grained cross-bedded quartzite can be observed (Dhital, 2015). Surficial deposits such as alluvium, boulder, gravel, sand, silt, and clay are also common in the region. Thus the combined and cumulative impacts of natural as well as anthropic activates have created a complicated and unique environment for soil erosion.

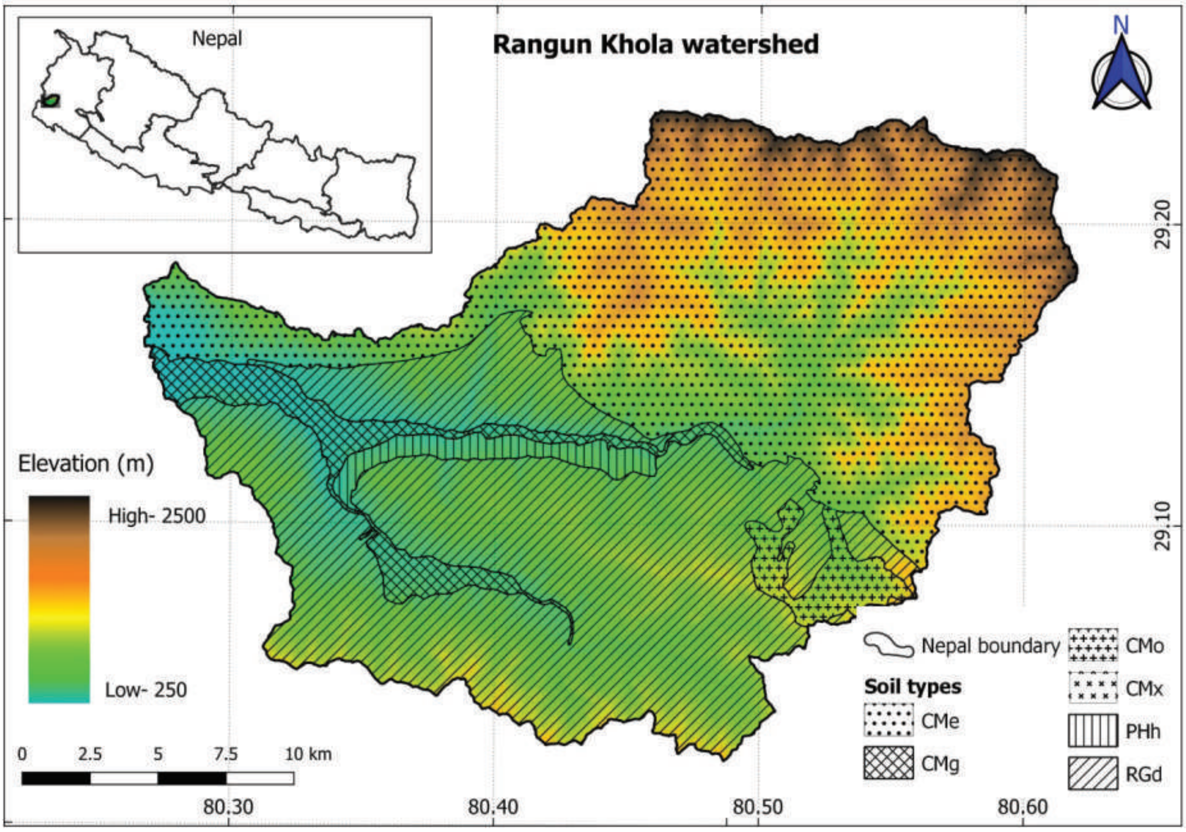

Figure 1: Study area depicting elevation range (250 to 2500 m) and different soil types (CMe- Eutric Cambisols, CMg- Gleyic Cambisols, CMo- Ferralic Cambisols, CMx- Chromic Cambisols, PHh- Haplic Phaeozems, RGd- Dystric Regosols)

Data set and sources

The spatial datasets for this study were obtained from various sources, as shown in Table 1. The data sets were all converted to raster format with the same resolution as the DEM.

Model Description for soil Erosion

The RUSLE empirical model was used in this study to forecast yearly soil loss in the landslide prone area. According to Renard et al. (2017), this RUSLE model calculates possible average soil loss (A) using the equation (1).

$$A = R \times K \times LS \times C \times P. \quad (1)$$

Where, A is the average soil loss (ton ha^{-1} year^{-1}) at a point (spatial location of grid cell), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (ton ha MJ^{-1}mm^{-1}), LS is slope-length and slope steepness factor (dimensionless), C is the land management practice factor, and P is the conservation support practice factor (dimensionless).

Table 1: Datasets used for the RUSLE modelling and their sources

Datasets	Data source
DEM	ALOSPALSAR DEM obtained from the Alaska Satellite Facility homepage.
Soil map	Soil and Terrain Database (SOTER) for Nepal, acquired from ISRI data hub (https://data.isric.org/geonetwork/srv/eng/catalog.search#/home) (scale 1:50,000)
Land Cover map	Esri's 2020 land cover map with 10m resolution was utilized.
Rainfall map	Mean Annual District Level Precipitation of Nepal Produced by DHM
Landslide inventory	Google Earth Pro, Landsat images, Past studies (Dhital, 2015; Pathak & Devkota, 2022b, 2022a), and field visit

Rainfall erosivity factor (R)

This rainfall erosion factor (R) describes the intensity of precipitation at a particular location based on the amount of soil erosion (Koirala et al., 2019; Thapa, 2020). It quantifies the effect of raindrop amount and rate of runoff associated with rainfall and its unit is expressed in Mj mm $ha^{-1}h^{-1}year^{-1}$. During this study, the rainfall map produced form mean annual district level precipitation of Nepal produced by DHM was used to generate a rainfall erosion factor. This map shows mean annual precipitation over the district, an equation integrated to make the R-factor given by Morgan et al. (1998).

$$R = 38.5 + 0.35P. \quad (2)$$

Where, R = Rainfall Erosivity Factor, P = Mean Annual Rainfall in mm

Support practice factor (P)

The P factor is the ratio of soil loss caused by a given support method to the loss caused by upslope and downslope tillage (Pijl et al., 2020). The lower the P value, the more effective the conservation measure in reducing soil erosion is thought to be. Contouring, strip cropping (alternative crops on a particular. slope formed on the contour), and terracing are conservation practice components covered in this term. Tables were used to calculate the ratio of soil loss when contouring and contour strip cropping were used to those where no conservation measures were used, with the P factor set to 1.0. Farming operations in sloppy agricultural land in Nepal occur by the development of terraces that closely mimic contour farmland, which is a conservation farming method. The support practice factor used in this study is presented in Table 2.

Table 2: P factor values for slope as per agricultural practice (Kumar and Kushwaha 2013)

Slope %	Contouring
0–7	0.55
7–11.3	0.60
11.3–17.6	0.80
17.6–26.8	0.95
> 26.8	1.00

Soil erodibility factor (K)

The soil erodibility factor K is a function of percentage of silt and coarse sand, soil structure, permeability of soil and the percentage of organic matter. It is the rate of soil loss per rainfall erosion index unit as measured on a standard plot and often determined using inherent soil properties (Radziuk & witoniak, 2021). Soil texture, organic matter, soil structure, and soil profile permeability are the key soil variables that influence K factor (Baskan, 2021). K factors of large soil groups were computed equation (3), and depicted in Table 3 which was previously employed by various earlier researchers in the similar terrain (Koirala et al., 2019; Thapa, 2020).

$$K = Fcsand * Fsi - cl * Forgc + Fhisand * 0.1317 \quad (3)$$

where,

$$Fcsand = [0.2 + 0.3\, exp\, exp\left(-0.0256\, SAN\left(1 - \frac{SIL}{100}\right)\right)]. \quad (4)$$

$$Fsi - cl = \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \quad (5)$$

$$Forgc = \left[1 - \frac{0.25C}{C + exp\, exp\,(3.72 - 2.95C)}\right]. \quad (6)$$

$$Fhisand = \left[1 - \frac{0.070SN1}{SN1 + exp\, exp\,(-5.51 + 22.9SN1)}\right]. \quad (7)$$

where, SAN, SIL and CLA are % sand, silt and clay, respectively; C is the organic carbon content; and SN1 is sand content subtracted from 1 and divided by 100.

Cover-management factor (C)

The cover-management factor (C) is used to reflect the effect of cropping and other management practices on erosion rates. It measures the combined effect of all the interrelated cover and management variables, (Mukharamova et al., 2021). It was derived from a land use/cover classification obtained from Esri's 2020 land cover map (Karra et al., 2021). First, the raster map was converted to polygon and the attributes with same land use type were merged in ArcGIS. From this, six types of land use were

Table 3: Soil classification and computation of K-factor

Soil	Carbon (g/kg)	Sand (%)	Silt (%)	Clay (%)	F_{csand}	F_{si-cl}	F_{orgc}	F_{hisand}	K
Eutric Cambisol	9.6	40	40	20	0.741	0.885	0.929	0.980	0.079
Endosodi-Gleyic Cambisol	11.9	70	10	20	0.399	0.719	0.877	0.996	0.033
Skeleti-Ferralic Cambisol	6	80	10	10	0.358	0.812	0.980	0.998	0.037
Eutri-Chromic Cambisol	3.2	70	10	20	0.399	0.719	0.995	0.996	0.037
Calcaric Phaeozem	13.8	70	10	20	0.399	0.719	0.834	0.996	0.031
Siltic Phaeozem	46.8	10	70	20	1.126	0.927	0.750	0.941	0.097
Humi-Leptic Regosol	27.3	40	40	20	0.741	0.885	0.751	0.980	0.064

obtained (Table 4). For each land use type, C values were assigned through reference (Panagos et al., 2015). The C factor ranges from 0 to approximately 1, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow, while lower C means a very strong cover effect resulting in no erosion.

Table 4: Cover management factor(Panagos et al., 2015)

Land use	C factor
Forest	0.03
Shrubland	0.03
Grassland	0.01
Cultivated area	0.21
Barren land	0.45
water body	0.00

Topographic factor (LS)

The total topography of the RUSLE adds two variables to soil erosion: the length factor (L) and the steepness factor (S) (Lu et al., 2020; Sabzevari & Talebi, 2019). The LS factor is obtained by adding the L and S factors by using the equation used by Pan & Wen (2014) to determine the LS factor was implemented in this study.

$$LS = 1.07 \left(\frac{\lambda}{20}\right)^{0.28} * \left(\frac{\alpha}{10^0}\right)^{1.45} \quad . \quad (8)$$

Where L is the slope length factor, S is the slope steepness factor, k is the field slope length in meters, and a is the slope angle in degrees. The % slope was calculated using the DEM, and the field slope length was calculated using a grid size of 12.5 m. The LS factor was calculated using ArcMap 10.5.

Potential Erosion Map and Correlation with Landslides

Five different factor maps were then input and processed to prepare raster map in ArcMap 10.5 and these raster maps were integrated using RUSLE relation to generate potential erosion map. Zonal statistics tool was also used for computing an area-weighted mean of the potential erosion between slope and LULC classes. Due to the absence of models or procedures to evaluate soil erosion intensity values in the study region, the soil erosion intensity map was correlated with landslide inventory map developed from satellite imagery, previous research (Pathak & Devkota, 2022b, 2022a) and a comprehensive field survey. Landslide sites over the last 20 years are overlaid with a soil erosion map generated by the RUSLE model and the frequency ratio-based statistical approach was used to examine correlation.

Results and Discussion

Factor maps

The results showed that the Rainfall Erosivity Factor (R) value ranges between 300 and 1300 Mj mm $ha^{-1}h^{-1}yr^{-1}$ with the highest rainfall in southern part of the study area (Fig. 2a). Soil Erodibility Factor (K) value ranged from 0.033 to 0.097 ton ha MJ^{-1} mm^{-1} (Fig. 2b). The Support Practice Factor (P) value ranged from 0.55 to 1 where a higher value indicates there is no any support practice such that erosion is at its maximum due to the absence of any practice (Fig. 2d). The value of the Cover Management Factor (C) ranged between 0 and 0.45 (Fig. 2e).

Potential Soil Erosion Rates

The potential soil erosion map of the Rangun Khola watershed produced utilizing RUSLE model and classified into six classes (Fig. 3, Table 5). It has been observed that the erosion ranges from 0 to 151 t $ha^{-1}yr^{-1}$ in the study area.

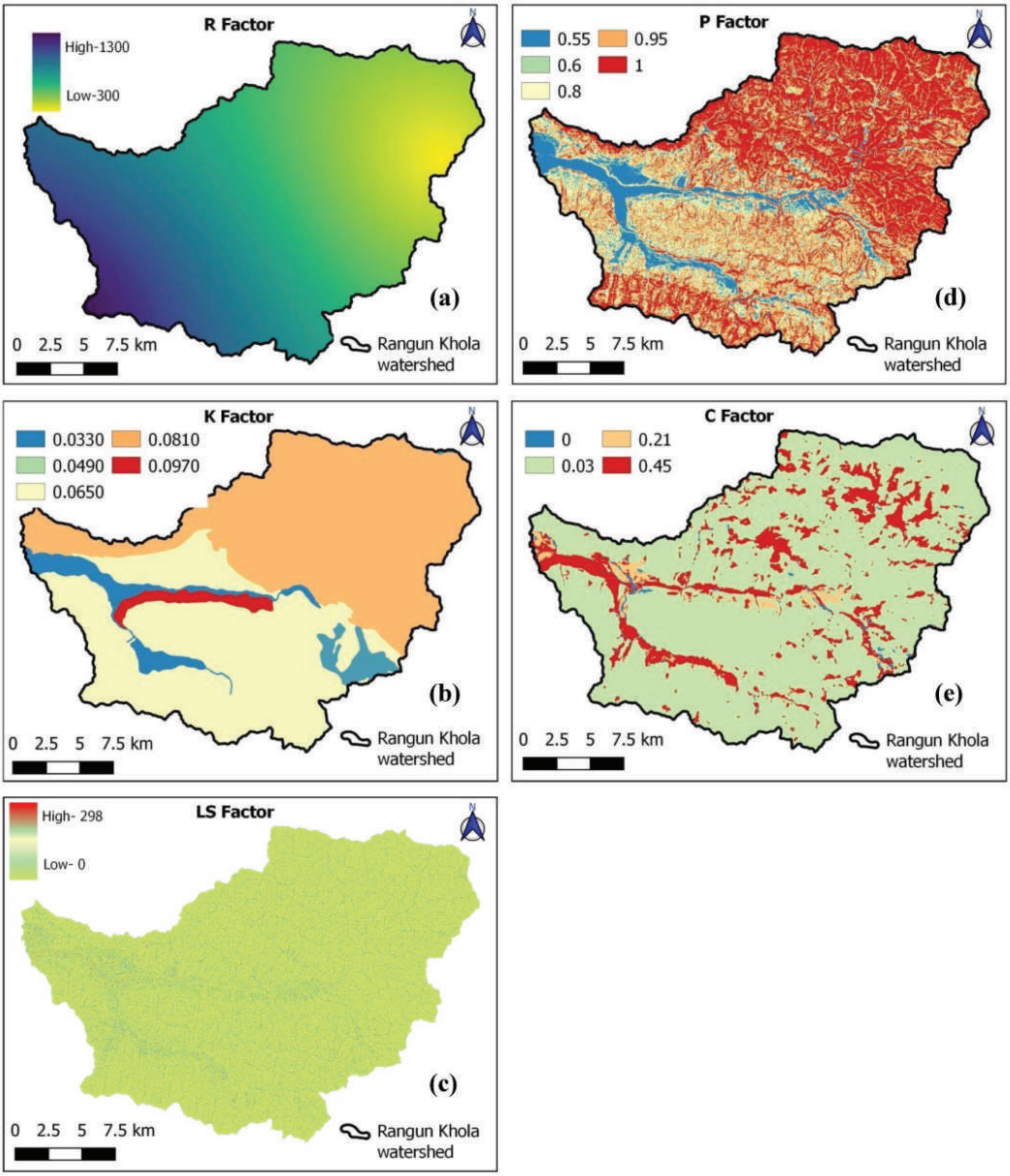

Figure 2: Five factor maps of soil erosion of study area, a Topographic factor map, b cover management factor map, c support practice factor, d soil erodibility factor map, e rainfall erosivity factor map

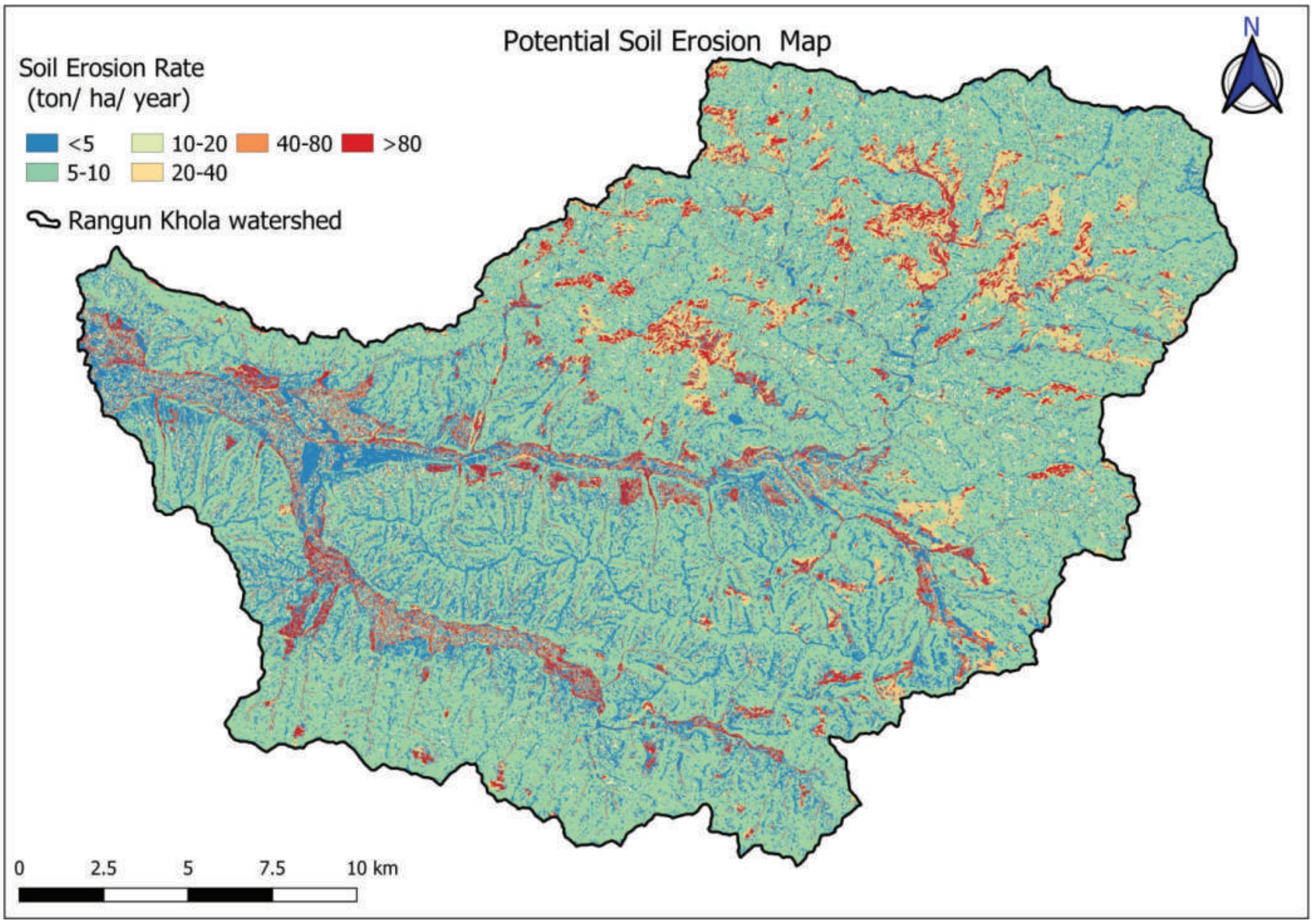

Figure 3: Potential soil erosion prone zone map of Rangun Khola watershed depicting six levels of soil erosion potential

The soil erosion higher than 80% consists of a 9.06% area (Table 5). It also shows that 8.20% of the area consist of very high, 3.18% high and 2.53% of serve risk zones need conservation to reduce the risk of soil erosion. The mean erosion rate high in barren lands, followed by cultivated area, and shrubland , and the highest soil loss rates observed in steep slopes(>26.8%).

Correlation of soil erosion map

Landslide locations, occurred during the past 15 years, are overlaid with the potential soil erosion map of using RUSLE model and are depicted in Fig. 4. In order to determine the association between these two related occurrences in the research region, frequency ratio techniques are based on the observed correlations between distribution of landslides and potential soil erosion.

Table 5: Area and the amount of soil loss in Rangun Khola watershed

Class	Rate of erosion	Count	Area (ha)	Percentage of area	Severity
1	< 5	667513	10429.89	17.8	Low
2	5-10	1954514	30539.28	59.21	Moderate
3	10-20	99600	1556.25	3.18	High
4	20-40	25683	401.2969	8.2	Very high
5	40-80	79242	1238.156	2.53	Severe
6	>80	293767	4590.109	9.06	Very severe

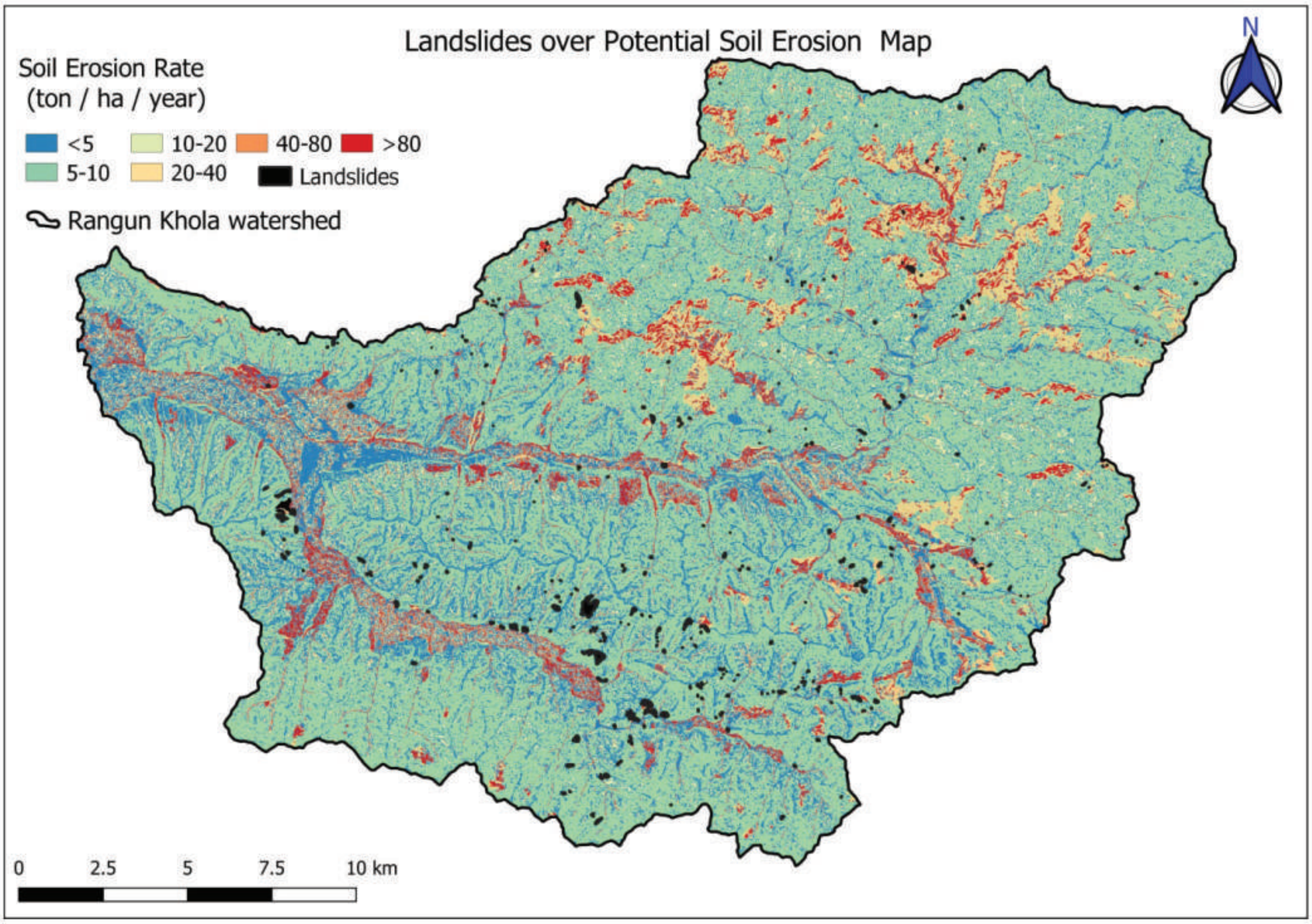

Figure 4: Landslide inventory (polygons) overlaid on potential soil erosion map of Rangun Khola watershed

The frequency was calculated from the analysis of the relationship between landslides and the attribute factors as given in Table 6. In the relationship analysis, the ratio is that of the area where landslides occurred to a particular area of erosion prone zone. A value of 1 is an average value. If the value is greater than 1, it means a higher correlation, and a value lower than 1 means a lower correlation of occurring soil erosion. The relationship between soil erosion and landslides occurrence shows that a very serve erosion level has a higher probability of landslides with frequency ratio of 4.41, which indicates higher probability of landslide occurrences. For serve, very high and high erosion levels, the frequency ratio is 3.49, 2.50 and 2.04, respectively. Similarly for low and moderate erosion levels frequency ratio was 0.46 and 0.50 that indicates it has a low probability of landslide occurrences.

Table 6: Frequency ratio values of landslide occurrences vs. potential soil erosion map

Soil Erosion levels	Pixels in domain	Pixels %, (a)	Landslide pixel count	Landslide occurrence, % (b)	Frequency ratio (b/a)
Low	667513	21.39	609	9.87	0.46
Moderate	1954514	62.64	1923	31.18	0.50
High	99600	3.19	401	6.50	2.04
Very high	25683	0.82	127	2.06	2.50
Severe	79242	2.54	547	8.87	3.49
Very severe	293767	9.41	2561	41.52	4.41
Total	3120319	100	6168	100	1

Fig. 5 displays the frequency ratio for each level of potential erosion susceptible to landside graphically. The frequency ratio and soil erosion levels have a linear relationship depicted in the graph. This correlation result demonstrates a reasonable level of agreement between the landslide event/location data and the erosion map and validates the model result.

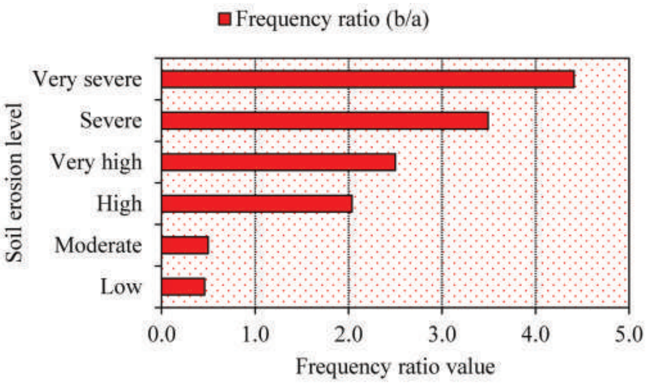

Figure 5: Frequency ration analysis between potential soil erosion map and landslide events between years 2005-2020 AD

RUSLE is the most commonly applied soil loss estimation model (Erol et al., 2015; Kumar et al., 2022). It can predict soil loss using limited information especially in developing countries where data collections are scarce (Thapa, 2020). Although the applicability of RUSLE model in mountainous terrain with steep slopes still questionable (M. Kumar et al., 2022), yet most widely used in similar terrain (Devatha et al., 2015; Koirala et al., 2019; Kumar & Kushwaha, 2013; Thapa, 2020). The potential soil erosion map prepared in this research revealed that the Rangun Khola watershed which is highly susceptible to landslide events (Pathak & Devkota, 2022a, 2022b) is also vulnerable to soil erosion due to five major factors, a high annual precipitation, the soil characteristics, mainly texture and steep slopes, land covers and soil conservation practices along the slopes. The range of potential soil erosion in this region ranges between 0 to 151 t $ha^{-1}yr^{-1}$, with an average (43 ton $ha^{-1}yr^{-1}$) higher than that of national average (25 ton $ha^{-1}yr^{-1}$) and falls in the range (0-273 ton $ha^{-1}yr^{-1}$) estimated for Nepal in the past study (Koirala et al., 2019).

The soil erosion increases with an increase in the steepness, which is also reported by Koirala et al. (2019) and Thapa (2020) in mountain of Nepal. Similarly the results of the potential soil erosion in different land covers were found to be similar to that of (Thapa, 2020) where barren land was highly vulnerable to the erosion. Land-use types with crop cultivation are much more exposed to soil loss than land-use types under semi or natural vegetation such as grassland, rangeland, shrub land, and forest. The erosion rate in undisturbed forestland is usually very low. Studies indicated that the reduction of overstorey canopy (Mohammad & Adam, 2010); removal or alteration of vegetation, destruction of forest (Karamage et al., 2016), land cover change mining (Borrelli et al., 2017) and landslide event (Pathak & Devkota, 2022a) significantly increase soil erosion risk which supports our finding that the forests and grasslands have low erosion rates in comparison with other land use.

The average erosion potential in current study suggests that the soil loss is above the tolerable limits and attention is needed to reduce the soil loss in vulnerable areas. Though there are no standard tolerable limits for soil losses in the mountain terrains, it is suggested that special soil and water conservation measures need to be applied for erosion rate greater than 35t $ha^{-1}yr^{-1}$ (Mandal & Sharda, 2013). In addition to harming the land, erosion causes sedimentation downstream to have a number of detrimental effects. Therefore, it is crucial to plan and carry out erosion control measures. The most vulnerable locations where the impact is expected to be highest must be the focus of the control measures in order to be as successful as possible.

It is necessary to assess the accuracy of the empirical models for the validation of the model outputs. But there are no proper validation techniques for potential soil erosion estimation from the RUSLE models and the results are compared with the field-based measurements over a set of sites for verification (Pradhan et al., 2012) or the results are compared with the estimated erosion from published field data (Koirala et al., 2019; Thapa, 2020). The frequency ratio approach suggested by Pradhan et al. (2012) and Gayen et al. (2020) was utilized. The frequency ratios for each level of potential erosion susceptible to landside exhibited a linear relationship. This can be the meaningful and reasonable level of agreement between the landslide event/location data and the erosion map that validates the model result. However, due to the enormous heterogeneity of the mid-hills of Nepal's geography, soil, cultural practices, and rainfall distribution, there is a wide range of erosion levels. For the model to be properly validated and improved, a one-to-one comparison of the estimates across a range of sites is necessary. Future investigations into places recommended for conservation efforts may include such studies, and the model and suggestions may be improved through an iterative process.

Conclusion

Rangun Khola watershed is very susceptible to soil erosion and landslides; therefore there was a need to study the soil erosion prone zones of this area. The present study demonstrates the application of RUSLE model in potential soil erosion estimation quantitatively. The soil erosion map was compared to the landslide inventory map and verified using the location of landslides by frequency ratio analysis. The results of this correlation showed a satisfactory agreement between the soil erosion intensity map and landslide events. Furthermore, the empirical model RUSLE for assessing soil erosion is used to evaluate soil erosion potentials in this area and to detect the sensitive zones presenting a priority of protection. Potential soil erosion map helps the decision makers to know the maximum erosion that can take place in the watershed and design land use/cover systems to reduce this non-point source pollution. Application of the RUSLE has many advantages: it provides quantitative data for comparison with qualitative assessments in erosion studies; data requirements for RUSLE are not too complex or unattainable and are compatible with GIS and easy to implement and understand from a functional perspective.

Acknowledgement

The authors would like to acknowledge and thank to all anonymous reviewers for their constructive comments which were helpful to bring the manuscript into its current form.

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Journal of Environment Sciences (2023), **Volume IX**, 94-103
https://doi.org/10.3126/jes.v9i1.56481

Land Use and Cover Change Detection in Shankharapur Municipality, Kathmandu Using Spectral Indices

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Abstract

The surging increase of the urban population has been accompanied by a sharp increase in urban built-up areas. The growth of population contributing to rapid expansion of built-up area in recent decades has caused a substantial Land Use Land Cover (LULC) change across Nepal and in particular Kathmandu Valley (KV). In this study, a Normalized Difference Vegetative Index (NDVI) and Normalized Difference Built-up Index (NDBI) was applied to three Landsat imagery collected over time (2002, 2013, and 2022) and one Sentinel-2 imagery that provided recent and historical LULC conditions for, Shankharapur municipality that lies in the eastern part of Kathmandu. The three-land use land cover categories were identified and mapped from the value of NDBI and NDBI. We found that over a period of 20 years (from 2002 to 2022), the Shankharapur municipality has lost 14.64% and 25.97% of its forests and sparse vegetation, and increase in the settlement/open land by 5.48% and 226.73% as indicated by NDVI and NDBI for Landsat imagery respectively. The increase in settlement/open land can be summed to the augmented activities like constructing new building and increase forest and land defragmentation including construction of road and land planning to fulfill the demand of influx of people after the earthquake of 2015. The results of NDVI and NDBI from Sentinel-2 imagery also support the increase in settlement/open land and decrease in forest and sparse vegetation. Also, agriculture cover increased by 4.25 sq.km between 2002 to 2013 and increased by 4.85 sq.km. from 2013 to 2022 as indicated by NDVI derived from Landsat imagery. However, the significant amounts of losses of forest and sparse vegetation during 20 years have been absorbed by the expanding urbanized areas and agriculture land as more land is subjected to the built-up and land planning along with the wood-logging as a result of aftermath of the earthquake, 2015, where population has increased by 19.4 % in the span of 10 years from 2011 to 2021 and is never retreating in terms of changing land cover. Therefore, such trends if unchecked can result in loss of biodiversity and ecosystem services associated with deteriorating conditions for human well-being.

Keywords: *Land Use Land Cover, NDBI, NDVI, Satellite Imagery*

Introduction

Although urban areas make up only a small fraction of the total global land area, they host more than 54% of its population, furthermore, the urban population is expected to rise by over 2 billion by 2050 (UN, 2014). The surging increase of the urban population has been accompanied by a sharp increase in urban built-up areas (Zheng et al., 2021). Synoptically, this rapid urbanization has led to the depletion of resources and multiple environmental problems and disasters, exacerbated the problems of water scarcity, air pollution, and urban heat-island effects, and imposed strong pressure on global and regional sustainability (Tang & Ma, 2018; Xian et al., 2019; Zheng et al., 2021). Urban built-up areas expansion have far-reaching impacts on human society and living environments all over the world (Zheng et al., 2021).

According to Preliminary census report of 2021 (CBS, 2021), has revealed the urban population to be 66.08 percent and rural population of 33.92 percent. Adjusting the population after the Federal restructure from rural to urban area, the population of the urban area was 63.19 percent and rural population was 36.81 percent during census 2011. Hence, comparing population between 2011 and 2021 shows that urban population has increased by 2.89 percent. The growth of population contributing to rapid expansion of built-up area in recent decades have caused a substantial LULC change across

Nepal and in particular Kathmandu Valley (KV). Rapid urbanization—coupled with lack of proper planning and high rural-urban migration—is the key driver of these changes. With 3.94% urban growth rate between 2010 and 2014, the KV is going through significant transformation of its landscapes in recent years making it important to understand the dynamics of LULC change processes, including their interactions with local and regional environmental change (Ishtiaque et al., 2017). In addition, predictions of land use and land cover change trends for 2030 shows a worsening trend with forest, agriculture and water bodies to decrease by an additional 14.43%, 6.67% and 25.83%, respectively. The highest gain in 2030 is predicted for urbanized areas at 18.55% (Wang et al., 2020).

Understanding and monitoring the dynamics of land use and land cover changes, their intensity, direction, drivers, and impacts provide useful information for sustainable development planning (Lu et al., 2004) and therefore remains an important goal in the field of land cover change science. Remote sensing in combination with GIS technology has been proven to provide scientifically credible results and policy recommendations that have assisted decision-makers and planners to advance sustainable development especially in fast growing urban settings (Appeaning Addo, 2010). As a result, remote sensing and GIS have become popular tools for better understanding of spatiotemporal and spectral characteristics of land use and land cover changes at local and global scales (Wang et al., 2020; Weng, 2001). Change detection, the process of identifying differences in the state of a feature or phenomenon by observing it at different times (Singh, 1989) is useful in many applications related to land use and land cover (LULC) changes, such as shifting cultivation and landscape changes, urban landscape pattern change, deforestation, quarrying activities and landscape and habitat fragmentation and other cumulative changes (Abd El-Kawy et al., 2011).

Despite rapid growth in population and expansion of urban area, only a few LULC change studies have been conducted on Kathmandu Valley to date and considering the expansion of urban built-up areas as a result of increased population and simultaneous diminution in other land use land cover especially that occurred after the post-civil war and massive earthquake that occurred in 2015 (Ishtiaque et al., 2017), an assessment would be crucial in conceptualizing and interpreting the changing LULC patterns in the area. Thus, the objective of this study is to examine the LULC dynamics in the period of 2002-2022 using Landsat imageries using Normalized Difference Vegetation Index and Normalized Difference Built-up Index tools in ArcGIS Pro.

Materials and Methods

Study Area

Shankharapur municipality lies at the eastern part of the Kathmandu district and is the smallest municipality in the terms of population. According to Census 2021, the total population of Shankharapur municipality is 30414 of which 15188 are male and 15226 are female (CBS, 2021). The municipality is situated at an altitude ranging from 1,100 meters to 2,400 meters above sea level and covers an area of 60.21 sq.km. Shankharapur municipality is located at 27°42’56.68"N-27°47’32.11"N latitude to 85°25’42.41"E-85°33’56.36"E longitude.

Shankharapur municipality being the area that lies within the Kathmandu district, it is expected to experience the same climate as that of Kathmandu. The Kathmandu district has a sub-tropical climate (below 2000 m) and temperate climate (above 2000 m) and is influenced by south Asian monsoon (UNDESA, 2014). The annual average precipitation is about 1407 mm with monsoon period that lasts from June to September accounting for more than 80% of its annual precipitation. The annual average temperature in the valley is around 18.1°C, with some mountain tops remaining under seasonal snow (Ishtiaque et al., 2017). The main vegetation type of the district is mixed conifer and broadleaved forests at lower elevations, slowly transitioning to conifers to shrub land and occasional snow at higher elevations (Wang et al., 2020).

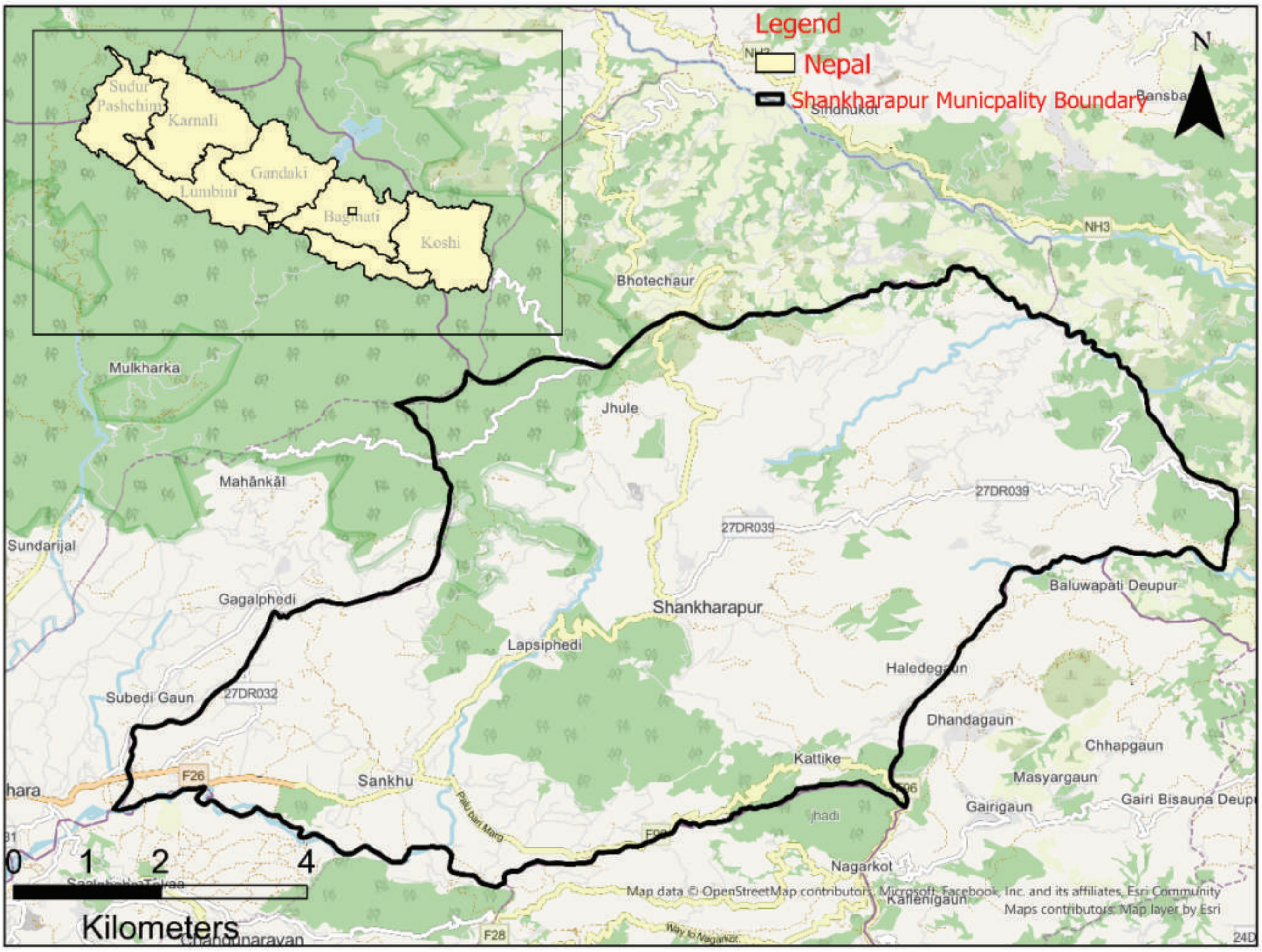

Figure 1: Location of Study Area: Shankharapur Municipality

Data acquisitions and Use

Landsat 9-OLI-2 and Landsat 8-OLI captures the images in 11 different band, Landsat 07 ETM+ captures the images in eight different band. All three images from the Landsat captures all the images with the spatial resolution of 30m except Panchromatic band which has spatial resolution of 15 m. Whereas, Sentinel-2 consists of twelve different bands with spatial resolution of 10 m, 20 m and 60m. The details of the bands of the images acquired from the different satellite are presented in Table 1 below.

The satellite imagery required for the study is acquired from two different open source. Earth explorer from USGS is used to download the Landsat 9 (March), Landsat 8 (November) and Landsat 7 (February) image from the year March, 2022, November, 2013 and February, 2002 respectively. Similarly, Copernicus open hub is used for downloading the Sentinel-2 imagery for the year December, 2022. The imagery obtained and processed have the cloud cover less than 10%. Imagery of Landsat 9 and Sentinel-2 image is used to compare the difference in NDVI and NDBI of the study area due to the difference in spatial resolution of the image.

Image Processing

Pre-Processing is the initial step of processing which is carried out to correct for any distortions due to the characteristics of the image systems and imaging conditions (Raut et al., 2020). However, the image obtained from the source do not require preprocessing as all the Landsat image downloaded are Level-2 Science Product which are preprocessed data products that have undergone several processing steps to correct for various atmospheric and instrumental effects. In addition, the Sentinel-2 image was Level-2a product which

Table 1: Bands with their resolution and wavelength of different satellite imagery

Bands	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)		Landsat 9 and 8 Operational Land Imagery (OLI) and Thermal Infrared Sensor (TIR)		Sentinel-2 S2B Level 2a		
	Image Source: https://earthexplorer.usgs.gov				Image Source: https://scihub.copernicus.eu		
	Band Name (Resolution in Meter)	Wavelength (micrometer)	Band Name (Resolution in Meter)	Wavelength (micrometer)	Band Name (Resolution in Meter)	Central Wavelength (nm)	Bandwidth (nm)
1	Blue (30m)	0.45-0.52	Ultra-Blue (30m)	0.435-0.451	Coastal/Aerosol (60m)	442.3	45
2	Green (30m)	0.52-0.60	Blue (30m)	0.452-0.512	Blue (10m)	492.1	98
3	Red (30m)	0.63-0.69	Green (30m)	0.533-0.590	Green (10m)	559	46
4	NIR (30m)	0.77-0.90	Red (30m)	0.636-0.673	Red (10m)	665	39
5	SWIR 1 (30m)	1.55-1.75	NIR (30m)	0.851-0.879	Vegetation Red Edge (20m)	703.8	20
6	Thermal (60m)	10.40-12.50	Short-Wave Infrared SWIR-1 (30m)	1.566-1.651	Vegetation Red Edge (20m)	739.1	18
7	SWIR 2 (30m)	2.09-235	SWIR-2 (30m)	2.107-2.294	Vegetation Red Edge (20m)	779.7	28
8	Panchromatic (15m)	0.52-0.90	Panchromatic (15m)	0.503-0.676	NIR (10m)	833	133
8a	-	-	-	-	Vegetation Red Edge (20m)	864	32
9	NA	-	Cirrus (30m)	1.363-1.384	Water Vapour (60m)	943.2	27
10	NA	-	Thermal Infrared -TIR1 (100m)	10.60-11.19	SWIR-Cirrus (60m)	1376.9	76
11	-	-	TIR2 (100m)	11.50-12.51	SWIR (20m)	1610.4	141
12	-	-	-	-	SWIR (20m)	2185.7	238

has been subjected to radiometric corrections, geometric refinement and atmospheric corrections.

The individual bands for different years downloaded was stacked (Band 3, 4, and 5 for Landsat 7, Band 4, 5 and 6 for Landsat 8 and 9 and Band 4, 8 and 11 for Sentinel-2) to get final composite layer which was carried out in ArcGIS Pro. Then, the composite bands imageries were subjected to the clip by the administrative study area of Shankharapur municipality. For each composite imagery Normalized Difference Vegetative Index and Normalized Difference Built-up Index were calculated. The indices thus obtained are minuscule validated by the google image of respective years to compute the threshold value for differentiating the LULC types. Then, the land use/land cover was classified by dividing the value of indices into Forest/Sparse Vegetation, Agriculture land and Settlement/Open area including plotting land/ Water bodies and Sandy Areas and then reclassify in ArcGIS Pro. Water bodies and sandy areas are also included in Settlement since only Salinadi river which flows through the middle of the Shankharapur municipality which indices value are very narrow and are unpresentable in the map.

Land Cover Classification and Change Analysis

Normalized Difference Vegetative Index (NDVI) and Normalized Difference Built-up Index (NDBI) are used to determine the change in the vegetation and built-up area for the past 20 years in the Shankharapur municipality.

NDVI is widely used vegetative indices technique to determine the distribution of vegetation based on the characteristic reflectance patterns of green vegetation. The NDVI value varies from -1 to 1. Higher the value of NDVI reûects high Near Infrared (NIR), means dense greenery and lower value represents the area with no greenery. NDVI was calculated by the following formula;

NDVI = (NIR – RED) / (NIR + RED)

Therefore, For Landsat 7 data, NDVI = (Band 4 – Band 3)/ (Band 4 + Band 3)

For Landsat 8 and 9 data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

For Sentinel-2 data, NDVI = (Band 8 – Band 4) / (Band 8 + Band 4)

NDBI is used to determine the distribution of the built-up area based on the characteristic reflectance patterns of built-up area. NDBI value also ranges between -1 to 1. Normalize Diûerence Built-up Index value lies between -1 to +1. Negative value of NDBI represent water bodies whereas higher value represents dense build-up areas. NDBI value for vegetation is low with higher value representing the built-up areas. NDBI is calculated by the following formula;

NDBI = (SWIR-NIR) / (SWIR+NIR)

For Landsat 7 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4),
For Landsat 8 and 9 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5),
For Sentinel-2 data, NDBI = (Band 11– Band 8) / (Band 11 + Band 8)

For calculating the NDVI and NDBI Landsat 7 imagery was used for the year 2002, Landsat 8 imagery was used for the year 2013 and Landsat 9 imagery was used for the year 2022. Similarly, Sentinel-2 imagery was also used to calculate NDVI/NDBI for the year 2022 to compare the results of Landsat 9 as spatial resolution of Sentinel-2 is high to that of Landsat (10m to 30m). Based on the value of the indices of NDVI and NDBI land use/land cover was classified for the year 2002, 2013 and 2022. NDVI and NDBI for the different years was compared and change detection of land cover in area was calculated.

Results and Discussion

Results of the NDVI an NDBI for the year 2002, 2013 and 2022 are presented in the Table 2. The results for the land use land cover types are classified in three different types as: Forest and Sparse Vegetation, Agricultural Land and Settlement/Open Land which also includes plotting land, water bodies and sandy areas.

Analysis of Land Use and Land Cover Classes for 2002

The results of the analysis of the 2002 image (Figure 2) have shown the agricultural land dominated the landscape with 35.21 sq.km indicated by both NDVI and NDBI. Similarly forest and sparse vegetation acquired 23.56 sq.km and 21.55 sq.km whereas, the least covered land cover types is settlement including open land and water bodies/sandy area as analyzed from NDVI and NDBI respectively. Both, NDVI and NDBI indicates that the settlement area is confined to the south-west and less dense and sparse vegetation in the north-east part of the municipality. Agriculture cover is widely spread and majority of land is conquered in every part of the municipality as major population of the municipality is dependent in agricultural production for the income generation activities during year 2002.

Table 2: Composite table of area statistics of Shankharapur municipality of 2002, 2013 and 2022 for Landsat Imagery

Land Use Land Cover Types	Normalized Difference Vegetative Index (Area in Sq. Km.)				Normalized Difference Built-Up Index (Area in Sq. Km.)			
	2002	2013	2022	Area Change (20 Years)	2002	2013	2022	Area Change (20 Years)
Settlement/Open Land	1.01	1.44	3.30	3.80	2.5	3.44	4.08	1.58
Agriculture	39.46	35.21	40.06	1.00	34.57	35.21	38.99	4.42
Forest and Sparse Vegetation	19.74	23.56	16.85	-4.80	23.14	21.55	17.13	-6.01

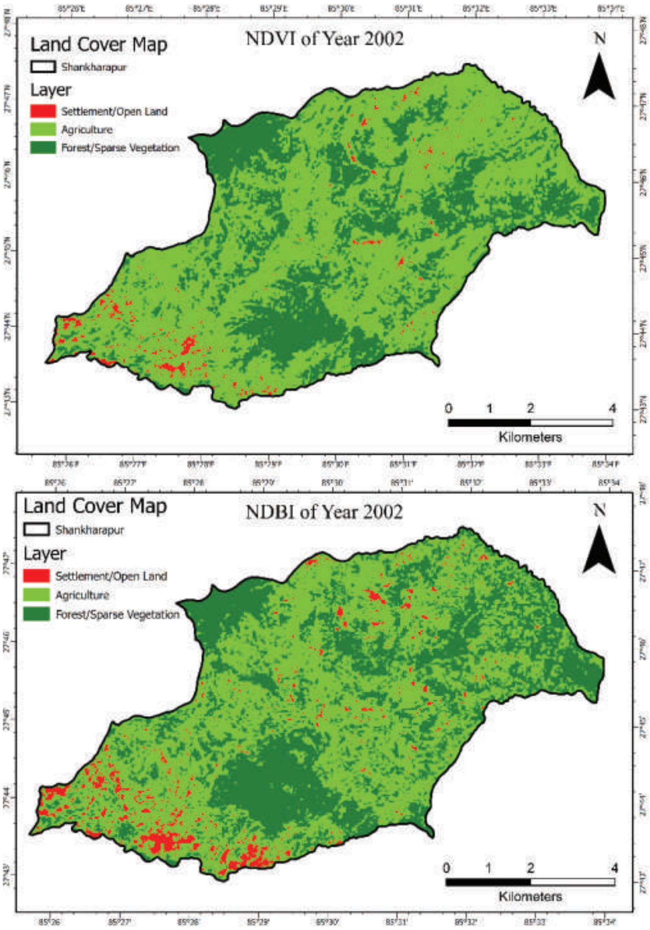

Figure 2: NDVI and NDBI of the Year 2002 derived from Landsat 07 Imagery

Analysis of Land Use and Land Cover Classes for 2013

Compared to 2002 results, findings from the year 2013 shows an increase in the cover of forest area and decrease in agriculture area followed by a slight increase in settlement cover as shown in Figure 3. In 2013, NDVI indicated that settlement/built up areas and open land is 1.44 sq.km, agriculture covers 35.21 sq.km. and forest and sparse vegetation covers 23.56 sq/km. Whereas, NDBI of same year indicated the settlement/built up areas and open land covers 3.44 sq.km, agriculture covers 35.21 sq.km. and forest and sparse vegetation covers 21.55 sq/km. Both of the indices show same area covered by the agriculture land but NDBI show significant increase in settlement area as NDBI, measures the amount and density of built-up areas by using SWIR and NIR reflectance. Comparing between NDVI between 2002 and 2013 the forest and settlement and open land has been increased in the northern and north-east part of the municipality and reducing agriculture cover indicating more people abandoning agricultural land and the shifting their income generation activities from farming and conversion of agriculture to sparse vegetation. One of the study also showed that after the 1990s, there has been a slight decrease in the rate of land area conversion to agricultural land, especially around Kathmandu (Paudel et al., 2018). However, in contrast NDBI show slight increase in agriculture and decrease in vegetation probably due to the difference in surface reflectance calculating the indices.

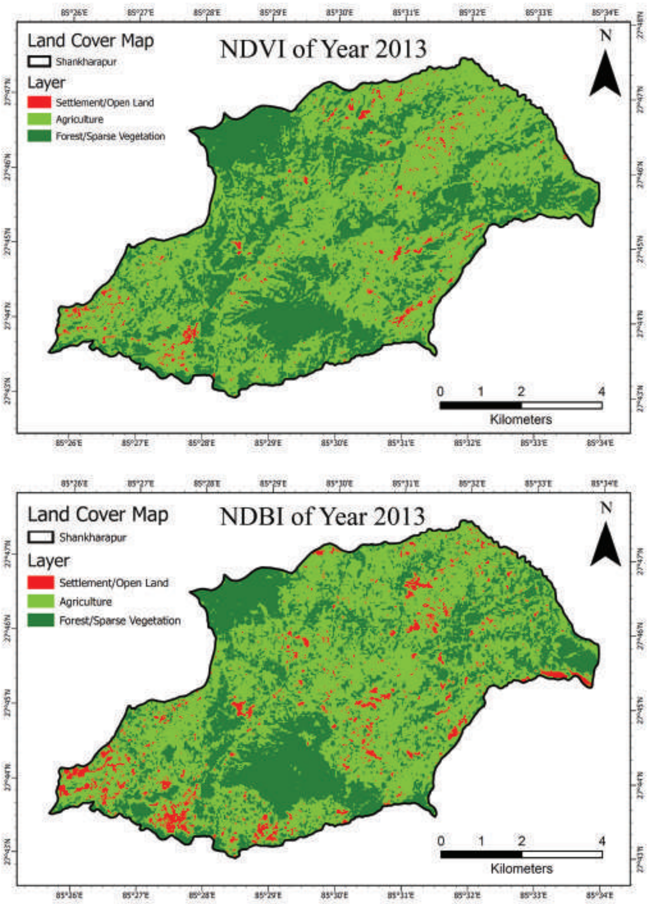

Figure 3: NDVI and NDBI of the Year 2013 derived from Landsat 08 Imagery

Analysis of Land Use and Land Cover Classes for 2022

NDVI from Landsat imagery for the year 2022 have indicated the settlement/open land, agriculture, forest and sparse vegetation cover to be 3.3021 sq.km., 40.06 sq.km. and 16.85sq.km. and from Sentinel-2 imagery to be 1.95 sq.km, 38.72 sq.km. and 19.52

sq.km. respectively. Similarly, NDBI from Landsat imagery for the same year shows settlement/open land, agriculture, forest and sparse vegetation cover to be 4.08 sq.km., 38.99 sq.km. and 17.13 sq.km. and from Sentinel-2 imagery to be 2.29 sq.km., 39.70sq. km. and 17.70 sq.km. respectively. The difference of the land cover area represented by Landsat and Sentinel imagery is due to the differences in band widths, spatial resolutions, and data processing, different sensors can deliver notably different NDVI behaviors, particularly between spaceborne and airborne sensors (Huang et al., 2021). Whereas, Both NDVI and NDBI showed the increase in settlement area in the surrounding land area in south-west and north-east part of the municipality in the area with easily accessible by road. Comparing the NDVI and NDBI from Sentinel-2 imagery for the year 2022 showed settlement/open land to be 1.95sq.km and 2.79 sq.km, agriculture cover 38.72 sq.km. and 39.70 sq.km. and forest and sparse vegetation to be 19.52 and 17.70 respectively.

Land Cover Change Analysis

The land use and land cover from 2002 to 2022 calculated from Normalized Difference Vegetative Inex (NDVI) and Normalized Difference Built-up Index (NDBI) showed important trends in land use transition from one class to another. The distribution of transition between land use classes detailed coverage of area transition (sq.km. and %) from one to other classes were presented in Table 2, 3 and 4. NDVI has represented the area of a total change of 226.73% (3.80 sq.km) in Settlement/Open Land between 2002-2022 in whereas, Forest and Sparse Vegetation represented 32.79% in 2002, increase to 39.13% in 2013 and then again decrease to 27.99% in 2022 with total decrease of 14.64% (4.80 sq.km) between 2002-2022. However, NDBI showed a slight decrease in forest and sparse vegetation of 1.59 sq.km (2.64%) between 2002-2013.

Concerning with results of NDVI, the increase in forest and vegetation and reduced agriculture area

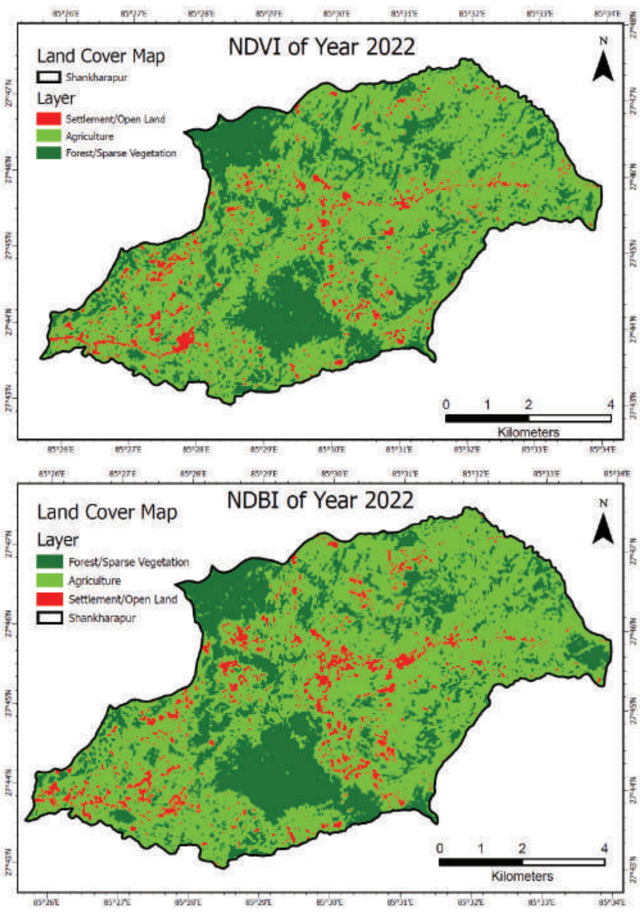

Figure 4: NDVI and NDBI of the Year 2022 derived from Landsat 09 Imagery

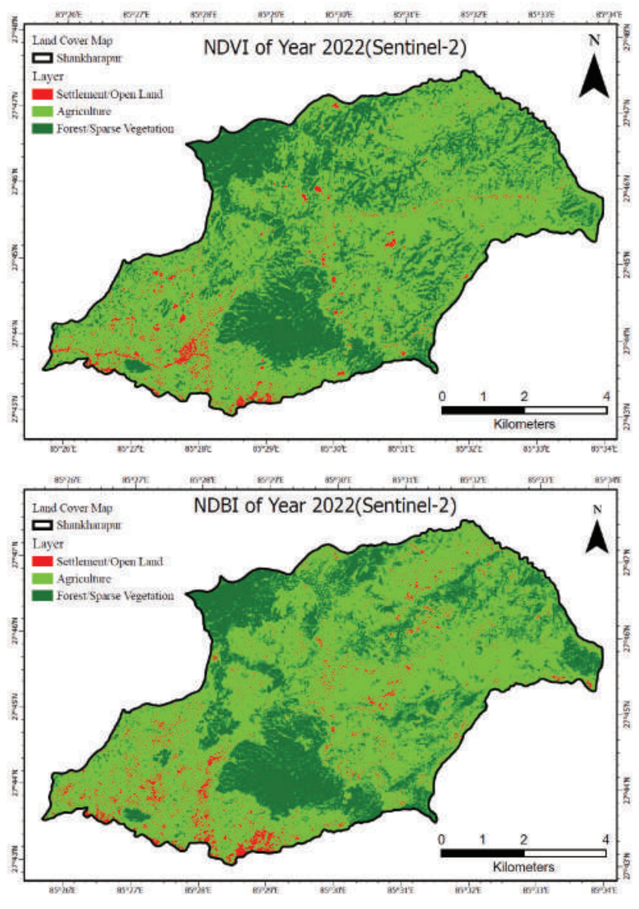

Figure 5: NDVI and NDBI of the Year 2022 derived from Sentinel-2 Imagery

Table 3: Composite table of NDVI area statistics (%) of Shankharapur municipality of 2002, 2013 and 2022

Land Cover Types (NDVI)	2002 Area (%)	2013 Area (%)	2022 Area (%)	Change %	Change %/Year
Settlement/Open Land	1.68	2.39	5.48	226.73	11.34
Agriculture	65.54	58.48	66.53	1.52	0.08
Forest and Sparse Vegetation	32.79	39.13	27.99	-14.64	-0.73

Table 4: Composite table of NDBI area statistics (%) of Shankharapur municipality of 2002, 2013 and 2022

Land Cover Types (NDBI)	2002 Area (%)	2013 Area (%)	2022 Area (%)	Change %	Change %/Year
Settlement	4.15	5.71	6.78	63.20	3.16
Agriculture	57.42	58.48	64.76	12.79	0.64
Forest and Sparse Vegetation	38.43	35.79	28.45	-25.97	-1.30

can be attributed to the abandoned agricultural practices due to the shortage of labor resulting in less agriculture practices in the area between 2002 and 2012. This is supported by influx of remittance in Nepal as the economically independent age groups has moved to the foreign employment for better income opportunities as credited to remittance inflow which was NPR 47.22 billion in FY 2000/01 which is more than quintupled to NPR 253.55 billion in 2010/11 (NPC, 2020). In addition, the settlement/open land as indicated by NDVI increased by 226.73% with 11.34% change every year for the period of 20 years and 63.20% increased with 3.16% increase every year for the similar period as represented by NDBI. Both of the indices regarding the settlement area showed the tremendous increase in the land use class. This increase sums up the augmented activities like constructing new building and increase land defragmentation and land planning to fulfill the quest of building the new home and people inflowing in Kathmandu valley after the earthquake of 2015, increased remittances by 20.9 percent in 2015 versus 3.2 per cent in 2014 (IOM, 2019). Also, the decreased forest land between 2002 and 2012 can be linked to a number of activities or events can lead to forest fragmentation including road construction, logging, conversion to agriculture, wildfires, and human conflict over a forest patches (Uddin et al., 2015). Between 2002-2010 NDBI indicated a slight increase in the agricultural land in similarity with the spatiotemporal distribution of agricultural land in Nepal revealing an increasing trend between 1910 and 2010 and this expanded rate of increase in agricultural land has varied between different eco, physiographic, and altitudinal regions of the country, significantly driven by population changes and policies over the period of this investigation (Paudel et al., 2018). During the period between 2013-2022, both NDVI and NDBI indicated the increase in agriculture and decrease in forest and sparse vegetation cover comprehend the increased logging of private forest to supply the increased demand of wood for the construction of new house affected by the earthquake. The findings are similar with another study which shows the built-up area of Kathmandu Valley has increased from 38 sq. km in 1990 to 119 sq. km in 2012 over the period of 22 years, with a 211% increase (Timsina, 2020). Similarly, a recent study conducted by (Ishtiaque et al., 2017) shows that Kathmandu Valley's urban area is expanded up to 412% in last three decades. In addition, another study over a period of 20 years (from 1990 to 2010), the Kathmandu district has lost 9.28% of its forests, 9.80% of its agricultural land and 77% of its water bodies and these losses have been absorbed by the expanding urbanized areas, which has gained 52.47% of land (Wang et al., 2020).

Conclusion

This study used GIS and remote sensing techniques to detect and predict land use and land cover changes in the Shankharapur municipality over a 20-year period by using NDVI and NDBI. The observations in the Shankharapur municipality exhibits the magnitude and extent of threats and challenges of changing landscapes, land cover and land use from increased migration with unplanned urbanization trends occurring at south-west, north-east at major road locations.

Quantitative evidence from this study indicates that the Shankharapur has undergone significant land use and land cover changes since 2002. Forest and agricultural lands dominated the land use and land cover of the municipality, however there is an increase in settlement and open land area between 20 years period from 2002 to 2022. This dramatic increase in the settlement is due to rapid increase in urbanization which remains a key driver of land use and land cover changes and is taking over agricultural and forest lands. Other factor attributing to the urbanization in the area includes the rapid increase in the remittance in the area, shifting agriculture-based income to foreign employment, and natural hazard like earthquake etc. This small town in the eastern part of Kathmandu Valley which population has increased by 19.4 % in the span of 10 years from 2011 to 2021 and is never retreating in terms of changing land cover. Such trends if unchecked can result in loss of biodiversity and ecosystem services associated with deteriorating conditions for human well-being, thereby increasing the vulnerability of humans and ecosystem to small changes in the system including climate (Wang et al., 2020).

Thus, the rate of these land conversions has advanced after the rapid urbanization post-civil war since 2006, and natural hazard i.e., earthquake in the year 2015 coupled with lack of stringent government policies regarding land planning and conversions and weak monitoring in the face of corruption (Wang et al., 2020).

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Journal of Environment Sciences (2023), **Volume IX**, 104-117
https://doi.org/10.3126/jes.v9i1.56485

Identification of mammalian indicators of climate in Chitwan Annapurna Landscape (CHAL) to assess climate change

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Abstract

The consequences of climate change on species and ecosystems are evident, and the landscape of Nepal does not remain unaffected. Himalayan region is climate sensitive, even a tiny fluctuation in climate can markedly affect numerous species and their habitats. Moreover, the Himalayan region is inhabited by some of the most threatened and endangered biodiversity on Earth, including habitat specialists and endemic species, which may accelerate the extinction of some species. Hence, species affected by climate change should be monitored and identified as faunal indicators of climate change in (Chitwan Annapurna Landscape) CHAL. For that, we compared studies conducted by the National Trust for Nature Conservation (NTNC) and World Wildlife Fund for Nature (WWF Hariyo Ban Program). First, we identified the common and overlapping species. Second, we identified the critical species for climate monitoring based on habitat range, elevation, role as habitat specialist/generalist, and impact observed in previous studies based on the species occurrence in that region. Species with a long-life span, specialist habitat type, and short home range are exposed to climate change for extended periods, making them more vulnerable as per the literature. In particular, our results demonstrate that the one-horned rhinoceros found in the lower belt of Nepal and snow leopard, and pika, being habitat specialists, with low reproductive rate and cannot tolerate change in temperature experience a high impact owing to climate change and can be used as indicators of climate change. In addition to that Assasames Monkey and elephant has medium impact and hence can be considered as the indicator to monitor climate change. However this study does not incorporate specific species-based study regarding the impact of climate change which is required to assess climate change sensitivity to facilitate global wildlife protection.

Keywords: *biodiversity, Himalaya, Chitwan Annapurna Landscape, climate change, faunal indicator, mammals.*

Introduction

Climate change has recently been recognized as a threat to the entire world and a problem for the twenty-first century. Climate change is already having an impact on wildlife at local (Thapa et al., 2015), regional (Aryal et al., 2014), and global levels (Habibullah et al., 2022). Moreover, high-altitude, cold deserts, such as the trans-Himalayan region, are among the most vulnerable ecosystems to climate change (Xu et al., 2009; Dong et al., 2009). The contrasting biodiversity of Nepal has suffered a moderate to high impact owing to climate change (Shrestha et al., 2014). The general trajectories and rates of response of species and natural communities to ambient changes in climate can be predicted through the analysis of various data sources and use of various types of climate models (Dawson et al., 2011). Yet, the specific impacts of climate change on natural ecosystems, including ecosystem processes and service delivery, remain unclear (Parmesan, 2005). Recent assessments have predicted that the average annual temperature in the Himalayan region will increase faster than the global average, and precipitation patterns are also expected to change (Li et al., 2013; Shrestha et al., 2012; Xu et al., 2009). Román-Palacios et al. (2020) showed that extinction occurred at locations with change in mean annual temperature, but more significant increases in maximum annual temperature. Such impacts are already visible in Nepal, field studies have detected upward shifts in tree species along the tree-line in the Nepalese Himalaya (Gaire et al., 2011, 2013; Shrestha and Devkota, 2010; Vijayprakash and Ansari, 2009). Forest covers over 22% of the land in Tibetan Plateau which is expected to expand by the end of the century (Ni, 2011). Because different species have different physiological tolerances and dispersal adaptations, the individual species that comprise natural communities will likely respond and shift at different rates (Lavergne et al., 2010). The loss of native vegetation occurs discontinuously and leads to the breakup of the original land cover into distinct patches, separated by a matrix of land converted to a variety of anthropogenic land uses (Ewers and Didham, 2006; Fahrig, 2003). These native patches become smaller and more isolated from each other as the loss of native vegetation progresses. This long-standing, intense, and global process of native vegetation conversion has created a social demand for scientific support in mitigating the effect of habitat loss and fragmentation on biodiversity and ecosystem services (Haila, 2002). Some species of birds, reptiles, amphibians, and butterflies require particular habitats, hosts, food sources, and environmental conditions also known as habitat specialist species (e.g., temperature, shade/sunlight, moisture, and humidity). Such habitat specialist species will be most sensitive to change (Magura et al., 2020).

Climate change is also likely to intensify the uncertainty surrounding the long-term water supply of the Himalayas and Tibetan Plateau. This, in turn, will impact biodiversity as well as the lives and livelihoods of the local population (Xu et al., 2009). Forrest et al. (2012) revealed that the habitat of the snow leopard may be lost owing to a shifting tree-line and consequent shrinking of the southern edge of the Himalayan range. Also, the study of Koju et al. (2021) in the central Nepalese Himalaya indicated that the population density of pika species has decreased. However, while many climate change studies have concentrated on community and individual perceptions (Fox, 2002), there is a lack of information specifically related to faunal indicators of climate change in high-altitude ecosystems.

Therefore, this study is done as the follow up study of the World Wildlife Fund (WWF) Nepal/Hariyo Ban Program in CHAL region after identification of mammalian species. Indicator species were chosen based on a list of desirable features that cause changes in species behavior owing to climate change. Apart from literature, expert opinions were taken into consideration. In light of previous studies on faunal indicators, the lack of Nepalese data on faunal indicators prevents a thorough investigation. During the selection of indicator species, previous research, threat analyses, and species conservation action plans developed by the Nepalese government were used as a guide (Table 1). This study aims to establish a baseline for faunal (mammal) ecology that is particularly affected by climate change, and hence act as an indicator of climate change in the future, which could be imperative to conservation planning in Nepal and elsewhere. Climate indicators are species that have a direct or indirect impact on the ecosystem that is dependent on climatic conditions. This study identifies six mammalian climate change indicators in Nepal that have an impact on its native terrestrial biological systems. Additionally, we discuss how this approach can be useful to integrate the potential effects of climate change into conservation strategies for other high-conservation-value mega species.

Materials and Methods

Study area

High mountains of the Himalayas comprise the northernmost region of Nepal, with rugged terrain, deep gorges, glaciers, and snow-capped mountain peaks (Shrestha et al., 2019). This study was conducted in the Chitwan Annapurna Landscape (CHAL) area (Fig. 1), located between 27.16° and 29.30° N, and 82.70° and 85.70° E in central Nepal, covering a total area of 32,090 km^2. The CHAL area encompasses the Gandaki/Narayani River Basin, which includes the rain shadow area of the trans-Himalayan area, and the snow-capped mountains of Annapurna, Manaslu, and Langtang in the north; out of the four physiographic regions of Nepal are represented in the studied landscape. The CHAL area has a vast elevation gradient (from < 100 to > 8000 m above sea level) with a climate ranging from tropical (Tarai), through subtropical, temperate, and subalpine, to alpine (High Himal), including a trans-Himalayan cold and dry climate similar to Tibet. The study area comprises two conservation areas (Annapurna and Manaslu), two national parks (Chitwan, also a World Natural Heritage Site, and Parsa), one hunting reserve (Dhorpatan), and two Ramsar wetland sites (Beeshazari and Pokhara lake systems).

CHAL support some Nepal's most threatened and endangered biodiversity, including habitat specialists and endemic species (Basnet et al.,2000) and high biodiversity value, being an essential transit route for migratory birds, and is home to endangered species, such as the snow leopard, red panda, and Himalayan black bear (Gautam et al., 2013). CHAL, thus contains topographic, climatic, ecological, and socio-economic variations along

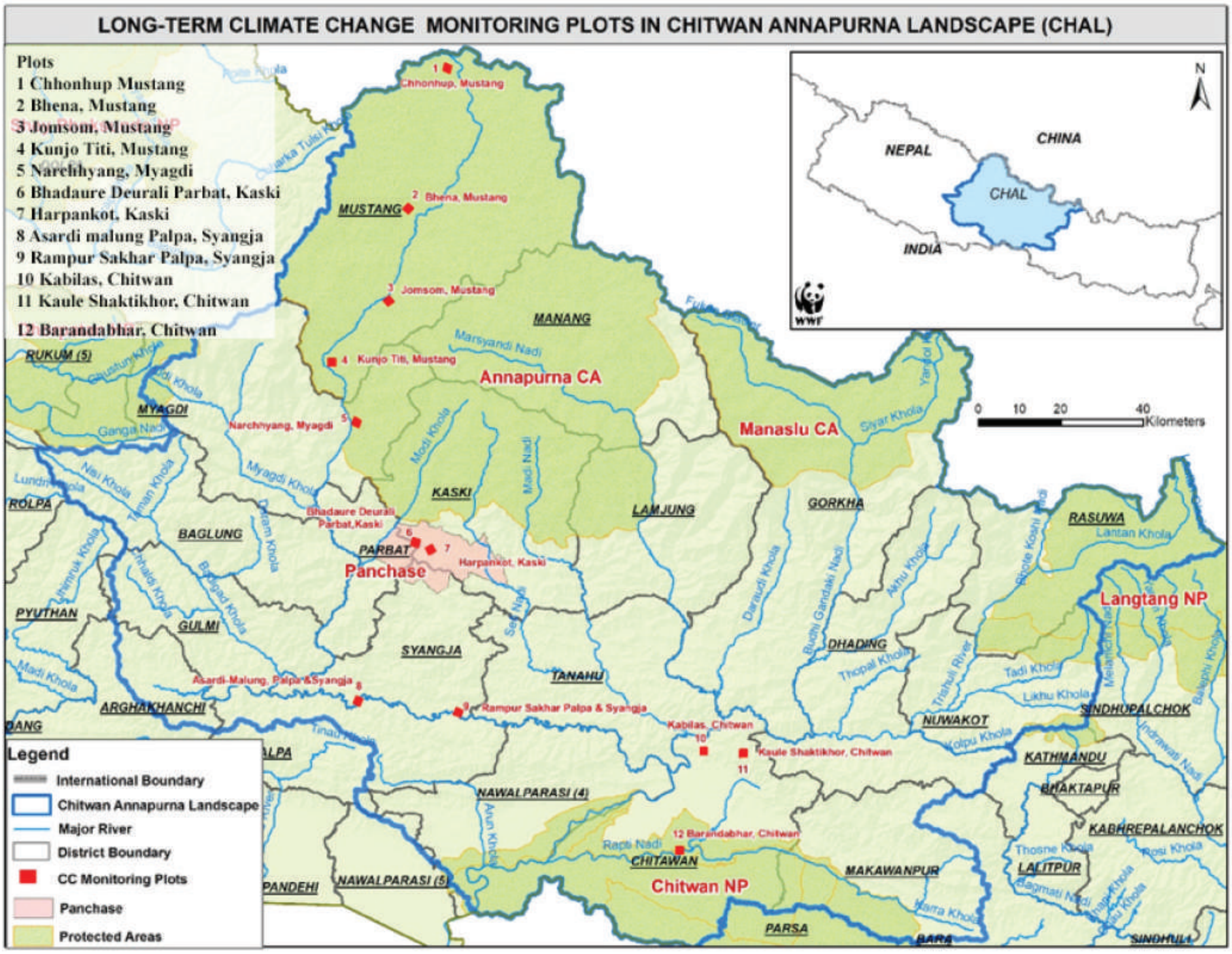

Figure 1: Location of climate change monitoring plots in the CHAL area. (Source: WWF, Nepal)

an elevation gradient within Nepal. To establish baseline data for the conservation of biodiversity in this area, we took the data from 12 permanent monitoring plots, set up by HBP (each 2 km^2) within the CHAL (Fig. 1) which represents Siwalk region (205 masl) to High Mountain (4740 masl).

Methodology

Our study was based on information collected primarily from the field through an accepted scientific procedure whereby data on mammals and birds were obtained using detailed surveys along a transect. Transects were arranged to cover representative habitats and altitudes within each plot area. The total length of each transect was 7.7 km. Transects were constructed following man-made trails owing to the rugged geographic terrain. Based on the size of the study area, the number of sampling plots was calculated. The equipment used for mammals was a camera trap, Sherman trap, or tube trap, while a mist-net or bat detector vernier caliper was used for bat counting. Binoculars were used for bird counting; other pieces of equipment (camera, compass, measuring tape (20 m), field notebook, first aid kit, and gloves) were also used. Moreover, previously published findings and data were considered and thoroughly examined in this research.

To determine the overlapping and common species in the 12 plots in 2015 and 2019, commonly occurring species were noted. The similarity index was calculated using the Jaccard index (1912) (cited in Leydesdorff, 2008) (Equation 1) to assess the similarity of the species between two given years. The Jaccard index gives the proportion of species out of the total species list of the two sites, which are common to both sites:

$SJ = ca + b + c$……………. (1)

where, SJ is the similarity index, c is the number of shared species between the two sites, and a and b are the number of species unique to each site.

Identification of climate change indicator species

Climate change indicator species were identified using the presence absence data. The species present in the data were then analyzed further in two phases. First, we conducted a preliminary plot-wise review of animals (mammals) to establish analytical questions and discover the conservation status of the recorded animals. Second, indicator species were chosen based on the literature, expert opinion, and a list of desirable characteristics that cause changes in species behavior owing to climate change. Previous research, threat analysis (threats to the species due to CC as per several research), and species conservation action plans created by the Government of Nepal were taken as references during the selection of the indicator species for mammals. Similarly, for bird species, migratory species were the main focus of the selection process, but we did not restrict ourselves to these species alone.

After selecting major indicator mammal species, they were ranked based on the impact caused. Various variables were selected for this purpose. The variables and rank of the mammals were based on the habitat range, elevation, role as habitat specialist/generalist, and impact seen in previous studies (Table 1).

Results and Discussion

Common species

The study of animals in the CHAL in 2015 was compared with that conducted in 2019. Between 2015 and 2019, the population is seen high in all plots except plot 9. Likewise, the population of mammals also increased in most plots.Similarly, the highest number of common mammals was in plot 5, while plots 2, 3, and 6 had no mammals in common. The detailed comparison of species can be found in ANNEX I.

Table 1: Variables and rank for indicator species (mammals)

S.N.	Variables	References	Ranking
1	Home range/elevation range	Abe, 1982; Chalise, 2003; Jackson, 1996; Kafley et al., 2009; Khan & van Strien, 1997; Koirala et al., 2016; Oli, 1997; Paudel et al., 2012; Simcharoen et al., 2014; Smith et al., 1998	High altitude (home range small)
			Mid altitude (home range medium)
			Low altitude (home range high)
2	Habitat (generalist/ specialist)	Aryal et al., 2010; Khatiwada & Haugaasen, 2015; Patel et al., 2016; Regmi et al., 2020.	Generalist
		Aryal, 2009; Baral et al., 2003; Giri, 2009; Subedi et al., 2013; Koju et al., 2021; Regmi et al., 2020	Specialist
3	Food requirements	Kazmi et al., 2021; Achyut & Kreigenhofer, 2009	Generalist/carnivore
		Darcan, 2018; Malakoutikhah, 2020	Specialist/herbivore
4	Observed impact (as per other studies)	Dahal, 2011; Harwood, 2001; Prasain, 2018; Subba et al., 2017	Direct/high
		Forman et al., 2008; Karki et al., 2009; Zomer et al., 2014	Medium
		Durant et al., 2007; Eriksson et al., 2009; Shrestha et al., 2018	Indirect/low
5	Habitat type		Wetland/snow
		Llorens, 2008; Seebacher et al., 2015; Şekercioğlu et al., 2012	Alluvial plain
			Terrestrial
6	Impact indicator		High
		Laidre et al., 2008	Medium
			Low

Table 2: Species comparison between 2015 and 2019

Plot	Year	Total Mammals	Common Mammals
1	2015	8	2
	2019	3	
2	2015	2	0
	2019	4	
3	2015	6	0
	2019	5	
4	2015	7	1
	2019	7	
5	2015	11	11
	2019	12	
6	2015	4	0
	2019	11	
7	2015	4	2
	2019	11	
8	2015	5	2
	2019	12	
9	2015	6	2
	2019	11	
10	2015	6	1
	2019	14	
11	2015	2	2
	2019	14	
12	2015	13	7
	2019	13	

Identifying common/overlapping species in the plots

The larger mammal, on the other hand, occupies extensive areas because their habitat overlaps with those of other species; this is clearly necessary for their survival. The dispersion of mammals depends on their need for water; those that do not require water can remain within a particular habitat, whereas those in need of water migrate during dry seasons (Lamprey, 1963). Plot 5 had the most common mammals (11), while plot 10 had the fewest (1). There were no common mammal species in plots 2, 3, or 6 (Figure 2).

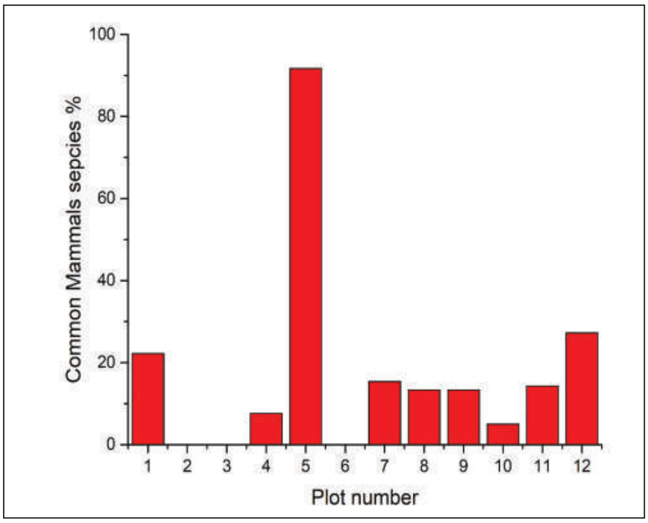

Figure 2: Plot-wise common mammal percentages.

Indicators of climate change monitoring

Climate change impacts the terrestrial ecosystem, which struggles to adapt to new conditions (Williams et al., 2003a). Some of the known impacts of climate change on the forests and biodiversity of Nepal include shifts in agro-ecological zones, prolonged dry spells, higher incidences of pests and diseases, increased emergence and quickened spread of invasive alien plant species, increased incidence of forest fire in recent years, changes in the phenological cycles of tree species, shifting of the tree-line in the Himalaya, and wetland depletion (MoEST, 2010).

The mammal species that could be considered indicators of climate change monitoring are listed in Table 3. This shows that the one-horned rhinoceros, snow leopard, and pika, being habitat specialists, suffer a high impact from climate change and can be used as indicators of climate change.

Table 3: List of climate change indicator species.

SN	Mammals	Indicator ranking
1	One-horned rhinoceros	Medium
2	Bengal tiger	Low
3	Asian elephant	Medium
4	Pika	High
5	Snow leopard	High
6	Monkey	Medium

A shift in acceptable habitats for terrestrial organisms is one of the most likely effects of climate change (Thuiller et al., 2011). The details of mammal species that experience the impacts of climate change are listed below:

Pika species (*Ochotona sp.*)

Climate change can cause an increase in the high migration of high-altitude endemic animals such as pikas. Warmer temperatures disrupt the natural habitat of the pika, driving the creatures to seek refuge in colder climes higher in the mountains. While pikas used to be present at 2180 m asl at Ulleri, ACA (Abe, 1971), they might have migrated to higher elevations in recent years due to change in microclimate/habitat as microclimate seems a major influential factor in pika distribution (Shrestha and Gurung, 2019). Pikas are extremely sensitive to temperature fluctuations, and rising average minimum temperatures have harmed their natural environment. Temperature is considered as important limiting factors (Thapa et al., 2019). Pikas have been lost from lower-elevation areas that were hotter and drier, and lower-elevation habitats that lacked a thermal refuge (Beever et al., 2010). Research has indicated that alpine mammals such as pikas are vulnerable to climate change (Moritz et al., 2008). In addition to that low reproductive Because pikas are sensitive to heat stress and rely on access to cooler microclimates to behaviorally thermoregulate, the pika can be considered a climate change indicator (Beniston, 1994).

One-horned rhinoceros (*Rhinoceros unicornis*)

Rhinoceros are considered habitat specialists and are confined to tall grasslands and riverine forests on the alluvial floodplain of the Himalayan foothills, where water and green vegetation are accessible all year (Jnawali, 1995; Dinerstein, 2003). They are habitat specialists, requiring mud pools for wallowing to regulate body temperature; hence, wallowing locations must be available, and these may be affected by any change in the climate. Specialist species are more vulnerable to climate change compared with generalist species (Brown, 1995; Pimm et al., 1995). In addition, the climate is likely to impact the abundance of food resources and spatiotemporal availability of water for this species (Pant et al., 2020). Other impacts of climate change includes, the expansion of invasive alien species, such as *Mikania micrantha*, into rhinoceros habitat may degrade the prime habitat of rhinoceros (Subedi, 2012; Murphy et al., 2013), as will the occurrence of extreme events, such as floods, forest fires, and droughts (Pant et al., 2020; Sharma, 2019). Therefore, rhinoceros in Nepal are likely to be 'moderately vulnerable' to the impacts of climate change (Pant et al., 2020).

Royal Bengal tiger (*Panthera tigris tigris*)

Although climate change is causing catastrophic habitat loss for Bengal tigers in mangrove habitats (Rahim et al., 2015; Mukul et al., 2019), being a landlocked country, the combined effects of climate change and sea-level rise may not have such a significant impact in Nepal. However, different climate change-related indirect consequences may persist. Habitat degradation triggered by the invasion of alien invasive species, especially *Mikania micrantha* and *Lantana camara*, drying up of wetlands including ox-bow lakes, decrease in prey, and extreme weather conditions, such as protracted droughts and enhanced floods and flash floods, are likely to become more common as climate variability increases (DNPWC, 2016). Changes in temperature and precipitation, resulting in shifts in plant phenology, winter severity, drought and wildfire conditions, invasive species distribution and abundance, predation, and disease can directly or indirectly affect tiger prey such as ungulates (Malpeli et al., 2020). Also, rising temperature and changes in precipitation patterns may result in substantial shifts or changes in wetlands, grasslands, and forest types and their species compositions (Thapa et al., 2016), as the Tiger species has been trapped in high altitudes of 2511 m (Thapa et al., 2022) and 3100 m (Bista et al., 2021).

Snow leopard (*Panthera uncia*)

The snow leopard is adapted to rugged mountain habitats at high elevations, including grassland, shrubland, bare areas, ice patches, and agricultural mosaic, which are especially vulnerable when facing global climate change (Forest et al., 2012). The predicted loss of snow leopard habitat in the Himalayas is predicted to be 30%, mainly along the southern distribution range, to alpine zones. The endangered snow leopard inhabits the rugged and fragile landscape of the Himalayas (Jackson, 1984) and is one of the largest predators in this energy-deficient, high-altitude environment. These species are vulnerable wild mammals native to mountainous regions of 12 Asian countries. The snow leopard faces numerous overlapping threats, including being killed by herders retaliating against livestock losses, illegal wildlife trade, loss of prey and habitat, and climate change. Ripple et al. (2014) revealed that one of the major limiting factors resulting in a decrease in the number of *Panthera* species is altitude. However, altitude does not directly impact habitat suitability, it indirectly influences *Panthera* distribution through temperature (Aryal et al., 2014). A further study by Aryal et al. (2016) acknowledged that annual mean temperature is the major climatic factor responsible for controlling the distribution of snow leopards in energy-deficient, high-altitude environments.Potential Range Shift of Snow Leopard in Future Climate Change Scenarios by Li et al. (2022) found that snow leopards would move northwest by about 200 km in 2070 in two global climate models for different representative concentration pathways. Also, climate can markedly affect predators through its impact on the relative timing of food requirements and food availability (Durant et al., 2007) as the prey of the snow leopard like blue sheep will be reduced under future climate change (Aryal et al., 2016) which leads to food availability.

Asian Elephant (*Elephas maximus*)

Suitable habitat for Asian elephants is vulnerable to climate change. Under future climate scenarios, the prime habitat of Asian elephants is predicted to decrease (Li et al., 2019). Kanagaraj et al. (2019) also showed that owing to the combined effects of climate change and human pressure, the habitat now accessible to Asian elephants will be destroyed by the end of this century. According to model estimates by Kanagaraj et al. (2019), changes in climatic water balance, followed by changes in temperature and other continuing human-induced disturbances, will be the primary drivers of future changes in elephant distribution in India and Nepal, and there will be a shift towards higher elevation seeking available water (Moritz et al., 2008). Elephants will face a shortage of natural food if the range of woodland diminishes owing to climate change, forcing them to forage on farmland (Li et al., 2018). Although Asian elephants occur across a range of diverse habitats and feed on a variety of abundant vegetation, owing to their limited dispersal ability, long gestation period, modest reproductive rate, and relatively moderate genetic variety within the species, they have a low adaptive capacity to changing climate and are thus considered vulnerable to climate change (WWF, 2021).

Assam macaque (*Macaca assamensis*)

The distribution of Assam macaque could be reduced owing to adverse changes in the global climate. Climate change poses one of the most significant threats to global biodiversity (Araújo, 2014) and will impact the geographic distributions and population dynamics of species. Climate change threatens endangered species and challenges current conservation strategies. Although the Assam macaque is categorized as near-endangered globally (Boonratana et al., 2008), in Nepal it is designated as endangered owing to its restricted distribution of fewer than 22,000 km^2 with an estimated area of occupancy of approximately 914 km^2; it is experiencing a continuing decline in population and in the areal extent and quality of its habitat (Molur et al., 2003). Aryal et al. (2016) suggested that these Assam species cannot respond to the condition of rapid climate change and habitat loss. Also the species have low genetic diversity and shallow genetic structure (Khanal et al., 2018), narrow elevation range (Chalise, 2013) and habitat specialist (Khanal et al., 2019). These species mainly eat crops (maize, rice, wheat, millet, and cardamom fruits); changes in weather patterns make it challenging to determine sowing and harvesting schedules and hamper suitable crop selection (Palazzoli et al., 2015). Another negative impact is an extensive decrease in soil fertility through the loss of carbon from the soil owing to reduced soil moisture. This could in turn result in a reduction in crop yield and agriculture productivity (Chettri et al., 2009) and affect species indirectly.

Conclusion

In this study within the time range of two periods 2015 and 2019 common species in the 12 plots with variation in the elevation range set by HBP are calculated. Plot 5 shows more overlapping species in temporal scale with 11 common mammal species. In some plots (2, 3 and 6) none of the common species were recorded. With the reference for identifying the indicators of climate change, pika and snow leopard have the highest impact. Similarly, one horned rhinoceros, Assames Monkey and Asian elephant have medium impact. And the Bengal tiger might have low impact. Those species with specialist habitat type, food requirements, low rate of reproduction, low genetic diversity can generally be considered as species which can be used for the monitoring of climate change. As this study uses the presence of species in the CHAL area by HBP with further use of previously conducted research and findings, further research with prediction of habitat with impact due to climate change is warranted.

Acknowledgments

The authors would like to acknowledge the World Wildlife Fund for Nature (WWF-Hariyo Ban Program) for providing species presence-absence data. Author would like to thank the Second Tibetan Plateau Scientific Expedition and Research Program for providing the grant. This research has been funded by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (grant no. 2019QZKK0103).

Supplementary Materials

ANNEX-I

Table: Details of all 12 plots

Plot No.	Location (District)	GPS Coordinates		Altitude (m)	Habitat-Vegetation	Remarks
		Latitude	Longitude			
1	Lo Manthang; ACAP	29.288	83.921	>4000m	Alpine Rangeland	Potential for invasion by subalpine conifer
2	Bhena; ACAP	28.984	83.815	3500-4000	Schrubland of Juniper	Ecotone between subalpine scrub and alpine vegetation
3	Jomsom ; ACAP	28.784	83.761	3000-3500	Grassland & Alpine Forest	Shrublands and grasslands, with some Juniper dominated forests
4	Lete; ACAP	28.653	83.617	2500-3000	Mixed broadleaf-conifer forest	Ecotone between subalpine conifer and wetland
5	Narchyang;ACAP	28.521	83.674	1500-2500	Chirpine forest	Possibility of forest conversion
6	Chitre, Kaski-Parbat	28.257	83.813	2000-2500	Subtropical broadleaf and Chir pine forest	Potential climate refugia
7	Bhadaure Tamagi; Kaski	28.24	83.85	1000-1500	Subtropical broadleaf mixed with confier	Climate vulnerable subtropical broadleaf and evergreen forest
8	Asardi (Palpa)	27.918	83.654	380-1050	Subtropical hill forest	Climate refugia
9	Tilakpur (Syangja)	27.887	83.899	315-700	Subtropical hill forest	Climate vulnerable
10	Kabilas (Chitwan)	27.786	84.509	500-1000	Subtropical broadleaf forest	Climate vulnerable subtropical broadleaf forest
11	Kaule (Chitwan)	27.779	84.595	1500-2000	Subtropical broadleaf forest	Cliamte resilient subtropical broadleaf forest
12	Khorsor , Barandabar (Chitwan)	27.571	84.442	181-201	Subtropical broadleaf forest	Important climatic corridor for many species

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Journal of Environment Sciences (2023), **Volume IX**, 118-127
https://doi.org/10.3126/jes.v9i1.56486

Assessing and Comparing Environmental Assessment Pathways in Nepal

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Abstract

National Environmental Impact Assessment Guideline (NEIAG), 1993, is the major guiding legal document for the project level environmental assessment in Nepal which has provided the concrete methods for impact identification, prediction and evaluation for the proposals to be implemented. Environment Protection Act, 1997 (EPA-1997) and Environmental Protection Regulations, 1997 (EPR-1997) highlighted the categories and thresholds of the proposals requiring Initial Environmental Examination (IEE) and Environmental Impact Assessment (EIA), requirements of public hearing particularly for EIA, environmental monitoring by concerned ministries for IEE and Ministry of Environment (MoE) for EIA, Environmental Audit for EIA, punishments of five to twenty-fifty lakhs for implementing proposals without the approval of Environmental Assessment (EA) reports, timeline of fifteen days public notice, approval of IEE report within twenty-one days and sixty days for EIA report, provisions for Supplementary Environmental Impact Assessment (SEIA) and brief formats of the reports. Environment Protection Act, 2019 (EPA-2019) and Environment Protection Regulations, 2020 (EPR-2020) has advanced the existing provisions of EPA-1997 and EPR-1997. Brief Environmental Study (BES) has been added as a new project level environmental assessment required for the particular projects. EPA-2019 and EPR-2020 has empowered the provincial and local governments for conducting and approving the proposals to be executed in respective level of governments. Public hearing is made mandatory for all levels of environmental assessments. Proposals implemented without the approval and/or violating the provisions of approved reports are charged with the amount of fine up to five lakhs for BES, up to ten lakhs for IEE, and up to fifty lakhs for EIA. Requirement of Strategic Environmental Analysis (SEA) for plans, policies and programs is a new legal concept of environmental assessment at strategic level. The timeline for approval of Scoping Document (SD), Terms of Reference (ToR), BES and IEE report is within fifteen days of report submission, within sixty days of report submission for EIA report, submission of final BES, IEE and EIA report is mandatory within two years of SD and ToR approval and initiation of proposal implementation is within three years of EA report approval. The recent legal provisions also have provided room for updating of BES report, IEE report and Environmental Management Plan (EMP) as per the requirement of the proposal implementation. Blacklisting the consultants for not assuring the standards of reports as required by the government, detail formats of reports, language of the reports to be in Nepali language and alternative analysis of the mitigation measures for particular impact and suggestion of the best mitigation measures are some additional provisions in the newer legal provisions.

Keywords: *Alternative Analysis, Environmental Assessment Reports, Scoping Document, Strategic Environmental Analysis, Terms of Reference*

Introduction

National Environmental Impact Assessment Guideline, 1993 (NEIAG-1993) was promulgated with the objective to access environmental impacts likely to be caused by a project, and promote its positive impacts and mitigate or eliminate adverse impacts by undertaking preventive and other effective measures after integrating the environmental impacts in the planning cycle of all the projects to be initiated in Nepal, prior to their initiation, so as to make the economic benefits from development projects sustainable. This guideline provided thresholds for conducting Initial Environmental Examination (IEE) in Annex-1 and Environmental Impact Assessment (EIA) in Annex-2. Also this guideline has provided concrete methods for impact identification, prediction and evaluation during the environmental assessment of the proposals. Environment Protection Act and Environment Protection Regulations were consequently promulgated in 1997 which elaborated the detail process and provisions of environmental assessment in Nepal. The process of Scoping, preparing Terms of Reference (ToR), requirements of legal deeds, requirements of public hearing, public notices and letter of recommendations from respective Village Development Committees (VDCs) and concerned stakeholders, timeline for collection of suggestions and comments, letter of recommendations from concerned bodies, forwarding and approving the documents etc. were highlighted comprehensively. After federalism, GoN has recently formulated and promulgated Environment Protection Act, 2019 (EPA-2019) and Environment Protection Regulations, 2020 (EPR-2020). These recently promulgated environmental laws have focused on the federal structures of impact assessment, strategic level of environmental assessments, shortened timelines for various aspects of the assessments, interventions in the environmental monitoring and environmental audit process and provisions. This study aims to review the comparative process and provisions on environmental assessment envisioned in EPA-1997 and EPA-2019. Similarly, the amendments in EPR-2020 over EPR-1997 have been compared.

Methods

NEIAG-1993, EPA-1997, EPA-2019, EPR-1997 and EPR-2020 were reviewed and the major provisions regarding environmental assessment were reviewed. The technical and administrative procedures and provisions for environmental assessment in these laws were compared and major variations and additional provisions of the laws were also assessed.

Comparative Analysis of the Environmental Assessment Provisions

Provisions as per EPA, 1997 and 2019, and EPR, 1997 and 2020

1. ***Types of Project Level Environmental Assessment:*** EPA 1997 and EPR 1997 were the environmental laws promulgated and implemented prior to federalism in Nepal. Hence, these laws emphasized on each and every development projects in Nepal that needs environmental assessment and approval prior to their implementation. The laws had identified two types of project level environmental assessment through IEE and EIA. The projects listed under Schedule-1 of EPR-1997 had to undergo through IEE and the projects under schedule-2 had to undergo through EIA.

   The EPA-2019 has identified three types of project level environmental assessments through BES, IEE and EIA. Section (3) of EPA-2019 has envisioned that proponents are required to prepare, approve and implement environmental assessment of any development proposals as mentioned in schedules 1, 2 and 3 of EPR-2020. The proposals under schedule-1, schedule-2 and schedule-3 of EPR-2020 requires BES, IEE and EIA respectively.

2. ***Thresholds of Impact Assessment:*** There were 12 (*aa to aha*) categories of proposals that require IEE in schedule-1 and 12 categories of proposals (*aa to aha*) that require EIA in schedule-2 of EPR-1997. Proposals that were not listed in these schedules but had investment of five to twenty-five crore Nepalese Rupees (NRs) required to conduct and approve IEE report and proposal with investment more than twenty-five crore NRs required to conduct and approve EIA report.

   Schedules 1, 2 and 3 of EPR-2020 have identified the categories of proposals that needs to go through BES, IEE and EIA respectively. There are 11 (*ka to ta*) categories of proposals that require BES in schedule-1, 12 categories of proposals (*ka to tha*) that require IEE in schedule-2 and 12 categories of proposals (*ka to tha*) that require EIA in schedule-3. EPR-2020 has not provided the absolute monetary threshold for the proposals however the integration of monetary threshold within some of the proposals can be observed in these schedules.

3. ***Approval of EA Reports:*** EPA-1997 and EPR-1997 had provision of EA report approval by

concerned ministry for IEE reports and Ministry of Environment (the ministry with the name 'Environment' integrated/disintegrated along with the name of other ministry) for EIA reports.

EPR-2019 and EPR-2020 have provided the provision for the submission and approval of the respective reports by central, provincial and local government under their jurisdiction. Regarding the proposals of central government, EIA report has to be submitted to Ministry of Forests and Environment (MoFE) whereas the BES & IEE report has to be submitted to the concerned ministries for central government proposals. Regarding the proposals of provincial government, it has dedicated the power of submission and approval of the respective assessment report as per the provincial environmental law. Similarly, regarding the proposals of local government, the act has provision of submission and approval of EIA report as per respective provincial environmental law where as for the submission and approval of BES and IEE report provision has been made as per the local government environmental law.

4. ***Public Hearing:*** Rule (7-2) of EPR-1997 had mandated to conduct public hearing once at Village Development Committee (VDC) or Municipality where the proposal was going to be implemented for the only proposals that required EIA.

   Section (3) sub-section (5) of EPA-2019 has significantly stated for conducting public hearing for all kind of environmental assessments. Hence, any plans, policies & programs requiring SEA at strategic level and any proposals requiring BES, IEE and EIA has to conduct public hearing. As per Rule (6) of EPR-2020, proponent requires to notify the concerned stakeholders through various means of media, conduct at least one public hearing or more than one as per requirement, collect the concerns of the stakeholders in written form i.e. minutes and also in audio-visual records and integrate these concerns in the respective environmental assessment reports.

5. ***Environmental Monitoring:*** Rule (13) of EPR-1997 had mandated environmental monitoring and evaluation of approved EA reports by concerned ministries for IEE and MoE for EIA (i.e. approving bodies).

   Section (39) of EPA-2019 has indicated MoFE and Department of Environment (DoEnv) as the institutions responsible for the monitoring of all the provisions and activities as mentioned by the act. Similarly, provincial governments and local governments are also responsible for environmental monitoring of their respective proposals, provisions and activities as envisioned in their respective environmental laws. Rule (45) of EPR-2020 has initiated the provision of self-monitoring of respective proposals by the proponents and submitting those monitoring reports to the concerned ministries including MoFE and DoEnv in each six months of period.

6. ***Environmental Audit:*** Rule (14) of EPR-1997 has mandated MoE for environmental audit. Environmental audit of the EIA approved proposals had to be conducted after two years when the proposal had been implemented and delivered the services, distribution and productions.

   Section (13) of EPA-2019 has emphasized in the environmental audit of the approved EIA report after the implementation of the proposal. Environmental audit shall be carried out within twenty-four to thirty months when the proposal has initiated the distribution of the service and has been implemented. MoFE or designated institution/body are the institutions for environmental audit of the approved EIA reports.

7. ***Punishments:*** Section (18) of EPA-1997 had provision of punishment for implementing any proposal without the approval of EA reports and/or violating the provisions of approved EA reports during implementation and violation of any regulations or guidelines produced as per the act. Proponent had to pay up to NRs Five lakhs to NRs Twenty-Five lakhs (as amended in 2016) punishment amount for those proposals implemented without the approval of EA reports

or the proposals implemented with the violation of the provisions in approved EA reports.

Section (35) of EPA-2019 has provision of punishment for implementing any proposals without the approval of environmental assessment reports and/or violating and not implementing the provisions as mentioned in approved reports. The amount up to NRs Five Lakhs for BES, up to NRs Ten Lakhs for IEE and up to Fifty Lakhs for EIA is the absolute figure of punishment for either implementing the proposal without the approval of assessment reports and/or violating and not implementing the provisions mentioned in approved reports. Also, the proponent requires to pay fine of three folds of the punishment amount that has been mentioned earlier and the proponent neglects to implement the suggestions that has been already notified for violating the environmental rules.

8. *Timelines:* Timeline for various legal deeds has been clearly mentioned in the previous and recent environmental laws of Nepal.

8.1 *Timeline for publishing public notices:* Rule (4-1) of EPR-1997 had provision of publishing Fifteen days' public notice in daily newspaper during the conduction and preparation of SD for EIA. Similarly, as per Rule (7-2) of EPR-1997, fifteen days' public notice had to be published in national daily newspaper seeking suggestions and concerned stakeholders while conducting IEE and EIA. Prior to the approval of EIA report by MoE, thirty days' public notice had to be published in national daily newspaper. Altogether, at least one number of fifteen days' public notice in national daily newspaper had to be published for IEE and at least two number of fifteen days' public notice and at least one number of thirty days' public notice in national daily newspaper had to be published for EIA as per EPR-1997.

EPR-2020 has provisions of publishing at least two number of public notices for BES and IEE {Rule-6(4): for Public Hearing and Rule 7(3): public notice for public concern} and at least four number of public notices for EIA {Rule (4) sub-rule (2) for preparing Scoping Document, Rule-6(4): for Public Hearing; Rule 7(3): public notice for public concern and Rule 9(6): public notice along with the exposure through website for public concern}and the timeline of these all notices is for seven days. Also, the Regulations has envisioned to publish all the public notices in local newspaper for BES and IEE whereas all the public notices for EIA has to be published in national daily newspaper.

8.2 *Timeline for approval of EA reports:* Rule (11-1) of EPR-1997 mentioned that any proposal requiring IEE had to be approved by concerned ministry within twenty-one days of report submission. Similarly, Rule (11-5) of the rule had mandated MoE to approve EIA reports of the proposals within sixty days of report submission.

EPR-2020 has provided timeline for approval period of Scoping Document {Rule-4 (7)}, Terms of Reference {Rule-5(4)}, BES and IEE Report {Rule-9(8-*ka*)}, to be fifteen days of report submission and approval of EIA report to be thirty-five days of report submission {Rule-9(8-*kha*)}. Similarly, concerned ministries need to forward the Scoping Document {Rule:5(4)} and EIA report {Rule:8(4)} to MoFE within 15 days of registration.

8.3 *Timeline for collection of deeds:* EPA-1997 and EPR-1997 had not provided the clear timeline for collection of deeds and letter of recommendation letters from local governments. However, Rule 8(9) of EPR-2020 has provision of collecting the letter of recommendation letters from concerned local levels and concerned offices within 15 days of request letters registered at such offices. If recommendation letters are not received within this timeline, proponent can forward the environmental assessment reports to the approving bodies for the approval process.

8.4 <u>*Timeline for submission of EA reports*</u>: EPA-1997 and EPR-1997 had no such provisions of timeline for submitting EA reports after the approval of ToR and SD. However, Rule 8 (11) of EPR-2020 has mandated any proposal with approved ToR and SD, the EA report of which has to be submitted for approval within two years of ToR and SD approval. If the proponent fails to submit EA reports within two years of approval of ToR and SD, proponent needs to prepare and approve ToR and SD from the very beginning. However, Rule 8 (12) has provision for extension of time for one year if the proponent convinces the concerned ministries approving ToR and SD document with the valid reasons of delay in submitting the EA reports.

8.5 <u>*Timeline for implementation of EA reports:*</u> EPA-1997 and EPR-1997 had no such provisions of timeline for implementation of approved EA reports. But Rule 13 (1) of EPR-2020 has provision of initiation of implementation of the proposal within three years of the approval of the EA reports. However, Rule 13 (3) of EPR provides with the provision for extension of time for one year with the valid reasons. If the proponent fails to initiate the implementation of the proposal within the extended timeline, environmental assessment needs to be conducted and approved from the very beginning i.e. preparation and approval of ToR and SD.

9. ***Supplementary Assessments:*** Rule (11 *Kha*) of EPR-1997 had provision regarding supplementary EIA for the particular proposals requiring the updates in approved EIA reports (Additional Provision in 2016 amendments).

Section (11) of EPA-2019 and Rule (11) and Rule (12) of EPR-2020 has provided and highlighted with the provision of supplementary environmental assessment. Any changes in the physical infrastructure, design and form; transfer or alter the structure of the project; add the forest area or increase the capacity of the project with approved EIA can go through supplementary environmental impact assessment. For supplementary EIA, proponent has to follow all the procedural steps as required after the approval of Terms of Reference (ToR) report and Scoping Document (SD) report from MoFE but doesn't require to approve ToR and SD again.

10. ***Formats:*** EPR-1997 under Schedule-3, Schedule-4, Schedule-5 and Schedule-6 had provided the concise formats on ToR of IEE, ToR of EIA, format of IEE report and format of EIA report respectively.

EPR-2020 has provided detailed formats of required reports and documents. Schedule-4 of EPR is associated with the format of public notice of, and schedule-5 for format of, Scoping Document (SD). Schedule-6, schedule-7 and schedule-8 is associated with the format of Terms of Reference (ToR) of BES, IEE and EIA respectively. Schedule-9 of EPR has maintained the format for public notice to be published for environmental assessment. Schedule-10, schedule-11 and Schedule-12 has provided the format of BES, IEE and EIA reports respectively. Schedule-14 has the format for receiving the letters of recommendation from the local governments and concerned offices.

Additional Provisions for Environmental Assessment in EPA-2019 and EPR-2020

1. ***Strategic Environmental Analysis (SEA):*** Section (9) of EPA and Rule (10) of EPR has established the need and approval of SEA report at strategic level. The law has articulated for conduction and approval of SEA for plans, policies and programs (3Ps) of GoN publishing the notice of such in *Nepal Rajpatra*. Also, Section (3) sub-section (5) of EPA has provision for conducting public hearing of any proposals that implies to SEA too and Schedule-15 of EPR has provided thirteen points basis of SEA.

2. ***Updating of IEE and BES Report:*** Rule (12) of EPR has indicated the updating of BES and IEE

report as required. Any changes in the physical infrastructure, design and form; transfer or alter the structure of the project; decrease in the capacity of the project or require to add or reduce the total number of tree felling in approved BES and IEE report can go through updating of the environmental assessment. The concerned ministry approving BES and IEE report are responsible for approving and updating such reports as per the requirements. Section (10) of EPA also has provision of preparing, approving and implementing the Environmental Management Action Plan (EMAP) prior to the implementation of the proposal; the detail of which has not been emphasized and described in the EPR.

3. ***Team Composition:*** Schedule-13 of EPR, has provided the academic qualification and experiences of the human resources eligible for conducting environmental assessment. The basic requirement of academic achievement is Master's Degree in respective subject and the basic requirement of the experience is the involvement in preparation of at least three numbers of environmental assessment reports. For the involvement in the conduction and preparation of BES report, human resource with Master's Degree in Environmental Science, Environmental Engineering & Environmental Management and Master's Degree in the subject related to the concerned proposal with the involvement in the preparation of at least three numbers of EA reports is mandatory where as additional human resource with Master's Degree in Natural Resource Management, Forest Science, Zoology & Botany along with the involvement in the preparation of at least three numbers of environmental assessment report is mandatory for involvement in conducting and preparing IEE and EIA report. EPR has also provided the space for the human resources with the provided academic achievement of Bachelor's Degree and engagement in the preparation of environmental assessment report for five years of period to be eligible for conducting and preparing environmental assessment reports.

4. ***Blacklisting:*** Section (6) of EPA has provision of blacklisting the consultants up to five years and prohibiting to conduct & prepare the EA reports if they fail to maintain quality and standard of such reports as mentioned by GoN.

5. ***Language of the Assessment Reports:*** Rule 7 (7) of EPR has mandated the submission of EA reports in Nepali language. However, the reports can be prepared in English language for donor funded projects with executive summary and summary report in Nepali language.

6. ***Alternative Analysis:*** Section (4) of EPA has envisioned the alternative analysis of the mitigation measures in details and adoption of the best mitigation measure with the valid references and reasons of implementation. However, the formats of EA reports mentioned in various schedules of EPR has provided the options of alternative analysis to other concerns of the projects rather the alternative analysis of mitigation measures. Table 1 shows the overall comparisons of the provisions for environmental assessments in EPA-1997 and 2019, and EPR-1997 and EPR-2020.

Table 1: Comparative analysis of environmental provisions as per EPA-1997 and 2019, and EPR-1997 and 2020

S.N.	Components	EPA-1997 and EPR-1997	EPR-2019 and EPR-2020	Remarks
1.	Project Level Environmental Assessment	IEE and EIA	BES, IEE, EIA	BES level assessment has been added in EPA-2019 & EPR-2020
2.	Screening	IEE as per Schedule-1 and EIA as per Schedule-2 of EPR	BES as per Schedule-1, IEE as per Schedule-2 and EIA as per Schedule-3 of EPR	BES level assessment has been added in EPR-2020
3.	Approving Body	IEE by concerned Ministry and EIA by MoE	BES and IEE by concerned Ministry and EIA by MoFE	Provincial and Local Governments are mandated to approve concerned projects
4.	Public Hearing	Only EIA required public hearing	SEA, BES, IEE and EIA all require public hearing	EPA-2019 has made public hearing mandatory for all level of environmental assessments
5.	Environmental Monitoring	Concerned ministries for IEE and MoE for EIA were designated for environmental monitoring	Concerned ministries for BES and IEE and MoFE/DoEnv are designated for Environmental Monitoring	EPR-2020 has provision of Self-monitoring by proponent to be conducted at each six months and report to be submitted to concerned ministries and/or DoEnv
6.	Environmental Audit	1) Required only for EIA 2) To be conducted by MoE 3) Conducted after two years of implementation of the proposal	1) Required only for EIA 2) To be conducted by MoFE or designated body, 3) Conducted after two years and within six months (24 to 30 months) of implementation of the proposal	
7.	Punishment	NRs five to NRs twenty-five lakhs for implementing proposals without the approval of EA reports and/or violating the provisions of approved EA reports	When the proposals are implemented without the approval of EA reports and/or violating the provisions of approved EA reports, NRs up to five lakhs for BES, NRs up to NRs ten lakhs for IEE and NRs up to NRs fifty lakhs for EIA has been indicated	EPR-2020 has provision for charging up to three folds of the punishment amount if the proponent violates the previous concerns and charges
8.	Timelines	1) Fifteen days' public notice required to be published during EA, 2) IEE report to be approved within twenty-one days of report submission by concerned	1) Seven days' public notice required to be published during EA, 2) ToR, BES report and IEE report to be approved within twenty-one days of report submission by concerned ministries and MoFE	Amendment of EPR-1997 in 2016 BS had highlighted the change in the timeline of certain provisions particularly for National Pride Projects, projects requiring quick response in terms of natural disasters and the

S.N.	Components	EPA-1997 and EPR-1997	EPR-2019 and EPR-2020	Remarks
		ministries and EIA report required to be approved within sixty days of report submission by MoE, 3) No provision of timeline for collection of deeds and letter of recommendations 4) No provision of timeline for the submission of EA reports after the approval of ToR and SD reports 5) No provision of timeline for the implementation of approved EA reports	shall approve the SD for EIA within fifteen days of report submission and EIA report within sixty days of report submission, 3) Proponent requires to register request letter to the office of local government and concerned offices and office of local government and concerned offices requires to provide letter of recommendations within 15 days of the request letter registered 4) Proponent needs to submit EA report for approval within two years of approval of ToR and SD documents 5) Proponent needs to initiate the implementation of the proposal within three years of approval of EA reports	projects, of which, the government required immediate implementation in Rule (11-*ka*). 1) Timeline for publication public notice and collection of suggestions/comments of such proposals, for the purpose of scoping, was shortened to seven days from fifteen days. 2) The Timeline for publishing public notice for preparing IEE and EIA reports was shortened for seven days from fifteen days. 3) The timeline for approving the IEE report or forwarding the EIA report for approval was shortened to five days from twenty-one days. 4) Similarly, publication of public notice by MoE prior to the approval of the report was shortened to seven days from fifteen days.
9.	Formats	Concise formats of ToR of IEE, ToR of EIA, IEE report and EIA reports had been highlighted in Schedule-3, Schedule-4, Schedule-5 and Schedule-6 of EPR-1997	Detail formats on ToR of BES, IEE and EIA, formats of BES, IEE and EIA reports, format of SD, formats for public notices, formats for letter of recommendation to be collected has been provided	
10.	Strategic Environmental Analysis(SEA)	No provision of SEA	SEA for any plans, policies and programs of GoN are envisioned in the laws	
11.	Supplementary Environmental Impact Assessment (SEIA)	Provision regarding SEIA was added in amendments in 2016 BS and no provision of updating of IEE reports	Provision regarding SEIA, updating of BES and IEE report, updating of EMAP has been envisioned as per the required conditions	
12.	Team Compositions	No provision for the composition of teams for carrying environmental assessment	Schedule-13 has provided required team composition for carrying environmental assessment	

S.N.	Components	EPA-1997 and EPR-1997	EPR-2019 and EPR-2020	Remarks
13.	Blacklisting the Consultants	No provision for blacklisting the consultants carrying environmental assessment for fraud and low-quality reports	EPA has highlighted the provision regarding the consultants carrying environmental assessment when fraud and low quality reports	
14.	Language of the Reports	All the reports required to be produced in English language	All the reports required to be produced in Nepali language except for the proposals being implemented through donors	The donors funded proposals also requires to produce a summary report in Nepali language
15.	Alternative Analysis	Alternative analysis on the domain of project features, design, location, no forest option, no project option, time, construction materials etc. had been included	Alternative analysis on the domain of project features, design, location, no forest option, no project option, time, construction materials etc. has been included in the formats provided in the schedules. EPA has highlighted the alternative analysis of mitigation measures and best mitigation measures to be provided and adopted.	

Conclusion

Environmental assessment provisions were categorized into IEE and EIA in EPA-1997 and EPR-1997, whereas EPA-2019 and EPR-2020 have made additional provision of BES for respective proposals. The provision of public hearing was only focused for EIA in EPA-1997 and EPR-1997 whereas the requirement of public hearing has been made mandatory for all level of environmental assessments as per EPA-2019 and EPR-2020. Concerned ministry was empowered with the environmental monitoring of IEE and MoE was empowered with the environmental monitoring by EPA-1997 and EPR-1997, whereas environmental monitoring of BES, IEE and EIA has been empowered for MoFE and self-monitoring of such approved reports by concerned proponent and submission of such monitoring reports to concerned ministry, MoFE and DoEnv. The timeline for environmental audit has been revised by EPA-2019 and EPR-2020 to within twenty-four to thirty months of service delivery by the proposal implementation. The provision of punishment for not conducting environmental assessment and/or violating the provisions of approved environmental assessment has been revised in recent legal provisions. Similarly, the time to be taken by approving agency for approving EA reports has been revised. Approving agency had to approve IEE report within twenty-one days of submission as per EPA-1997 and EPR-1997 whereas EPA-2019 and EPR-2020 has highlighted the approval of ToR, SD, IEE and BES reports of the respective proposals within fifteen days of submission. Similarly, the timeline for approval of EIA report, as per EPA-1997 and EPR-1997, has been shortened from sixty days of submission to thirty-five days of submission by MoFE. The timeline for publishing respective public notices has been shortened from fifteen days to seven days for all project level environmental assessments. Strategic Environmental Analysis has been legalized and made mandatory for all plans, policies and programs of GoN. Besides the provision and process of supplementary EIA, these laws have highlighted the provisions regarding updating of BES and IEE reports as per the requirements of the proposals. Also, the provision of reviewing and updating Environmental Management Plan (EMP) has been emphasized in EPA 2019 and EPR 2020. EPA-2019 and EPR-2020 have also highlighted the right of provincial and local government proposals for their environmental assessments and approval by respective governments.

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Acknowledgement to the reviewers

We would like to thank Reviewers for taking the time and effort necessary to review the manuscript. We sincerely appreciate all valuable comments and suggestions, which helped in improving the quality of the manuscript

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