Influence of roads on forest characteristics of the Central Himalaya

MPhil Thesis

Submitted by

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Certificate

This is to certify that the dissertation titled **Impacts of roads on Forest of Central Himalayan Region** submitted by **Mr. Manjul Panwar** in partial fulfilment of the requirements for award of degree of MPhil of Jawaharlal Nehru University, New Delhi, has not been previously submitted in part or in full for any other degree of this university or any other university.

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(Manjul Panwar)

Dedicated to my loving father, a dedicated teacher, who left to the heavenly adobe just few months back.

I seek inspiration and blessings from him wherever he is, now and forever.

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Acronyms

UM	:	Unmetalled
M	:	Metalled
NH	:	National Highway
ANOVA	:	Analysis of Variance
NDVI	:	Normalized Difference Vegetation Index
PAST	:	PAleontological Statistics software
SPSS	:	Statistical Package for the Social Sciences software
SOC	:	Soil Organic Carbon
TN	:	Total Nitrogen

1 Introduction

In today's times when anthropogenic pressures are increasing on the forests, preserving the natural environment and the ecological equilibrium has become increasingly difficult (Anthwal et al. 2010). A large part of the natural forests has changed owing to human pressure and land-use practices (Foley et al. 2005; Mann, Rankavat, and Joshi 2020). Thus, it is important to study forests and their interaction with human activities because they host a wide range of habitats and biodiversity, and support human well-being through their ecosystem services. Biodiversity has also a major role to play in ecosystem stability by increasing the resistance of the ecosystem to extreme climatic events like drought and rainfall (Isbell et al. 2015) and other external disturbances. Despite such benefits to mankind and other support to the global environment, forests are being degraded and destroyed owing to human activities.

Human disturbance to the forest results in decreased ecosystem stability because of the changes in forest structure, loss of biodiversity and altered habitat quality (Chandrashekhar *et al*., 2003). Ram *et al.*, (2004) have mentioned that human disturbances affect soil and environmental conditions by altering species distribution and diversity of forests (Johnston and Johnston, 2004). Such disturbance leads to low crown cover that helps under-canopy vegetation to flourish and introduce to newer competitive species, such as invasion by exotic species. The exotic species are introduced by a variety of biotic and abiotic factors including frequent interaction of humans and human linked activities. Herein, introduction of migration trails and road network, particularly highways to natural ecosystems play crucial role (Forman and Alexander, 1998).

Road network and infrastructure are one of the factors that directly cause forest fragmentation (Lin et al. 2016). With time road density is increasing (Forman and Alexander, 1998), which along with related vehicular movement have a considerable impact on the adjacent vegetation and soil and thus change the plant communities (Zeng *et al.*, 2012; Deljouei *et al.*, 2018). India being one of the developing economies, is relying on strengthening and development of road infrastructure across the country. At the same time, India is also known for diverse habitats ranging from tropical rainforests to coastal wetlands (Anthwal *et al.*, 2010). At the apex resides the Himalaya which covers 18% of the total area and 31.05% of the total forest cover of India.

Their maximum contribution makes India a mega biodiversity centre of the world by harbouring 40% of the species endemic to the Indian Sub-continent (Ram *et al*., 2004; Anthwal *et al.*, 2010). The region is also known for the source of many rivers that serves water downstream to many states of the country and thus feeds a significant section of the country's population. The megadiverse Himalaya provides important ecosystem services but at the same time, is also one of the most vulnerable ecosystems (Kumar *et al*., 2019).

Roads are important for maintaining economic, educational and recreational activities but complex trade-offs are also involved in roads passing through tropical forests (Lugo and Gucinski, 2000). The ecological effects imposed by roads extend to a much wider area and is called the road effect zone (Forman and Alexander, 1998; Fig *et al.*, 2012). Some studies see the extent to which vehicular emissions extending into the forest (D. V. Singh *et al.* 2018; Mann *et al.*, 2019) but studies seeing the impact of roads on the structure of forests is limited. In fact, all road types, be it urban, rural or forest roads, are known to impact forests and their biodiversity(Mann *et al.,*2019). Researchers argue that these impacts can be reduced by building roads considering road ecology (Deljouei *et al.*, 2018). However, there needs to be a thorough understanding of the extent of the impact of roads on surrounding forests. In a sense, road segments or road networks can also act as corridors, so treating them as ecosystems and analysing road ecology will be helpful both in making policies as well as in formulating new methods for analysing the effects of these on the surrounding landscapes. Particularly in the case of India, in the Himalayan state of Uttarakhand, different anthropogenic pressures including road network development are known to act upon the forests that makes it sensitive and fragile (Joshi, 2018; Kumar *et al.*, 2019; Wang *et al.*, 2019).

Along with changes in the forest structure and composition, the road disturbance or roadside disturbance is also known for altering biological and chemical properties of soil including the soil organic carbon, nitrogen, microclimate, and other characteristics of the soil ecosystem (Johnston and Johnston, 2004; Jaworska and Lemanowicz, 2019). The properties of forest in general and soil, in particular, get influenced by the distribution of Soil Organic Carbon (OC) and Nitrogen (N) availability. This SOC in the upper soil layer gets affected by the decomposition of litter, both above and below ground while in the deeper soil gets majorly influenced by the previous land uses (Nath et al. 2018). While many factors are causing the loss of Nitrogen in the soil, one of the important factors causing the loss is forest degradation. This affects the productivity and the plant biomass of the forest ecosystem (Singh *et al*., 2007).

It is seen that there is a reduction of TN in the soil and an increase in the concentration of toxic heavy metals because of high vehicular emission associated with roads (D. V. Singh et al. 2018). Small changes in soil characteristics affects the ecosystem stability and fertility (Singh *et al.*, 2007).

With this backdrop, the proposed study focuses on understanding the influence of roads on the forest characteristics of the Central Himalaya, while taking a case study in the forested landscape. The study intends to investigate and assess the impacts of roads on forest structure while assessing Phyto-diversity along the gradient from the road. To further strengthen the argument of assessing the impact of roads on the forest, it proposes to characterise the distribution of SOC and N in the selected gradient. Owing to diverse population density distribution and accessibility to different geographic locations, the central Himalaya landscape is known for different road types, namely, National Highway (NH), metalled roads and un-metalled roads. To check this research hypothesis of the impacts of roads on the forest of the Central Himalayan region, the study proposes to analyse representative samples from different road types. The study assumes that assessing the impact of different roads on the Phyto-diversity and soil characteristics is essential in ecosystem conservation and preservation. It also helps in understanding and guiding possible eco-friendliness of road network infrastructure in developing countries in general and the Himalayan landscape in particular.

2 Literature Review

To carry out the study on the impacts of roads on the forest of the Central Himalayan region a detailed literature review was carried out keeping the focus to understand the work carried out while assessing the impacts on forest structure (Phyto-diversity of trees) and soil characteristics (SOC (%) and TN (%) estimations). Lugo and Gucinski (2000) have stated that the impacts of roads change with time but they start with a negative balance which mainly is the impact of construction activities while building a road. However, the ecological changes are generally interpreted negatively while dealing with the ecological effects of roads. Similarly, Deljouei *et al*. (2018) in their study highlighted that the unwanted impacts of roads can be reduced if the planning and design are done using road ecology. These two broad premises are the main motivation for this research work.

2.1 Impact of roads on forest

Forman and Alexander (1998) in their study have highlighted a variety of ecological effects that roads cause. They have pointed out that conditions altered by the road construction help the exotic species, which are disturbance-tolerant to predominate. The intensive management of the roadsides slows down the invasion by woody plants. The plants that grow near roads tend to grow fast because of the availability of sufficient light and water from the road drainage. An important assertion made in this study is that the ecological impacts that roads cause are far more than the direct damage caused due to road kills.

Foley *et al.* (2005) point out that road expansion together with numerous other land-use practices cause degradation of species richness of a forest and because of this biodiversity may decrease along with other ecosystem services.

Laurance *et al*. (2009) have reviewed the impacts of roads on the tropical forests of the world. They have highlighted that the impact of roads is acute on tropical rainforests. The findings suggest that there is a complex community that the forests are composed of and thus, some of the species are adapted to grow in the dense interiors of the forest in the understory conditions while others prefer open canopy conditions. Such ecologically specialized species are highly vulnerable to the environmental changes caused by roads.

Avon *et al.* (2010) conducted a study in managed oak stand in France to see the extent to which forest roads affect the forests. They found that there was a significant difference in the plant composition between the road verge and the forest interior habitats. In their study, they concluded that the effect of the main road extended to less than 5 m from the road verge to the forest interior. The non-forest species were present only near the road verge and not into the forest interior except for few species that were also present in the forest stands. Many bryophytes and vascular plants which were abundant in the forest interior, were absent near the road. They have mentioned as the conclusion of their study that even though the effect of the roads into the forests was not visible to much distance, but the building of a new forest road does have an effect on the plant populations.

Bignal *et al*. (2007) studied the ecological impacts caused by road transport on the local vegetation. In their study, they found that that the effect of air pollution caused by roads extended to approximately 100 m deep into the forest. They thus concluded that the effect of the air pollutants from the vehicular pollution had significant ecological impacts within 100 m of major roads.

Singh *et al.* (2020) studied the impact of pollutants on trees characteristics. They compared the trees grown near the roadside to the trees in the reserve forest. They found that the frequency of vehicles affects tree characteristics.

2.2 Impact of the road on soil

Johnston and Johnston (2004) conducted a study in the Australian Alps and concluded that road construction and maintenance disturbed the natural vegetation, soil properties and caused the propagation of exotic species. They characterized three ecotypes associated with roads and tested and compared the vegetation and soil characteristics amongst them. They found that there is a relationship between the occurrence of exotic species dominating along the road verge and the soil properties. Their results showed a significant difference in the amounts of nitrogen in the soils of natural areas and the road verge with more N in the soils of the natural undisturbed soils.

Wei *et al.* (2017) in their study on the forest soils of the southern Tibetan Plateau, analysed the forest soils to see the distribution and mineralization of organic carbon and nitrogen. They studied this in different forest types. They found that the OC or N was not affected by the forest type. Also, the OC in the soil doesn't get affected by N addition.

Singh *et al.* (2018) conducted a study to determine the vehicular impact on soil quality and found a significant decrease in organic carbon and available nitrogen in addition to other elements in the nearby roadside soils. Also, the concentration of toxic heavy metals from vehicular origin increased in the roadside soils and this showed a positive correlation with the vehicular density.

Jaworska and Lemanowicz (2019) studied the increase in heavy metals in soils of forest area because of the pollution caused by road traffic. They found that the pollution index for heavy metals was more in the surface layer soil samples. The study also showed that the emissions around the roads affected the adjacent soils up to a distance of 20-40 m from the road. In the soils at a distance of 100-150 m from the road, less impact was seen. The contamination by these emissions degrades the soil by inhibiting the growth of microorganisms. This is because it is the microorganisms that perform the process of decomposition and transformation of organic matter.

In general, multiple studies are suggesting that anthropogenic pressure and disturbance affects forest characteristics. For example, Isbell *et al.* (2015) have highlighted that anthropogenic changes/disturbances decreases ecosystem stability by reducing biodiversity. Similarly, Fig *et al.* (2012) have highlighted that the degradation of surrounding habitats of protected areas can result in a large loss of biodiversity. One of the recent studies (Nayak *et al*., 2020), suggests that road and power transmission infrastructure has resulted in more than 70% of reduction in large forest patches in India when compared to the locations where such infrastructures are excluded. Thus assessing the impact of sources of road induced disturbances and degradation becomes imperative. The impact on the forest can be studied using Phyto-diversity data. For assessing the impact on soil, the soil characteristics are to be assessed in different depths (e.g. upper 0–10 cm and lower 10–20 cm) to assess the variations in OC and N (Singh *et al*., 2007; Nath *et al*., 2018).

The literature review suggests that the studies on the impact of roads on forest and soil characteristics are very limited in India. Most of the studies have either commented on the impact on protected area and loss of wildlife and limited to none, are on the direct impact on the vegetation and soil characteristics. There are a few studies that have tried accounting for the impact of vehicular pollution on the surrounding landscapes including forests. Studies focusing on the impact on forest and soil characteristics are almost missing. However, road network infrastructure development through the forest landscape is a common practice. In the Himalayan landscape, wherein, the road is a necessity and the impetus is being given on strengthening and expansion of roads, such studies are important to understand the impact and also provide inputs for the policies towards this. This could be done by studying the impact of different types of roads on the structure of the forest, particularly the tree species diversity and important soil characteristic parameters.

Aim and objectives

Based on the details given in Chapter I (Introduction) and the Review of Literature carried out (Chapter 2), the following aims and objectives are identified to carryout out this research work. Each of the objectives designed has a few research questions which are to be expected to be answered through this research work.

Aim

To understand the influence of roads on the forest characteristics of the Central Himalaya.

Objective1: To assess the impact of roads on forest structure

RQ 1: *How does the Phyto-diversity vary with the increasing distance of forest from roads?*

RQ 2: *What is the impact of different types of roads on Phyto-diversity?*

Objective 2: To characterize the distribution of soil organic carbon and nitrogen with distance from road

RQ 1. *How do forest soil properties (soil organic carbon and total nitrogen) differ along with different road systems?*

RQ 2. *What is the impact of distance from the road on forest soil properties (soil organic carbon and total nitrogen)?*

3 Materials and Methods

3.1 Study area

The study area lies between 30° 03' 07.97" N to 30° 15' 23.35" N Latitude and 77° 57' 58.16" E to 78° 13' 55.94" E Longitude, at an altitude ranging from 377 to 785 meters asl. The forests come under the Dehradun forest division and Rajaji Tiger Reserve. The area is not just having a lush semi-evergreen forest and diverse wildlife but also roads and other anthropogenic features (Ogra, 2009) that pose challenges. Figure 1 shows the location of the study area and false colour composite (FCC) of Sentinel 2A data of 04-06-2019.

There are diverse forests found in the area that range from semi-evergreen to deciduous and from mixed broad-leaved to terai grassland. Sal forests are common (*About Rajaji National Park*). Doon valley is oriented in the northwest to southeast (NW–SE) direction and is surrounded by Lesser Himalaya in the northeast (NE) and the Siwalik ranges in the southwest (SW) (Mukesh *et al.*, 2011). The climate of the valley falls under sub-tropical to a temperate climate. The average temperature for the region ranges from 27.65˚C to 13.8˚C, with 40˚C as the average maximum temperature in June and an average minimum of 1.80˚C in January. The average rainfall received by the area is 207.33 cm with most of the rainfall during the monsoon season, June to September and particularly July and August the rainiest months (*Climate | District Dehradun | India*).

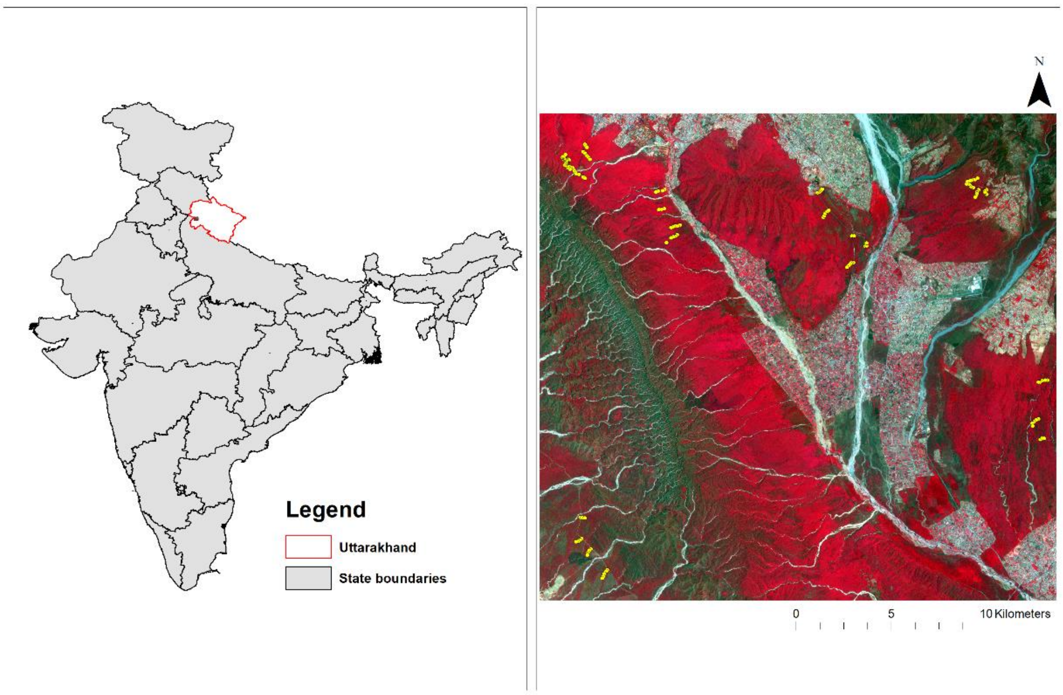


Figure 1: The study site: 1. The map of India showing Uttarakhand. 2. FCC satellite image showing the sample plots in yellow circles on the study region.

We carried out the study in the forest ranges – Barkot, Thano, Lachhiwala, Asarori and Ramgarh. The soils of the area have developed on the deep alluvial deposits comprising of very fine clay and partly sand with parent material derived from Doon alluvium. These alluvial and colluvial deposits are mixed with soft sandstones and quartzite boulders and pebbles (Mukesh *et al.*, 2011). The forest is primarily semi-evergreen with Sal as a dominant species. To carry out the sampling, road types, namely, National Highway (NH), Metalled road (M) and Unmetalled road (UM) were identified (Figure 4). Metalled roads are constructed with cement, concrete etc. while the unmetalled roads are just trails on the soil. The national highways are also constructed using concrete and cement. While metalled roads mostly handle the local traffic, the highways connect the cities. A Control Site (C) was also identified with the absence of any of such roads and other known source of disturbance. The description of the sites is given in table 1.

Table 1: The sites taken for the study of the road types: National Highway (NH), Metalled road (M), Unmetalled road (UM) and the control site (C).

Road Type	**Site name**	**Forest division**
NH	Asarori	Rajaji Tiger Reserve

	Lachhiwala	Dehradun Forest Division
UM	Barkot	Rajaji Tiger Reserve
	Ramgarh	Rajaji Tiger Reserve
M	Thano	Dehradun Forest Division
	Dhaulkhand	Rajaji Tiger Reserve
C	Chandrabadni	Dehradun Forest Division

3.2 Sampling design and data collection

A reconnaissance survey was carried out in April 2019. Intensive fieldwork was scheduled for June 2019. At each site, the transect was set perpendicular to the road. In each transect, 3 to 5 plots were constructed (depending on the topography and the on-ground challenges). The plots started from the road verge to as deep as 500 m into the forest. The first plot of 32 m × 32 m was just at the road verge and the subsequent plots at 100 m distance from the previous plot. Another transect was set at 1 km distance from the first one parallel to the road on the other side of the road. Likewise, 3-5 transects at each site were set (Figure 2).

A total of 7 sites including the control site were studied by constructing 124 plots with a size of 32 × 32 m each. The plots were geo-referenced with a GPS device (spatial accuracy ±3m) to obtain the exact position of the centre and the four corners. The number of individuals per plot ranged from 5 to 143 trees. A total of 46 species were detected throughout the study. The total no. of sampled individual tress was 4628.

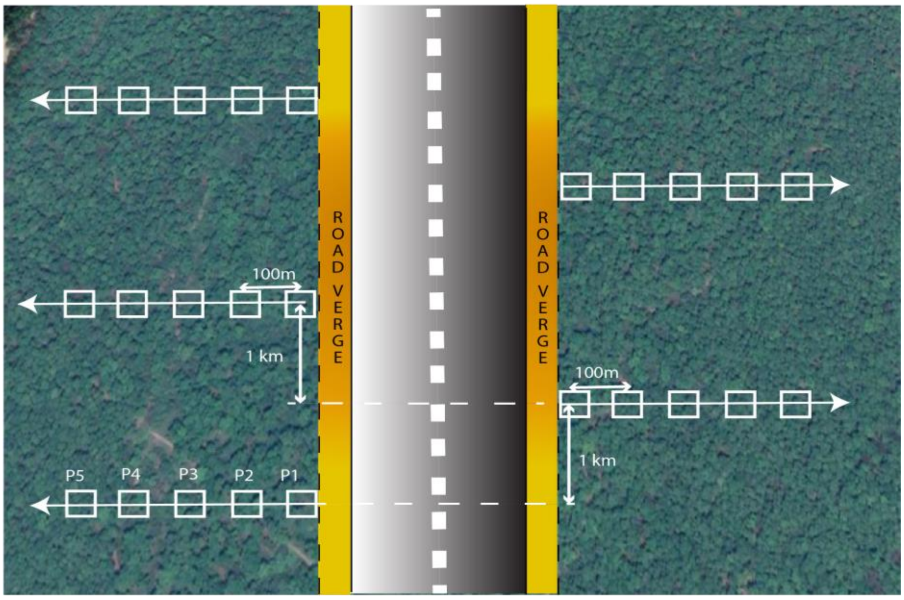


Figure 2: Diagrammatic representation of the sampling strategy. Five transects perpendicular to the road at 1 km distance from each other. Each transect had five plots of 32×32 m size separated by 100 m distance.

For the soil samples, the soil was taken at two depths, 0-10 cm and 10-20 cm from two points diagonally on each plot (Figure 3). These were stored in Ziplock bags. The samples covered the vertical relationships (two depths considered) and the lateral relationships (relationship of soil up or down the slope). Since the analysis results can get affected by the handling of the soil samples, we analysed all the soils with the same method so that the results are comparable for the study. The visible pieces of organic material were removed, the samples air-dried and mixed using the quartering and coning method in the laboratory. Later these were sieved from 2 mm sieve mesh to remove the fine plant roots. The two replicates from each plot were then combined into a composite sample to get a representative sample. We then analysed the soil samples in the laboratory for Soil Organic Carbon (Walkley Black method) and Total Nitrogen (Kjeldahl method).

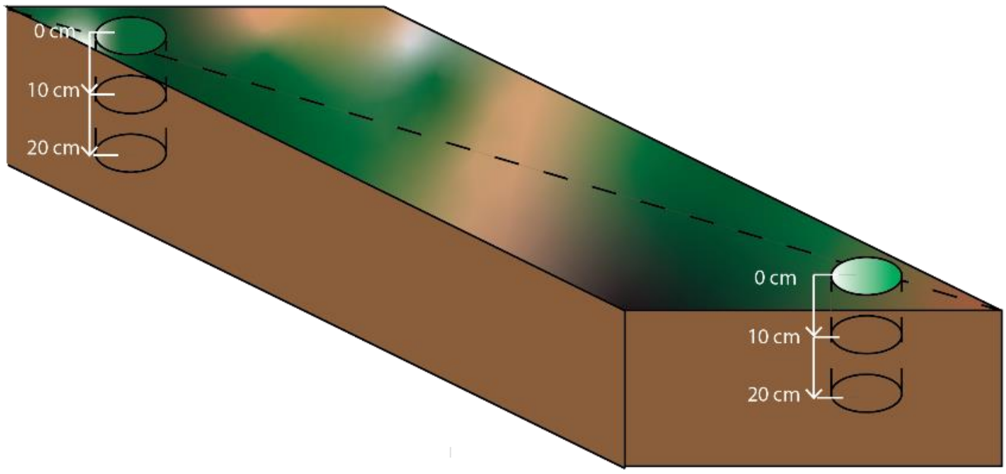


Figure 3: Diagrammatic representation of a single 32×32 m plot showing a sampling strategy for the soil samples. The samples collected at two depths 0-10 cm, and 10-20 cm diagonally on the plot

3.3 Indices calculation

Biodiversity Indices, namely Shannon diversity index, Shannon index, Dominance and Evenness were calculated using PAST (PAleontological Statistics) software (Hammer, Harper and Ryan, 1999). Following are the formulae for the indices used.

3.3.1 Shannon diversity index

This Shannon diversity index takes into account, both the number of individuals and the number of taxa. It ranges from 0 for communities with only one single taxon to high values for communities with many taxa, each with few individuals.

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

Where, p is the ratio of individuals of one particular species (n) divided by the total number of individuals (N)

ln is natural log, Σ is the sum of the calculations, s is the number of species.

3.3.2 Dominance

It ranges from 0 to 1. Value of 0 means that all taxa are equally present while a value of 1 means that one taxon dominates the community.

$$\text{Dominance (D)} = \sum_{i} \left(\frac{n_i}{n}\right)^{\mathbf{2}}$$

Where n_i is the number of individuals of taxon i.

3.3.3 Simpson Index

Measures 'evenness' of the community from 0 to 1.

$$\text{Simpson Index} = 1 - \text{Dominance}$$

3.3.4 Evenness

Calculated using Buzas and Gibson's evenness.

$$\text{Evenness} = \frac{e^{(H)}}{s}$$

Where e is exponent H is Shannon Index and s is the number of species.

3.4 Processing of the Soil Samples

3.4.1 Pre-processing

1. **Drying -** Air drying the samples for 4 to 8 days. We crumbled samples to break bigger peds and spread them in a well-ventilated room.
2. **Mixing -** We mixed the replicates by quartering and coning method.

3. **Grinding and sieving-** The soil was passed through a 2-mm mesh sieve to remove the coarse materials. Then ground and passed through 100 mesh sieve for further analysis (Nath *et al.*, 2018).
4. **Storing -** We then placed each soil sample in a zip-lock bag, labelled it permanently and stored it in a cool, dry location.

Figure 4: Pictures during the study. Pictures 1, 2 and 3 are depicting the field visit. 4, 5 and 6 show the National Highway, Unmetalled road and Metalled road, respectively. 7, 8 and 9 are pictures during the process of digestion, distillation and titration of the samples during soil analysis, respectively.

3.4.2 Laboratory Analysis

1. Soil Organic Carbon estimation

The Walkley–Black method is the most widely used method in many laboratories. This is because it is simple, rapid, inexpensive and requires minimal equipment (De Vos *et al.*, 2007). However, this method generally under-estimates the values as compared with standard dry combustion methods and that is why a correction factor is multiplied to the final results. The correction factor 1.3 is multiplied as from this method, only 77% avg. carbon is estimated. The result can be converted to corrected total organic carbon by multiplying the factor 100/77 = 1.3

Methodology used

1) The amount of sample was standardized. Here we used 0.2 gm sample.
2) 0.2 gm of 0.5 mm sieved soil sample (0.1 gm in some) was taken in a conical flask and add 10 ml $K_2Cr_2O_7$ was added into it.
3) Then slowly 20 ml H_2SO_4 was added to it. After shaking it for a minute, it was left for 30 min.
4) 200 ml of water was then poured into the solution.
5) 10 ml of orthophosphoric acid was added to it.
6) Then 0.2 gm NaF was put into the solution. The mixture was left for 1 hr 30 min.
7) Now, 1 ml Ferroin indicator was added just before titration.
8) The excess $K_2Cr_2O_7$ was titrated with 0.5 N ferrous ammonium sulphate till the colour changed from yellowish-green to greenish and finally brick red at the endpoint.
9) We simultaneously also tested blank without soil.

Reagents used

1) 1 N $K_2Cr_2O_7$: For this, dissolve 49.04 gm of dry $K_2Cr_2O_7$ in distilled water and make up the volume to 1000 ml.
2) Conc. H_2SO_4.
3) 0.2 M Ferrous Ammonium Sulphate solution: Dissolve 78.390 gm Ferrous ammonium sulphate in 50 ml conc. H_2SO_4 and dilute to 1000 ml with distilled water.
4) Ferroin Indicator.

Calculations

$$\% \text{ Soil Organic carbon} = (B - S) \times N \times 0.003 \times \frac{100}{Wt. of\ Soil\ in\ gm\ (oven\ dry)}$$

Where B = ml of std. 0.5 N ferrous ammonium sulphate required for blank

S = ml of std. 0.5 N ferrous ammonium sulphate required for soil sample

N = Normality of std. ferrous ammonium sulphate (0.5N)

2. Total Nitrogen Estimation

For Total Nitrogen estimation, the Kjeldahl method was used.

Methodology used

1) 1 gm soil was added in a dry digestion tube.
2) 3.5 gm of K_2SO_4-$CuSO_4.5H_2O$ catalyst mixture was added into it in the ratio of 8.8:1.
3) 10 ml conc. H_2SO_4 was then added.
4) The digestion tubes were then put into the digestion block.
5) The digestion unit was programmed to raise the temperature to 300°C for half an hour and to 390 °C and then was maintained for 3 hours.
6) After the digestion is complete, the samples were allowed to cool.
7) After cooling down the samples, 20-25 ml deionized water was added to the samples. This is done to prevent the solidification of the samples.
8) The tubes were then taken to the distillation unit.
9) In the distillation process, Ammonia gets released. This ammonia was collected in a 2% (w/v) boric acid solution containing 20 ml/l of mixed indicator (Bremner, 1960).
10) The distillate was then titrated with 0.05 M H_2SO_4. The colour changed from green to pink.

Reagents required

i. K_2SO_4-$CuSO_4.5H_2O$
ii. Conc. H_2SO_4
iii. Boric acid solution
iv. Mixed indicator
v. 0.05 M H_2SO_4

Calculation

Total Nitrogen % = (A – B) × Normality of H_2SO_4 × 0.014 × $\frac{100}{Wt. of\ Soil\ in\ gm\ (oven\ dry)}$

Where A= Volume of standard H_2SO_4 required for soil sample

B= Volume of standard H_2SO_4 required for a blank sample

3.5 Statistical analysis

Statistical analysis was done using IBM SPSS software 26 and the graphs were made using R studio. We carried out one-way ANOVA (Analysis of Variance) to find out if there is any significant difference between the groups of data. In the case where there was a significant difference detected by the one-way ANOVA test, a post hoc test was conducted to find between which groups the difference is actually present. For this, we used Tukey's HSD (honest significant difference) post hoc test.

4 Results

The findings of this study reveal that there is a significant difference in the Phyto-diversity parameters between the control site and the road sites. However, these Phyto-diversity parameters do not vary with increasing distance from the roads. The results of the analysis of Soil Organic Carbon (SOC %) and Total Nitrogen (TN %) show that the SOC (%) in the 0-10 cm soil depth was significantly more in the NH and UM road site but in the 10-20 cm soil depth, it was more in the UM road site. TN (%) in both the soil depths was significantly more in the M and NH sites.

4.1 Impact of roads on forest structure

4.1.1 Analysis across road types

Values of Shannon Index, Simpson Index, Evenness and Dominance (mean ± standard deviation, maximum and minimum values) for the Control site (C) and the three road sites, namely National Highway (NH) road site, Metalled (M) road site and Unmetalled road (UM) site are shown in Table 2. We found that the diversity indices, namely, Shannon and Simpson index show more value in the control site than in the road sites. Among the road sites, the difference was not significant. The evenness and dominance values, however, did not show any significant difference in the forests of the four groups (C, M, NH and UM). We also see from the box plot figure (figure 5), the distribution of the diversity values is not much in the control site while the values are more distributed in the road sites.

Table 2: Shannon Index, Simpson Index, Evenness and Dominance mean, maximum and minimum values for Control site (C) and the three road sites- National Highway (NH) road site, Metalled (M) road site and Unmetalled road (UM) road site.

Index	Descriptive Statistics	C	M	NH	UM
Shannon Index	Mean ± SD	1.14±0.1	0.68±0.42	0.82±0.42	0.76±0.3
	Max	1.44	1.73	1.85	1.33
	Min	1.02	0.13	0	0
Simpson Index	Mean ± SD	0.63±0.03	0.37±0.21	0.44±0.21	0.43 ±0.17
	Max	0.74	0.81	0.82	0.64
	Min	0.59	0.05	0	0
Evenness	Mean ± SD	0.67±0.11	0.7±0.17	0.65±0.16	0.66 ±0.17

	Max	0.94	1	1	1
	Min	0.52	0.39	0.32	0.33
Dominance	Mean ± SD	0.37±0.03	0.63±0.21	0.56±0.21	0.57±0.17
	Max	0.41	0.95	1	1
	Min	0.26	0.19	0.18	0.36

Mean ± SD is the Mean ± Standard deviation value. Max is the maximum value. Min is the minimum value.

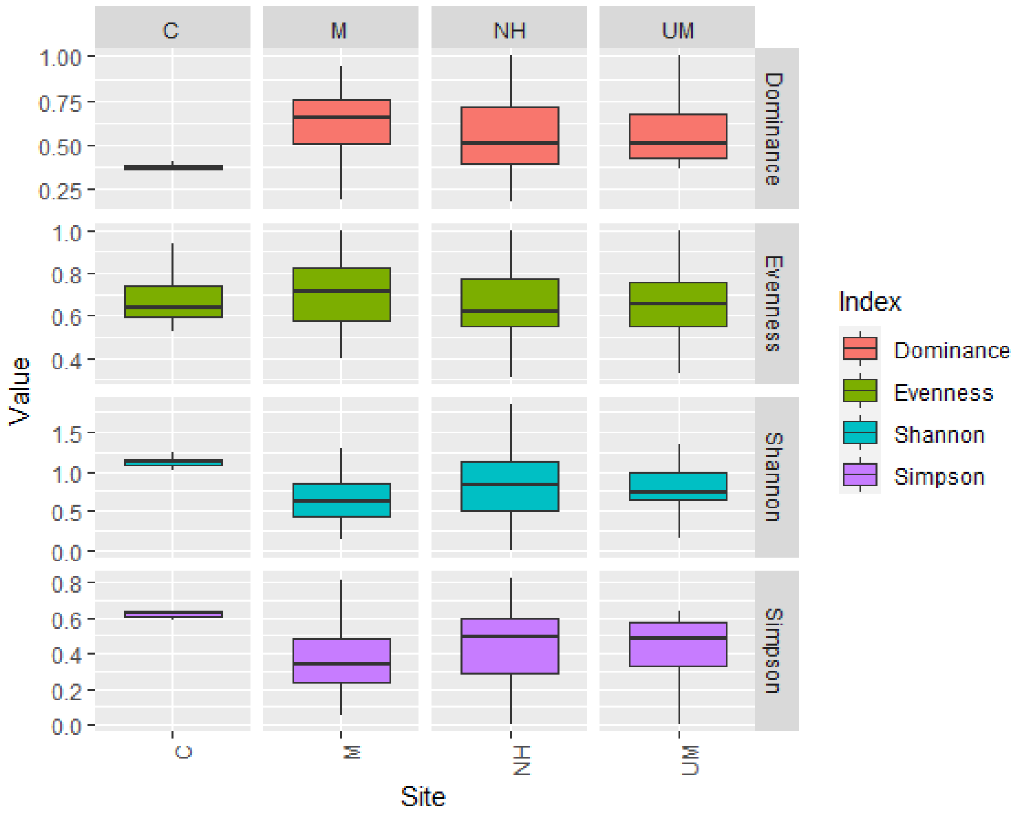


Figure 5: Box plots for Shannon Index, Simpson Index, Evenness and Dominance for Control site (C) and the three road sites- National Highway (NH) road site, Metalled (M) road site and Unmetalled road (UM) road site.

The forests in the control site, which are relatively undisturbed, have shown more Phyto-diversity on an average than the forests that are along the roadsides. Both, Shannon and Simpson diversity index showed the highest values for the control site. The Shannon diversity index, as stated above, showed the maximum value of 1.14±0.1 in the C site. This was followed by a value of 0.82±0.42 in the NH site, then by 0.76±0.3 in UM road site, and the least in the M road site with a value of 0.68±0.42. For the Simpson index, we observed the same pattern. C site with a value of 0.63±0.03 had the highest diversity in terms of Simpson index, followed by NH site with a value of 0.44±0.21, then by UM road site with a value of 0.43 ±0.17 and the least by M road site with a value of 0.37±0.21.

The values of the evenness index, however, didn’t show any much difference among the four sites. The values as calculated for the index, in decreasing order were 0.7±0.17, 0.67±0.11, 0.66 ±0.17 and 0.65±0.16 for M, C, UM and NH sites, respectively.

The dominance index showed a trend inversely to that of the diversity indices. The M road site with a value of 0.63±0.21 had maximum dominance while the control site had the minimum dominance index with a value of 0.37±0.03. The NH and UM road sites showed almost equal intermediate values of 0.56±0.21 and 0.57±0.17, respectively.

Statistical analysis

We used a one-way ANOVA test to see if the difference in the values of various indices calculated had any significant difference or not. All the indices except Evenness showed a significant difference among the groups (C, NH, M and UM), which means that all the four groups showed similar evenness. The F value and significance value (p-value) as calculated from the one-way ANOVA for Shannon index was $F_{3,120}$ = 7.082 and p=0.000, for Simpson index $F_{3,120}$ = 8.36 and p=0.000, for Evenness $F_{3,120}$ = 0.593 and p=0.621 and for Dominance $F_{3,120}$ = 8.36 and p= 0.000.

To further mark which groups showed significant difference amongst each other, we used Tukey’s post hoc test. The results of which are described below:

Tukey’s post hoc analysis showed that the Shannon index values in the C site varied significantly from all the three road sites, NH (p=0.016), UM (p=0.003) and M (p=0.000). There was no significant difference in the values among the road sites (p>0.05).

Simpson index also showed a significant difference between the control site and the road sites, namely NH site (p=0.002), UM road site (p=0.002) and M road site (p=0.000). Simpson index, just like the Shannon index, also showed no significant difference among the road sites (p>0.05).

For dominance index too, we made a similar observation where C site forests showed a significant difference from the forests along NH (p=0.002), UM road (p=0.002) and M road (p=0.00).

4.1.2 Analysis across the distance from the roads

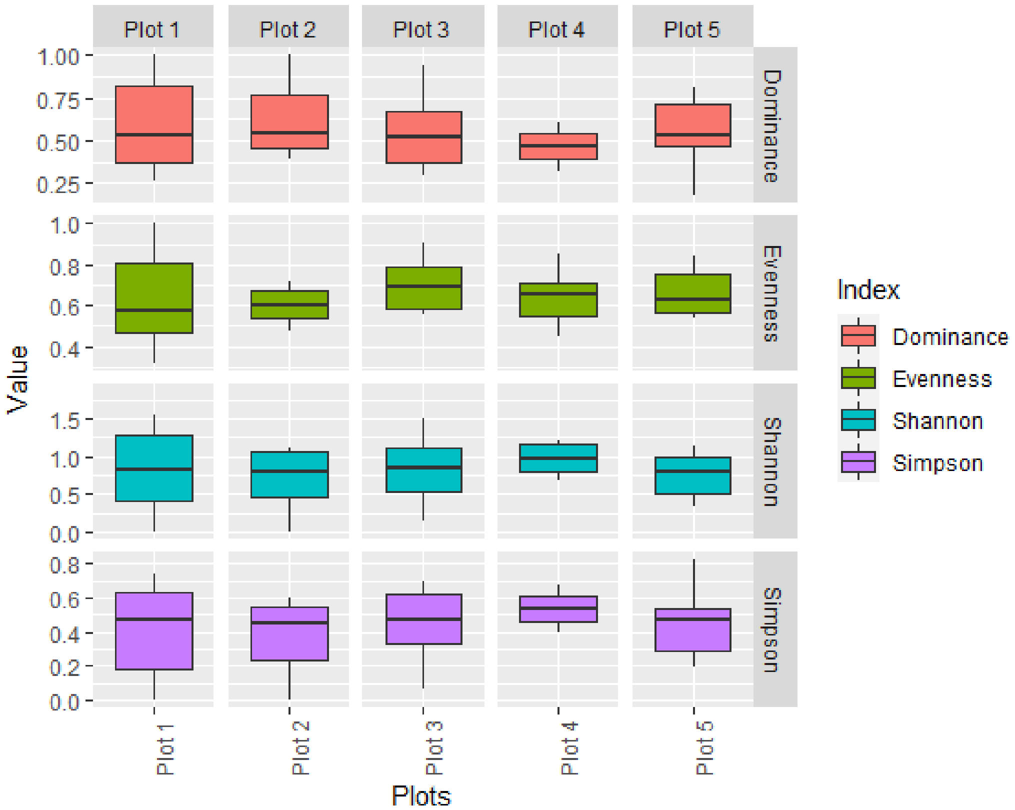
Table 3 shows the plot-wise values of Shannon Index, Simpson Index, Evenness and Dominance in the three road sites, National Highway (NH), Metalled (M) and Unmetalled road (UM). We selected the transects perpendicular to the roads with plot 1 on the road verge and then subsequent plots deeper into the forest. Figure 6 is showing the plot-wise distribution of Shannon Index, Simpson Index, Evenness and Dominance, in National Highway (NH) site, Metalled road (M) site and Unmetalled road (UM) site.

Table 3: Table showing the values of Shannon Index, Simpson Index, Evenness and Dominance in the three road sites, National Highway (NH), Metalled (M) and Unmetalled road (UM) plot-wise. Plot 1 is nearest to the road while plot 5 is the farthest from the road.

Site	Plot	Shannon index	Simpson index	Evenness	Dominance
NH	#1	0.82±0.59	0.41±0.29	0.62±0.24	0.59±0.29
	#2	0.72±0.41	0.39±0.22	0.64±0.17	0.61±0.22
	#3	0.82±0.44	0.45±0.22	0.7±0.13	0.55±0.22
	#4	0.97±0.22	0.53±0.11	0.64±0.14	0.47±0.11
	#5	0.85±0.52	0.45±0.22	0.66±0.12	0.55±0.22
UM	#1	0.8±0.31	0.45±0.18	0.61±0.16	0.55±0.18
	#2	0.76±0.37	0.41±0.19	0.59±0.14	0.59±0.19
	#3	0.66±0.34	0.37±0.2	0.74±0.22	0.63±0.2
	#4	0.78±0.26	0.46±0.16	0.73±0.16	0.54±0.16
	#5	0.89±0.17	0.5±0.08	0.62±0.07	0.5±0.08
M	#1	0.86±0.51	0.42±0.22	0.62±0.16	0.58±0.22
	#2	0.75±0.33	0.43±0.16	0.74±0.13	0.57±0.16
	#3	0.55±0.37	0.32±0.21	0.71±0.14	0.68±0.21
	#4	0.51±0.18	0.31±0.15	0.72±0.19	0.69±0.15
	#5	0.72±0.66	0.38±0.33	0.72±0.23	0.62±0.33

#1 at the roadside, and #2 100m, #3 200m, #4 300m, #5 400m from the roadside.

In the National highway site, we found the maximum value for the diversity index in plot 4 (0.97±0.22) and the minimum in plot 2 (0.72±0.41). For the Simpson index too, we found the maximum value at plot 4 (0.53±0.11) and minimum at plot 2 (0.39±0.22). Dominance index showed inverse trend with the lowest value in plot 4 (0.61±0.22) and the highest (0.47±0.11) in plot 2. But the evenness in both these plots was almost similar, with 0.64±0.14 in plot 4 and 0.64±0.17 in plot 2.



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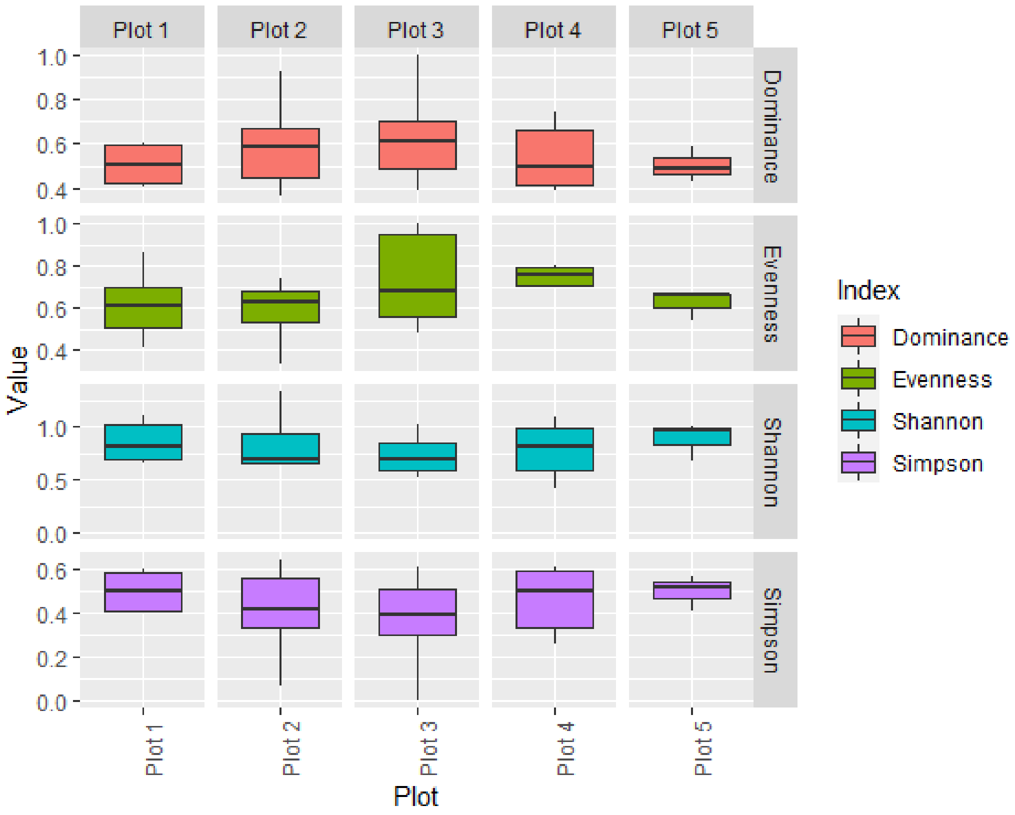
Plot 1
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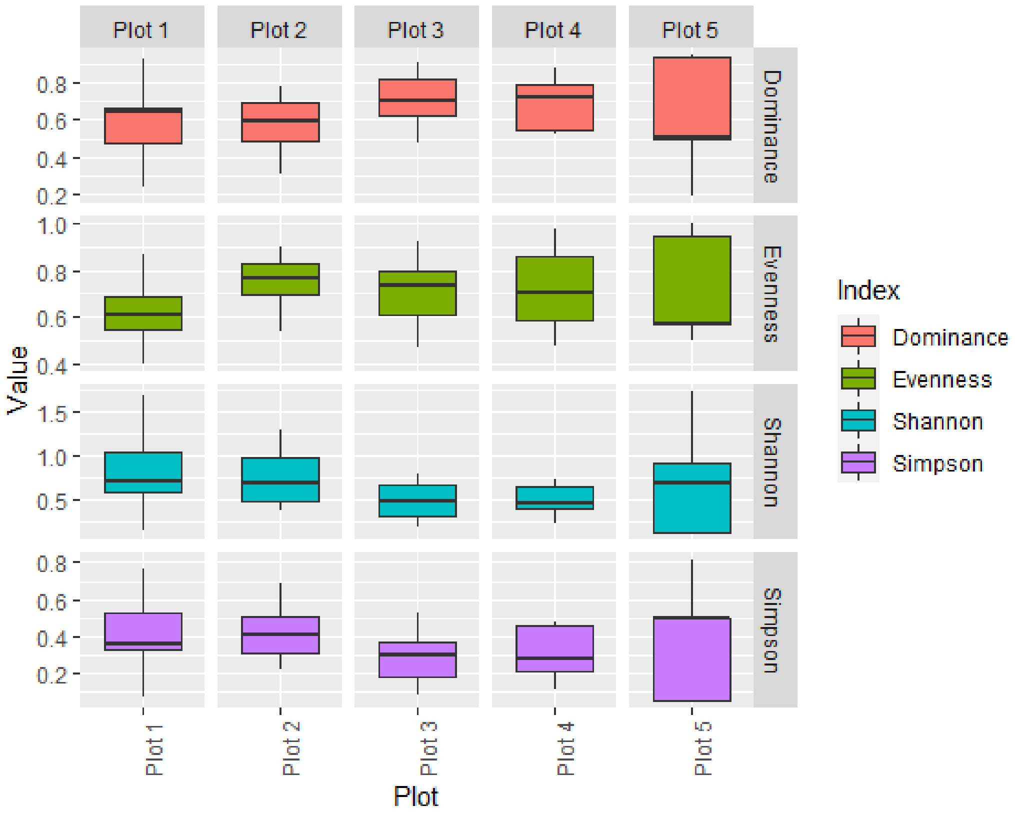


(3)

Figure 6: Box plot showing Shannon Index, Simpson Index, Evenness and Dominance values plot-wise in (1) National Highway (NH) site, (2) Metalled road (M) site and (3) Unmetalled road (UM) site.

In the unmetalled road site, the Shannon diversity index showed the highest value in plot 5 (0.89±0.17) and the lowest in plot 3 (0.66±0.34). A similar observation was recorded for the Simpson index, with a maximum value in plot 5 (0.5±0.08) and minimum in plot 3 (0.37±0.2). Dominance index showed the highest value in plot 3 (0.63±0.2) and the minimum in plot 5 (0.5±0.08). Evenness was also the highest in plot 3 (0.74±0.22) and minimum in plot 2 (0.59±0.14).

For the Metalled road sites, among all the five plots, the Shannon diversity index was recorded to be highest in plot 1 with a value of 0.86±0.51 while the minimum value of 0.51±0.18 was recorded in plot 4. Simpson index also showed the minimum value in plot 4 (0.31±0.15) and the maximum value in plot 2 (0.43±0.16). For the dominance index, plot 4 showed the maximum value (0.69±0.15) while plot 2 showed the minimum (0.57±0.16). For evenness, we found the maximum value of 0.74±0.13 in plot 2 and the minimum value of 0.62±0.16 in plot 1.

Statistical analysis

To test if there was any significant difference in the diversity indices in the various plots along with the increasing distance from the roads, the ANOVA test was run. ANOVA test results showed that there is no significant difference between the various biodiversity indices along with the increasing distance from the roads.

For NH site, the ANOVA results for Shannon diversity index along the various plots was $F_{4,33} = 0.298$, p=0.877; for Simpson index it was $F_{4,33} = 0.486$, p=0.746; for Evenness it came out to be $F_{4,33} = 0.287$, p=0.884 and for dominance it was $F_{4,33} = 0.486$, p=0.746. All showed the p value to be greater than 0.05 and thus there was no significant difference.

The ANOVA results for UM road forests for Shannon diversity index came out to be $F_{4,25} = 0.343$, p=0.846; $F_{4,25} = 0.362$, p=0.833 for Simpson index; $F_{4,25} = 1.077$, p=0.389 and $F_{4,25} = 0.362$, p=0.833 for Dominance index. Again, the p value was found to be more than 0.05 and hence there was no significant difference.

For M road forests, the ANOVA test results for the Shannon diversity index were $F_{4,31} = 0.877$, p=0.489; for Simpson index it was $F_{4,31} = 0.503$, p=0.734; for Evenness index it showed $F_{4,31} = 0.687$, p=0.606 and for Dominance index was $F_{4,31} = 0.502$, p=0.734. For this group too there was no significant difference as p value came out to be greater than 0.05.

The Phyto-diversity did not show any variation with increasing distance from the roads. But there was a significant difference in the Phyto-diversity parameters between the control site from the road sites.

4.2 Impact of roads on Soil Organic Carbon and Total Nitrogen

After pre-processing the soil samples, we did further analysis for SOC (%) and total N (%). The average SOC (%) in the 0-10 cm depth in the NH site, had a minimum and maximum value of 0.88 and 6.28, respectively. While in the 10-20 cm soil the minimum and maximum values were 0.57 and 4.05, respectively (Table 2.1). For Total N (%), this value ranged from a minimum value of 0.57 to a maximum value of 4.05 for the 0-10 cm depth and from 0.13 to 1.28 for the 10-20 cm depth (Table 4).

In the forests in the UM road site, the OC (%) in the 0-10 cm soil showed a minimum individual value of 0.24 and a maximum value of 4.1. For 10-20 cm soil, the minimum and maximum values were 0.83 and 5.27, respectively. The Total N (%) minimum and maximum value found in 0-10 cm soil were 0.01 and 0.22 respectively; and for 10-20 cm, this was ND (not detected) and 0.48 respectively.

The analysis of the soils of the M road site showed a minimum and maximum value of 1.09 and 2.84 respectively for OC (%) in the 0-10 cm soil. The minimum and maximum value of OC (%) in the 10-20 cm soil was 0.87 and 2.02 respectively. The individual Total N (%) minimum and maximum value in the 0-10 cm soil were 0.1 and 1.31 respectively. In 10-20 cm soil, it was 0.09 and 0.51 respectively.

Table 4: Mean, Maximum and Minimum values for OC (%) and Tot N (%) in the soils of the three road sites (National Highway (NH) road site, Metalled (M) road site and Unmetalled road (UM) road site) and the control site in 0-10 cm and 10-20 cm depth.

Site	Descriptive Statistics	SOC (%)		Total N (%)	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm
NH	**Mean ± SD**	2.79±1.26	1.93±0.81	0.3±0.32	0.29±0.32
	Max	6.28	4.05	1.28	1.12
	Min	0.88	0.57	0.13	0.11
UM	**Mean ± SD**	2.75±1.02	2.49±0.88	0.06±0.05	0.1±0.1
	Max	4.1	5.27	0.22	0.48
	Min	0.24	0.83	0.01	ND
M	**Mean ± SD**	1.86±0.54	1.41±0.37	0.35±0.34	0.19±0.12
	Max	2.84	2.02	1.31	0.51
	Min	1.09	0.87	0.1	0.09
C	**Mean ± SD**	2.45±0.84	1.66±0.61	0.03±0.01	0.02±0.01
	Max	4.39	3.22	0.04	0.06
	Min	1.34	0.98	0.02	0.01

Mean ± SD is Mean ± Standard deviation value, Max is Maximum value, Min is Minimum value.

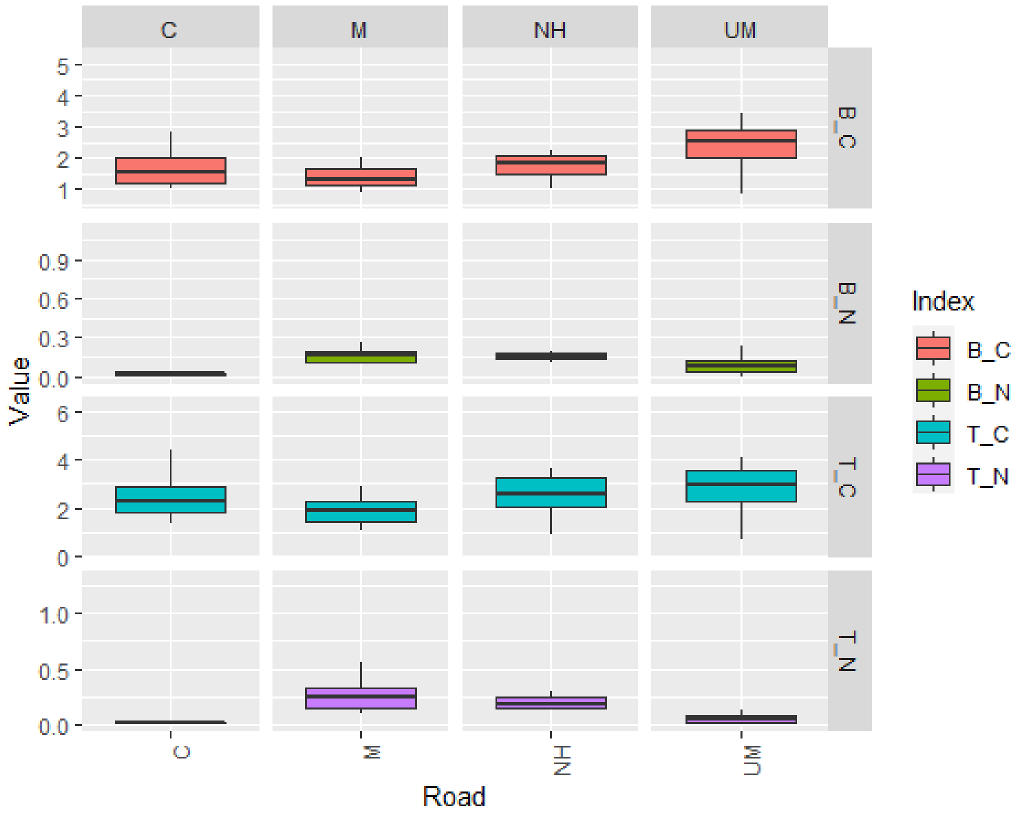


Figure 7: Box plot showing the values of OC (%) and Total N (%) in the 0-10 cm soil depth (T_C, T_N) and in 10-20 cm soil depth (B_C, B_N).

The average OC (%) in the two depths ranged between 1.86±0.54 (M) to 2.79±1.26 (NH) in 0-10 cm soil depth and 1.41±0.37 to 2.49±0.88 in 10-20 cm. The average Total N (%) ranged between 0.03±0.01 (C) to 0.35±0.34 (M) in 0-10 cm soil and between 0.02±0.01 (C) to 0.29±0.32 (NH) in 10-20 cm soil.

In the 0-10 cm soil depth, the highest average OC (%) was 2.79±1.26 in the forests of NH site while it was minimum in the forests of M road site with a value of 1.86±0.54. For the 10-20 cm soil depth, the forests in UM road site showed the highest average OC (%) of 2.49±0.88 while forests around M road showed the lowest average OC (%) of 1.41±0.37. In both the soil depths, the minimum average OC (%) was for the M road site.

The highest average Total N (%) in the 0-10 cm depth was 0.35±0.34 in the forests of M road site while the minimum was in the C site forests with a value of 0.03±0.01. In the 10-20 cm soil depth, the highest average Tot N (%) of 0.29±0.32 was in the forests along NH road while a minimum of 0.02±0.01 was in the control site.

Statistical analysis

We conducted a One-way ANOVA test to see if there is any significant difference between the groups for the average SOC (%) and average Total N (%).

The results for average SOC (%) are described below:

ANOVA results revealed that there were significant differences in the four groups for average OC (%) in 0-10 cm ($F_{3,82}$=3.354, p=0.023) and in 10-20 cm ($F_{3,82}$=9.366, p=0.000).

To further find the particular groups which differed significantly, a post hoc test was run. Tukey post hoc test for the average OC (%) in 0-10 cm soil revealed a significant difference between the M road site and NH site (p=0.034) and also between M road site and UM road site (p= 0.025). In the 10-20 cm soil depth, the test revealed that the average OC (%) in UM road site differed significantly from the rest of the sites, namely NH site (p=0.043), M road site (p=0.043) and C site (p=0.001).

Similar tests were used for Tot N (%) results of which are described below:

ANOVA test for average Total N (%) also showed significant difference both in the 0-10 cm depth ($F_{3,82}$= 12.197, p=0.000) and in 10-20 cm depth ($F_{3,82}$=9.34, p=0.000). Further Tukey post hoc test was carried out.

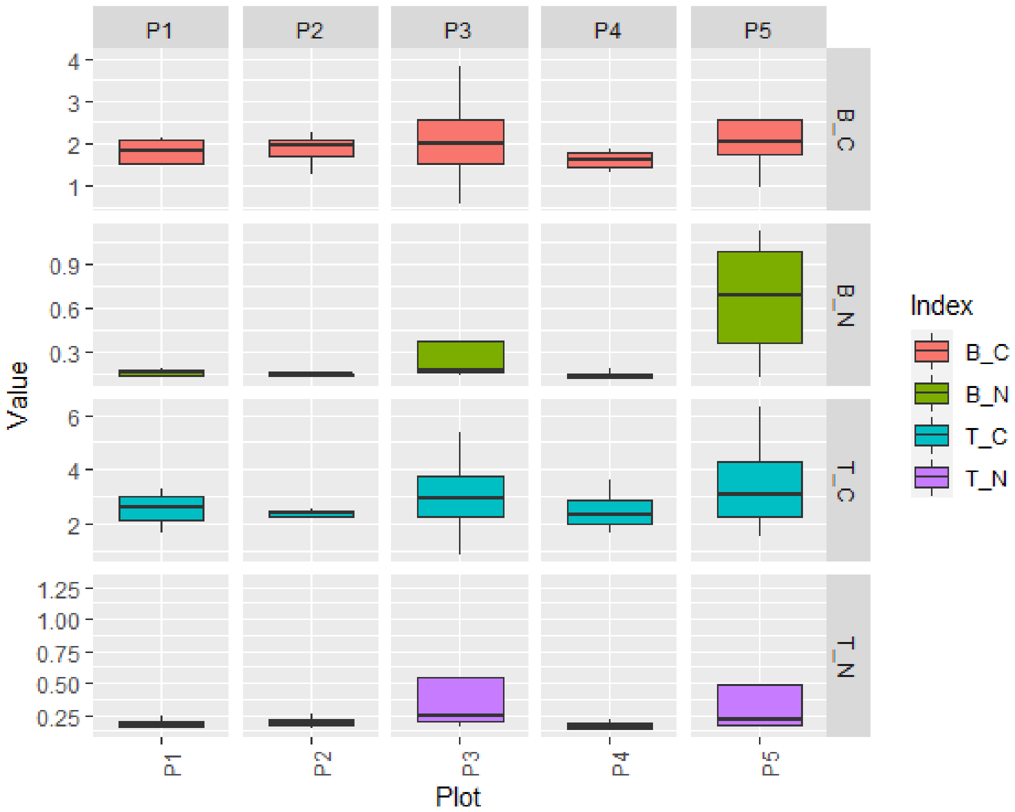
For average Total N (%) in the 0-10 cm soil samples, Tukey post hoc test showed that the control site differed significantly from the forests attached with M road (p=0.000) and NH (p=0.001). Also, the UM road forests differed significantly from the M road forests (p=0.000) and the NH forests (p=0.001). In the 10-20 cm soil depth the average Total N (%) in the Control site had a significant difference from the M road site (p=0.029) and NH site (p=0.000). There was also a significant difference between UM road site and the NH site (p=0.001).

The SOC (%) and Total Nitrogen (%) did not vary significantly with increasing distance from the roads. Along with the road sites in the 0-10 cm soil, the SOC (%) was significantly more in the NH and UM road site and in the 10-20 cm soil depth, it was maximum in the UM road site. TN (%) in the 0-10 cm soil depth showed significantly higher values in the M and NH site while in the 10-20 cm soil depth, it was more in the NH and M road site.

Table 5: Plot-wise SOC (%) and TN (%) in the soils of the three road sites, in 0-10 cm and 10-20 cm depth.

Site	Plot	SOC (%)		TN (%)	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm
NH	#1	2.55±0.72	1.81±0.33	0.19±0.04	0.16±0.03
	#2	2.32±0.31	1.85±0.42	0.2±0.05	0.14±0.02
	#3	3.05±1.85	2.1±1.33	0.49±0.53	0.37±0.41
	#4	2.51±0.83	1.6±0.25	0.17±0.04	0.15±0.03
	#5	3.5±2.04	2.28±1.29	0.44±0.49	0.66±0.46
UM	#1	2.38±1.23	2.3±0.77	0.07±0.03	0.13±0.17
	#2	2.21±1.14	2.03±0.62	0.05±0.05	0.08±0.08
	#3	3.38±0.55	3.01±1.06	0.05±0.05	0.08±0.05
	#4	3.02±0.98	2.58±1.06	0.03±0.05	0.08±0.05
	#5	2.73±0.42	2.6±0.34	0.13±0.08	0.16±0.13
M	#1	2.25±0.52	1.64±0.37	0.25±0.1	0.14±0.04
	#2	1.88±0.56	1.41±0.53	0.31±0.23	0.18±0.09
	#3	1.89±0.63	1.32±0.36	0.57±0.64	0.27±0.21
	#4	1.73±0.55	1.34±0.29	0.42±0.43	0.22±0.14
	#5	1.54±0.57	1.30±0.44	0.2±0.13	0.11±0.003

#1 at the roadside, and #2 100m, #3 200m, #4 300m, #5 400m from the roadside.



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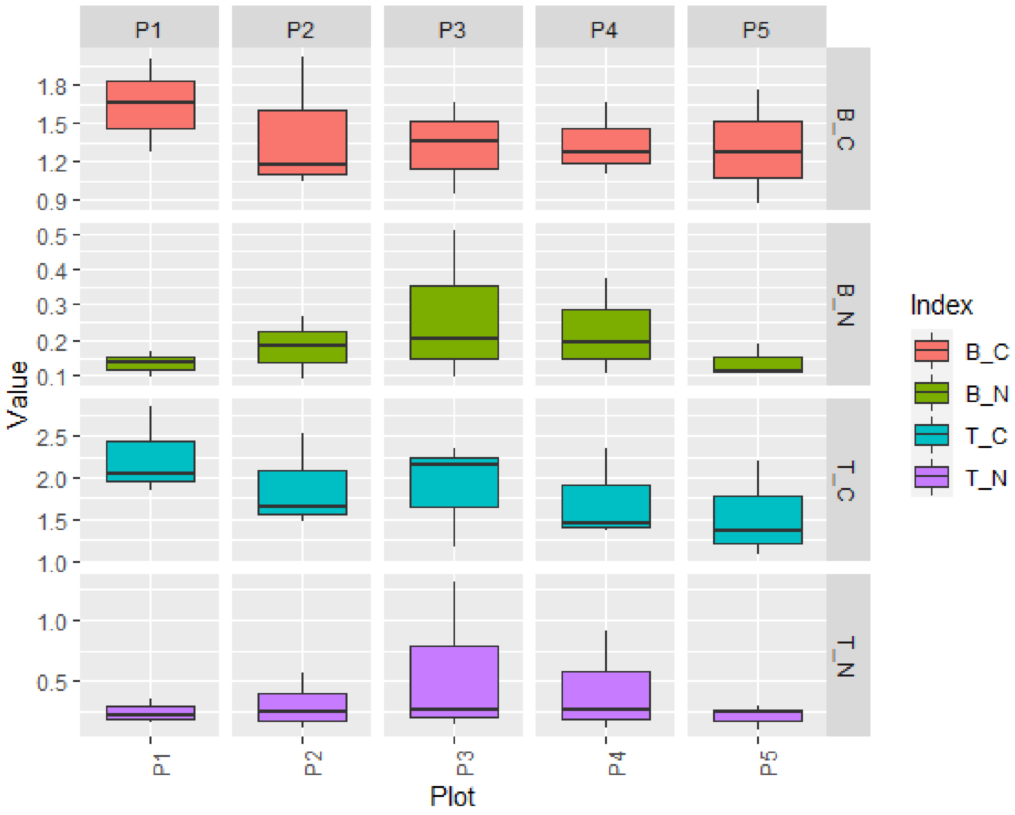
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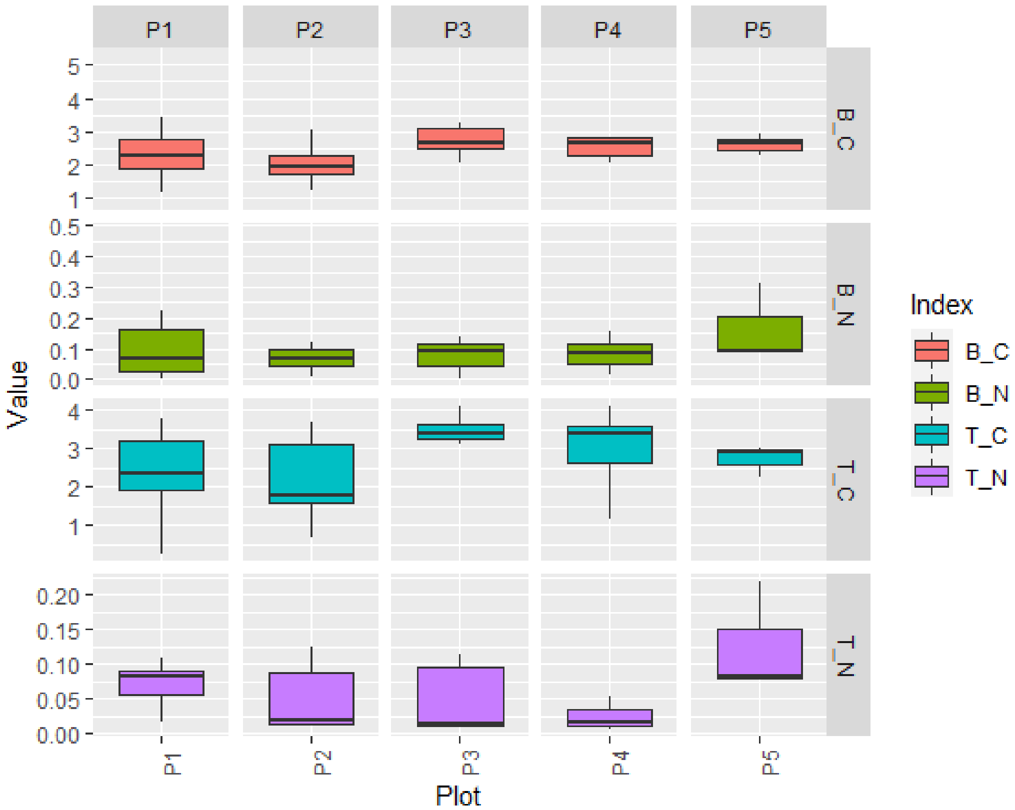

(3)

Figure 8: Box plot graphs showing the soil properties plot-wise, bottom Soil Organic Carbon (%) (B_C), bottom soil Total Nitrogen (%) (B_N), topsoil organic carbon (%) (T_C) and topsoil Total Nitrogen (%) (T_N) in (1) National Highway site (NH), (2) Metalled road.

To see the impact of the roads on the forest soils with increasing distance from the road, we calculated the average OC (%) and Total N (%) for each plot running from the road verge into the forest. We did this for all three sites to primarily see how far does the impact of roads go if any.

In the NH site, the maximum average SOC (%) in 0-10 cm soil was in plot 5 (3.5±2.04) and minimum in plot 2 (2.32±0.31). In 10-20 cm soil, it was maximum in plot 5 (2.28±1.29) and minimum in plot 4 (1.6±0.25). In both the depths, it was plot 5 that had the maximum average SOC (%). Also, in all five plots, the average SOC (%) in the 10-20 cm soil depth was lower than that in the 0-10 cm depth. The average TN (%) in the 0-10 cm soil was maximum in plot 3 (0.49±0.53) and minimum in plot 4 (0.17±0.04). For the 10-20 cm soil depth, it was maximum in plot 3 (0.37±0.41) and minimum in plot 2 (0.14±0.02). Plot 3 showed the maximum average N (%) in both the soil depths.

The average OC (%) plot-wise for UM site in the 0-10 cm soil, had the maximum value in plot 3 (3.38±0.55) and minimum in plot 2 (2.21±1.14). In 10-20 cm soil, the maximum and minimum value was in plot 3 (3.01±1.06) and plot 2 (2.03±0.62) respectively. Maximum average OC (%) in both soil depths was maximum in plot 3 and minimum in plot 2. The average Total N (%) in 0-10 cm soil had the maximum value in plot 5 (0.13±0.08) and minimum in plot 4 (0.03±0.05). In 10-20 cm, the maximum value was in plot 5 (0.16±0.13) while plot 2,3,4 had the minimum value of 0.08. Average Total N (%) showed maximum value for both the soil depths in plot 5 and minimum in plot 4.

The average values of OC (%) in the M road site calculated for each plot in the 0-10 cm soil showed a maximum value in plot 1 (2.25±0.52) and minimum in plot 5 (1.54±0.57). In 10-20 cm soil, it showed the maximum and minimum value in plot 1 (1.64±0.37) and plot 5 (1.30±0.44), respectively. In both the soil depths, plot 1 had the highest average OC (%) and plot 5 the lowest. The analysis of average Total N (%) in the 0-10 cm soil showed the maximum value in plot 3 (0.57±0.64) and minimum in plot 5 (0.2±0.13). This is the 10-20 cm soil was maximum in plot 3 (0.27±0.21) and minimum in plot 5 (0.11±0.003). Average Total N (%) was highest in plot 3 in both the soil depths and lowest in plot 5 in both the soil depths.

Statistical analysis

To check if there is any significant difference in the average OC (%) and average Total N (%) in the soils with increasing distance from the roads, we ran an ANOVA test.

ANOVA results for the NH values for average OC (%) in 0-10 cm and in 10-20 cm were $F_{(4,15)}=0.521$, p=0.722 and $F_{(4,15)}=0.369$, p=0.827 respectively. For average Total N (%), the test results in the soil were $F_{(4,15)}=0.908$, p=0.484 in 0-10 cm soil and $F_{(4,15)}=0.2.661$, p=0.074 in 10-20 cm.

ANOVA test results for forests associated with UM roads showed values of $F_{(4,26)}=1.627$, p=0.198 for 0-10 cm soil and $F_{(4,26)}=1.239$, p=0.319 in 10-20 cm soil. The values for average Total N (%) in the soil in 0-10 cm and 0-20 cm depth were calculated to be $F_{(4,26)}=2.054$, p=0.116 and $F_{(4,26)}=0.628$, p=0.647 respectively.

For the M road forests, the ANOVA results for average OC (%) in 0-10 cm and 10-20 cm soil depth were $F_{(4,10)}$=0.623, p=0.656 and $F_{(4,10)}$=0.357, p=0.833 respectively. For the average Total N (%) the significance values for 0-10 cm was calculated to be $F_{(4,10)}$=0.487, p=0.745 and $F_{(4,10)}$=0.673, p= 0.626 in 10-20 cm soil.

ANOVA test results showed that there is no significant difference in the plot-wise values both for the average SOC (%) and average TN (%). This means that there was no significant difference in average SOC (%) and average TN (%) in the soils with increasing distance from the roads.

5 Discussion

The study investigates the impact of road network infrastructure on forest structure and soil characteristics. The hypothesis is that different kinds of roads have varying impacts along them and these changes vary as one moves away from the road into the forest core. For analysing this, a field campaign was carried out in summer 2019. At each site, 32m × 32m sample plots were studied from the road verge towards the inside of the forest up to 500 m (relatively undisturbed). The tree species and the number of trees of each species in each plot were recorded and analysed. We found that the forest diversity at the control site is significantly more than that in the road sites while dominance was minimum at the control site. Representative soil samples were collected and analysed for Soil Organic Carbon (SOC %) and Total Nitrogen (TN %) at two different soil depths, 0-10 cm and 10-20 cm.

5.1 Impact of roads on forest structure

Anthropogenic disturbances impact plant diversity (Ram *et al*., 2004) and these plants and trees support a large number of life forms in a forest (Dar *et al.*, 2019), so it is important to look into the trees biodiversity of a forest.

Thus, in this study, we calculated the biodiversity indices for the forests attached to different road types. We also calculated these for a control site that was comparatively unaffected from road network.

To check if these values showed any significant difference, we used the ANOVA test. ANOVA results revealed that there was a significant difference in the studied groups for three indices, namely, Shannon diversity index, Simpson diversity index and Dominance. Evenness had no significant difference between the study sites. To further check that this difference was particularly between which groups, we used Tukey's post-hoc analysis.

The control site forests had more diversity, both in terms of Shannon and Simpson diversity indices than in the forests which were adjacent to roads. The dominance index also showed a significant difference between the road sites and the Control site, with the road site forests showing significantly more dominance than the control site. Among the road sites, the maximum diversity was in the NH site, then in the UM road site and then in the M road site but there was no significant difference. The difference seen on increasing distance from the roads also showed no significant difference.

The forests influenced by roads showed less plant biodiversity. One of the major reason for this is that road clearings open up the dense forests and many species which are specialized for thriving in forest interiors, cannot survive at the road edge open conditions (Laurance *et al*., 2009). Also, there are fluctuations in the light during day and night and also the areas near to road have a comparatively higher temperature and are drier than the forest interiors (Laurance *et al*., 2009). These might be the reason for the road site forests showing lesser Phyto-diversity than the Control site.

In the ANOVA test results, there was no significant change in any of the diversity indices with increasing distance from the roads. It means that the distance from the roads does not affect diversity. Previous studies have reported the impact of roads to a distance of less than 5 m (Avon *et al.*, 2010) to 100 m (Bignal *et al.*, 2007). The bigger plots and up to a greater distance into the forests in our study might be a reason for not seeing any significant change with increasing distance from the roads.

As our study did not yield any significant variation as hypothesized for the study, we tried looking at the distribution of vegetation cover in the past. We compared the vegetation cover using Normalized Different Vegetation Index (NDVI) images for 2010 and 2020 (for the month of May, cloud-free image close to the date of fieldwork and data collection). We observed that the vegetation health has increased over the years. Also, the forests of the study region have higher adaptability than the other regions of Uttarakhand (Kumar *et al.*, 2019). We can infer from this that the forests have adapted to the ecological changes caused by building and presence of roads and restored naturally over the years. This also justifies the results that showed no significant difference with increasing distance from the roads. It is difficult to estimate the age of roads (Mann *et al.*, 2020) as a road may be present for many years and may have gone through reconstruction periodically (Zeng *et al.*, 2010).

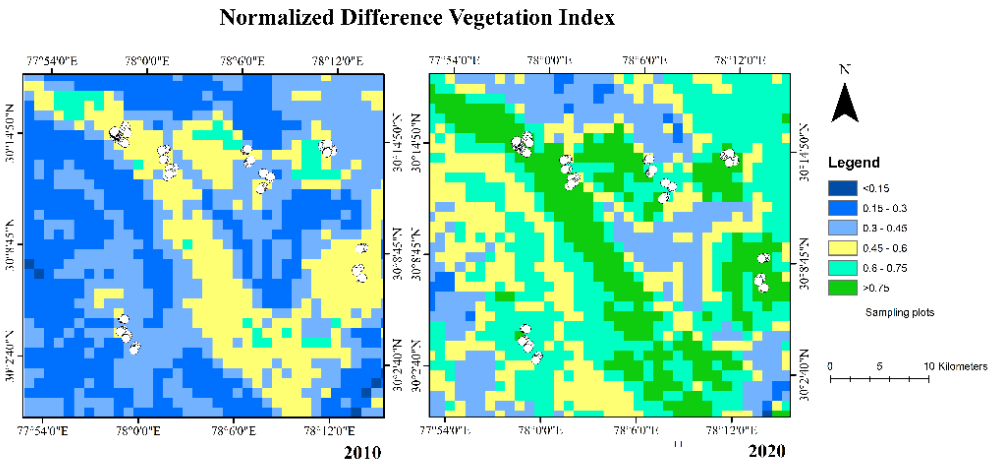

Figure 9: Normalized Different Vegetation Index (NDVI) comparison showing an increased vegetation cover and health in the recent image (2020) than that in 2010 (the study plots are shown in white squares).

5.2 Impact of roads on Soil Organic Carbon and Total Nitrogen

The statistical analysis by ANOVA showed that there is a significant difference between the soil properties of the different sites. Tukey’s HSD post-hoc test revealed which groups differed significantly.

The average OC (%) in 0-10 cm soil depth showed a value of 2.79±1.26 and 2.75±1.02 for NH and UM road sites, respectively. This value was significantly higher than that of the metalled road site that had a value of 1.86±0.54 which was minimum.

On comparing the values of average OC (%) in 10-20 cm soil depth, it was the UM road site that showed the maximum value of 2.49±0.88% and this was significantly higher than that in the other sites. We also saw that the soil in 10-20 cm depth showed lower average SOC (%) than that in the 0-10 cm soil depths. Earlier studies have also reported a lower SOC (%) in lower soil depths (Singh *et al*., 2007; Nath *et al.*, 2018).

The loss of SOC (%) can be as high as 50% because of the removal of vegetation cover (Nath *et al.*, 2018). The SOC (%) in the 0-10 cm showed significantly higher value in the UM and NH road site, while in the 10-20 cm depth it was significantly higher only in the UM road site. UM roads have negligible traffic in our study areas and used for walking or inspection by the forest officials. This least disturbance might be the reason for high SOC (%) in the soils of these sites. As the forests with less degradation shows more SOC (%) (Singh, 2010). Higher SOC (%) in the 0-10 cm soil depth of the NH site suggests that these roads might be present for a very long time, and since old roads have a high and continuous input of nutrients and energy (Zeng *et al.*, 2010), these have caused this increase in the SOC (%) value in the adjacent soils. Another reason for this can be the fact that roads cause physiochemical changes in the adjacent soils by increasing the availability of nutrients and water (Zeng *et al.*, 2010).

In case of TN (%), the first observation was that the C site showed the least value for TN (%) in both the soil depth with a value of 0.03±0.01% and 0.02±0.01% in 0-10 cm and 10-20 cm, respectively. It is the M road site that showed a maximum value of 0.35±0.34% in the 0-10 cm soil depth, followed by NH and UM road sites with a value of 0.3±0.32% and 0.06±0.05%, respectively. UM road site showed significantly lower values from NH and M road sites. TN (%) in the 10-20 cm soil depth showed the maximum value in the NH road site with a value of 0.29±0.32%. M road site followed this with a value of 0.19±0.12 and then the UM road site with 0.1±0.1%. C site, as stated earlier, had the least value. It is noteworthy here that the C site and UM road site differed significantly from the site with the maximum value i.e., the NH site.

The TN (%) in NH site is almost the same in both the depths which suggests that soil has a uniform nitrogen distribution which further suggests that the road is there for a long time and the adjoining soils and forests have adapted. The M roads site showed higher total TN (%) in the 0-10 cm soil depth which suggests that the runoff from roads might have caused this increase as the runoff water can have a substantial amount of dissolved nitrogen in various forms (Trombulak and Frissell, 2000; Coffin, 2007). The UM road site has shown lower TN (%) in the 0-10 cm soil depth. As mentioned earlier, UM roads have negligible traffic and there are not much vehicular emissions to influence the TN (%) in the adjoining areas. The C site has shown uniform concentration of TN (%) in both depths.

To check the difference in the values of the soil properties with increasing distance from the road, i.e. plot-wise, we used the ANOVA test. We found that there was no significant difference in the values of the soil properties along with the increasing distance from any of the three studied road types. Previous studies show that the spatial extent of the emissions associated with roads reach up to 100-150 m and the highest accumulation at 20-40 m distance (Jaworska and Lemanowicz, 2019). Our large plot sizes (with 100 m distance) might be the reason for not detecting the minute changes with increasing distance from the roads.

The study sites coincide with the study by (Mukesh *et al.*, 2011). In their study, the maximum SOC (%) was in the Barkot site which is one of the two UM road sites in our study. This is similar to our observation, where UM road site showed the maximum SOC (%) in both the depths. The M and NH sites in our study have shown relatively more TN (%) than in other sites. Whereas, the study by (Mukesh *et al.*, 2011) shows that these two sites have values almost equal to other road sites. This might be because of lesser number of sites taken by (Mukesh *et al.*, 2011).

6 Conclusion

The study aimed to understand the impacts of different type of roads on the forest characteristics of the Central Himalayan region. To understand this, we used three road types, National Highway (NH) road, Metalled (M) road, Unmetalled (UM) road and a Control (C) site to collect the required data and samples. For each road type, two sites each were studied. The data collection was done from near the road to at a distance of up to 500 m perpendicular to the road, at an interval of 100 m each. The collected information was used to calculate Shannon diversity Index, Simpson Index, Evenness and Dominance. Soil samples were collected from the respective plots to analyse Soil Organic Carbon (%) and Total Nitrogen (%).

Our results show that all road types have an impact on forest diversity. The forests that are associated with roads show less Phyto-biodiversity than the undisturbed forests. But we could not detect any significant variation in the road-wise Phyto-biodiversity in the forests, as per the studied parameters. The study also reveals that the Phyto-diversity does not vary with the increasing distance of forests from the roads in the studied sites. The difference that we saw in the indices was not significantly different. So, we conclude that there is no significant change in the Phyto-diversity of the forests with increasing distance from the roads.

On analysing soil samples, the SOC (%) in the 0-10 cm soil depth was found to be significantly more in NH and UM road site. While in the 10-20 cm soil depth, it was significantly higher in UM road site than in the rest of the sites. The TN (%) showed more value in the M and NH site in both the soil depths. With increasing distance from the roads, there was no significant difference detected in the SOC (%) and TN (%) in both the soil depths (0-10 cm and 10-20 cm).

The study concludes that

(a) the tree diversity does not vary much as we move from road proximity into the forests. There is an opportunity to assess herb diversity variation along different roads and distance from the road.

(b) there are variations in the distribution of SOC (%) and TN (%). This should be further investigated with the frequency of vehicular movement on the roads.

The study presented in this thesis is relying on the field data collected in one season. Intensive sampling can be attempted to collect data in different seasons to quantify the variations, if any.

The study has focussed only on the Phyto-diversity (tree species only), however, the roads are known to impact the faunal distribution and also wildlife accidents. Further road ecology assessments can be attempted with a focus on the faunal species distribution and incidents of human-wildlife interactions because of the roads. Remote sensing data used to support the discussions provide some insights into the interpretation. Thus, it will be interesting to assess the temporal remote sensing data and carry out spatial-temporal analysis using ecosystem and landscape metrics. Having long term ecological research designed in such a landscape might bring some insights to support the hypothesis of this research.

7 References

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