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Habitat suitability model of Endangered Eld's Deer (*Rucervus eldii thamin*): identifying potential areas for conservation in Chatthin Wildlife Sanctuary, Myanmar

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Contents

Pages

List of Tables

List of Figures

Abbreviations and Acronyms

%	Percent
/	Or
&	And
>	Greater than
<	Less than
a.s.l	above sea level
A-I	Aridity Index
°C	Degrees Celsius
AHPs	SEAN Heritage Parks
ANN	Artificial Neural Networks
ArcGis	Aeronautical Reconnaissance Coverage Geographic Information System.
ASCII	American Standard Code for Information Interchange
ASEAN	Association of Southeast Asian Nations
AUC	Area Under Curve
BANCA	Biodiversity and Nature Conservation Association
Bio1	Annual Mean Temperature
Bio2	Mean Diurnal Range (Mean of monthly (Max temp – Min temp))
Bio3	Iso-thermality (BIO_2/BIO_7) (* 100)
Bio4	Temperature Seasonality (Standard deviation *100)
Bio5	Max Temperature of Warmest Month
Bio6	Min Temperature of Coldest Month
Bio7	Temperature Annual Range (BIO_5/BIO_6)
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CV	Coefficient of Variation
CWS	Chatthin Wildlife Sanctuary
DEM	Digital Elevation Model
DIVA GIS	Data Interpolating Variational Analysis Geographic Information System

EN	Endangered
ENFA	Ecological Niche Factor Analysis
ENM Tools	A Toolbox for Comparative Studies of Environmental Niche Models
ERDAS	Earth Resource Development Assessment System
ET	Annual Evapotranspiration
et al.,	Etalia (Co-workers)
Etc.	et cetera
GCS	Geographic Coordinate System
GIS	Geographic Information System
GPS	Global positioning System
i.e.	That is
IUCN	International Union for Conservation of Nature
KBAs	Key Biodiversity Areas
Km	Kilometer
Km^2	Square Kilometer
Lao PDR	Lao People's Democratic Republic
m	Meter
MaxEnt	Maximum Entropy
mm	Millimeter
MONREC	Ministry of Natural Resources and Environmental Conservation
NBSAP	National Strategy Action Plan
NCNPP	Nature Conservation National Park Project
NEC	National Environment Commission
NTFPs	Non-Timber Forest Products
NWCD	Nature and Wildlife Conservation Division
PDR	People's Democratic Republic
r	Pearson’s correlation coefficient
ROC	Receiver Operating Characteristic
SCBI	Smithsonian Conservation Biology Institute
SDM	Species Distribution Modeling
SRTM	Shuttle Radar Topography Mission
SWS	Swesattaw Wildlife Sanctuary
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UTM	Universal Transverse Mercator
Viz.	Such as
WGS 1984	World Geodetic System 1984
Indaing forest	A Forest type dominated the tree; *Dipterocarpus tuberculatus*
Rut	Sexually active period/ mating season in male.

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Abstract

Out of total 40 species of Cervidae throughout the northern hemisphere, Myanmar harbors eight species of deer. Among these, Eld's deer is one of the most endangered species of the deer found in South and Southeast Asia. The Eld's deer *(Rucervus eldii thamin)* is listed as endangered under the International Union for Conservation of Nature Red list of threatened species due to rapid decline of their population in the world. Eld's deer is among the primary herbivores, meaning they feed on leaves, plants and fruits, normally provide the middle link in a food chain and they have a significant role in seed dispersal, thus helps in maintaining the forest structure and the productivity of forest ecosystems. The conservation of Eld's deer is mainly conducted in Chatthin wildlife sanctuary (CWS) and Swesattaw wildlife sanctuary. This study was conducted to generate the habitat suitability map of Eld's deer in Chatthin wildlife sanctuary, Myanmar and to identify the key variables associated with its distribution. The comprehensive information required to relate Eld's deer distribution with biophysical variables (including topography, temperature, precipitation, elevation, etc.) in Chatthin wildlife sanctuary is lacking. Thus, the correlative models with the species occurrence locations and environmental predictors were used to generate the map of the species current distribution and suitable habitat of Eld's deer in CWS. Maximum entropy model (MaxEnt) approach was used and the study area was classified into four classes i.e., highly, moderately, marginally and least suitable. AUC value was used to test the model accuracy. The result showed that value of test AUC was 0.923 having excellent predictive ability of the model. The variables with maximum percent contribution were Precipitation of Warmest Quarter (bio18) followed by the distance from the road (L_DR), distance from lake (L_DL) and Mean Diurnal Range (bio2). The predicted habitat suitability map can act as a baseline data for the nature and wildlife conservation division of forest department, Myanmar for implementing the conservation and management activities of protected areas and species to ensure long-term conservation and protection of the endangered species in Chatthin wildlife sanctuary.

Key words: species distribution, herbivore, precipitation, home range, Cervidae.

ချပ်သင်းတောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တောရှိ မျိုးသုဉ်းရန်အန္တရာယ်ရှိသော ဆွေသမင်မျိုးစိတ်များအတွက် နေရင်းဒေသသင့်လျော်မှုစံနမူနာနှင့် ထိန်းသိမ်းရေးအတွက် အလားအလာရှိသောနေရာများ လေ့လာဖေါ်ထုတ်ခြင်း

မြင့်စိုး–၃၊ ဦးစီးအရာရှိ
သဘာဝဝန်းကျင်နှင့်သားငှက်တိရစ္ဆာန်ထိန်းသိမ်းရေးဌာန
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်းချုပ်

ကမ္ဘာ့မြောက်ခြမ်းရှိ မျိုးရင်း(Cervidae)သမင်မျိုးစိတ် စုစုပေါင်း(၄၇)ရှိသည့်အနက် မြန်မာနိုင်ငံတွင် သမင်မျိုးစိတ် (၈)မျိုးရှိသည်။ ယင်းတို့အနက် ဆွေသမင်မျိုးစိတ် (Eld's deer) သည် တောင်အာရှ နှင့် အရှေ့တောင်အာရှတွင် တွေ့ရှိရသည့် မျိုးသုဉ်းရန်အန္တရာယ် အရှိဆုံး သမင်မျိုးစိတ်များထဲမှ တစ်ခုဖြစ်ပါသည်။ ဆွေသမင်(*Rucervus eldii thamin*)သည် ကမ္ဘာပေါ်တွင် ၎င်းတို့၏ အကောင်ရေ လျင်မြန်စွာကျဆင်းလာခြင်းကြောင့် IUCN ၏ ခြိမ်းခြောက်ခံနေရသောမျိုးစိတ်များစာရင်း(Redlist)တွင်မျိုးသုဉ်းလုနီးပါးမျိုးစိတ်စာရင်း ဝင်နေပါသည်။ ဆွေသမင်သည် အရွက်များ၊ အပင်နှင့် အသီးအနှံများကို ကျက်စား သော အဓိကသတ္တဝါများ (Herbivore) ထဲတွင်ပါဝင်ပြီး အစာကွင်းဆက်တွင် အလယ်အလတ်ချိတ်ဆက်မှုကို ပေးစွမ်းနိုင်ပြီး မျိုးစေ့များပျံ့နှံ့မှု (Seed dispersal)တွင် အရေးပါ သောအခန်းကဏ္ဍမှ ပါဝင်နေသောကြောင့် သစ်တောဖွဲ့စည်းပုံ(Forest structure) နှင့် သစ်တောဂေဟစနစ်၏ ကုန်ထုတ်စွမ်းအားကို ထိန်းသိမ်းရာတွင် ကူညီပေးနေပါသည်။ မြန်မာနိုင်ငံတွင် ဆွေသမင်မျိုးစိတ်ထိန်းသိမ်းရေးကို ချပ်သင်းတောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တောနှင့် ရွှေစက်တော်တောရိုင်း တိရစ္ဆာန်ဘေးမဲ့တောတို့တွင် အဓိကဆောင်ရွက်လျက်ရှိပါသည်။ ဤစာတမ်းတွင် ချပ်သင်းတောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တောအတွင်းရှိ ဆွေသမင်မျိုးစိတ်များ၏ နေရင်းဒေသသင့်လျော်မှုပြမြေပုံကို ဖန်တီးရန်နှင့် ၎င်းတို့၏ပျံ့နှံ့ ကျက်စားမှုနှင့်ဆက်စပ်နေသော အဓိကအချက်အလက်များကို ဖေါ်ထုတ်ရန် လေ့လာခဲ့ပါသည်။ ဆွေသမင်မျိုးစိတ်ပျံ့နှံ့ကျက်စားမှုနှင့် ဇီဝရုပ်ပိုင်းဆိုင်ရာပြောင်းလဲမှုများ (မြေမျက်နှာသွင်ပြင်၊ အပူချိန်၊ မိုးရွာသွန်းမှု၊ အမြင့်ပေ စသည်ဖြင့်)နှင့် ဆက်စပ်ရန် လိုအပ်မှုကြောင့် မျိုးစိတ်တွေ့ရှိရမှု နှင့် ပတ်ဝန်းကျင်ဆိုင်ရာခန့်မှန်းမှုအချက်အလက်များပါဝင်သော သင်လျော်သည့် Model တစ်ခု ကို အသုံးပြု၍ မျိုးစိတ်ပျံ့နှံ့ကျက်စားမှုမြေပုံနှင့် နေရင်းဒေသသင့်လျော်မှုပြမြေပုံကို ဖေါ်ထုတ် ခဲ့ပါသည်။ ချပ်သင်းတောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တောတွင် ဆွေသင်မျိုးစိတ်များအတွက်

နေရင်းဒေသ သင့်လျော်မှုအဆင့် (၄)ဆင့် (အလွန်အမင်း၊ အများဆုံး၊ အလယ် အလတ် နှင့် အနည်းဆုံး) သတ်မှတ်ခွဲခြားနိုင်ရန် Maximum entropy model (MaxEnt) ကို အသုံးပြုခဲ့ပါသည်။ AUC (Area Under Curve) တန်ဖိုးကို အသုံးပြု၍ Modle ၏ တိကျမှုကို စမ်းစစ်ခဲ့ပါသည်။ AUC တန်ဖိုး ၀.၉၂၃ ဖြစ်သည့် excellent predictive ability of the model ဖြစ်ကြောင်း ပြသနေသည့်အတွက် အဆိုပါ Model ကို အသုံးပြုခဲ့ပါသည်။ ရွှေသမင်မျိုးစိတ်၏ နေရင်းဒေသ သင့်လျော်မှုအတွက် အဓိကထောက်ပံ့ပေးနေသည့် အရေးပါသော အချက်အလက်များမှာ အပူးဆုံးကာလအတွင်း မိုးရွာသွန်းမှု(Bio_18)၊ လမ်းမှ အကွာအဝေး (Distance from road – L_DR)၊ ရေကန်မှ အကွာအဝေး(Distance from Lake – L_DL) နှင့် အမြင့်ဆုံးအပူချိန်နှင့် အနိမ့်ဆုံး အပူချိန်တို့၏ ပျမ်းမျှနှုန်း(Mean Diurnal Range – Bio2) တို့ဖြစ်ပါသည်။ ခန့်မှန်းရရှိသည့် နေရင်းဒေသသင့်လျော်မှုပြမြေပုံ (The predicted habitat suitability map)အား မျိုးသုဉ်းလုနီးပါး အန္တရာယ်ရှိမျိုးစိတ်ဖြစ်သည့် ရွှေသမင်မျိုးစိတ်များ ထိန်းသိမ်းကာကွယ်ခြင်း နှင့် ချပ်သင်းတောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တောစီမံအုပ်ချုပ်ခြင်းအတွက် အခြေခံအချက်အလက် (Baseline Data) အဖြစ် အသုံးပြုနိုင်မည်ဖြစ်ပါသည်။

Habitat suitability model of Endangered Eld's Deer (*Rucervus eldii thamin*): identifying potential areas for conservation in Chatthin Wildlife Sanctuary, Myanmar

1. Introduction

Eld's deer (*Rucervus eldii thamin*) is a highly endangered species of deer indigenous to Southeast Asian (McClelland, 1842). It has been extirpated from its historical range because of anthropogenic pressures such as hunting and habitat loss. It now persists only in isolated, small and fragmented populations from Manipur in North-east India to Myanmar, Thailand, Cambodia, Laos, Vietnam and Hainan Island in China (Wemmer, 1998; McShea *et al*., 1999). Four subspecies were identified; *Rucervus eldii eldii* in Manipur, India, *Rucervus eldii thamin* in central plains of Myanmar and western Thailand, *Rucervus eldii siamensis* in Lao PDR and in the northern and eastern parts of Cambodia and a fourth subspecies *Rucervus eldii hainanus* in Hainan's Island of China (Angoma and Hussain, 2013). Other common names for the Burmese Brow Antlered deer are Eld's deer and thamin. Eld's deer was firstly described in 1839 from Manipur Valley, India, by Captain Guthrie, who named it *Cervus frontalis*. Subsequently, it was renamed *C. eldii eldii* by McClelland (1841) after its discoverer, Captain Percy Eld. Later, McClelland (1842) renamed it *Cervus* (*Rusa*) *frontalis.* Thomas, in 1918, placed it under the genus *Rucervus*, thereby aligning it with the swamp deer (*Rucervus duvaucelii*), which has a close taxonomic relationship with the extinct Shomburgk's deer, *Rucervus schomburgki* (Corbet and Hill, 1992). Historically, three subspecies were recognized, namely *Rucervus eldii eldii*, *Rucervus eldii thamin* and *Rucervus eldii siamensis* (Gee, 1960; McShea *et al*., 2001; Balakrishnan *et al*., 2003; Johnson *et al*., 2004; Tordoff *et al*., 2005). A recently recognized fourth subspecies, found in Hainan Island of southern China, was named *Cervus eldii hainanus* by Xu *et al*., (1983).

40 species of Cervidae are distributed throughout the northern hemisphere, as well as in South America and Southeast Asia (Gilbert *et al*., 2006) and out of total 40 species, Myanmar harbors eight species of cervidae: Eld's deer or Thamin (*Rucervus eldii Eld's deer*), barking deer or muntjac (*Mumticais vaganalis*), sambar deer (*Rusa unicolor*), hog deer (*Hyelaphus porcinus*), leaf muntjac (*Muntiscus putaoensis),* gongshan muntjac (*Muntiacus gongshanensis),* fea's muntjac (Muntiacus feae) and tufted deer (*Elaphodus cephalophus*) (The Protection of Wildlife and Protected Areas Rules, Myanmar Forest Department, 1994). Among these, Eld's deer is one of the most endangered species, and the systematic management and conservation was only initiated at the beginning of the 1980s.

Average sizes of the annual home ranges were 9.04 (± 5.67) km^2 for males and 7.25 (± 3.45) km^2 for females and varied greatly among individuals of the same sex (males, 1.85-18.37 km^2 and females, 2.6-11.11 km^2) (Aung *et al.*, 2001). Annual home ranges are not different in different sexes, but home ranges differed seasonally, being larger in the hot dry season and narrow in rainy season based on the food availability and natural barriers like flooding. There was no interaction between sex and season. Males and females exhibited site fidelity for seasonal home ranges. Mean group size was highest in the hot dry season and lowest in the rainy season.

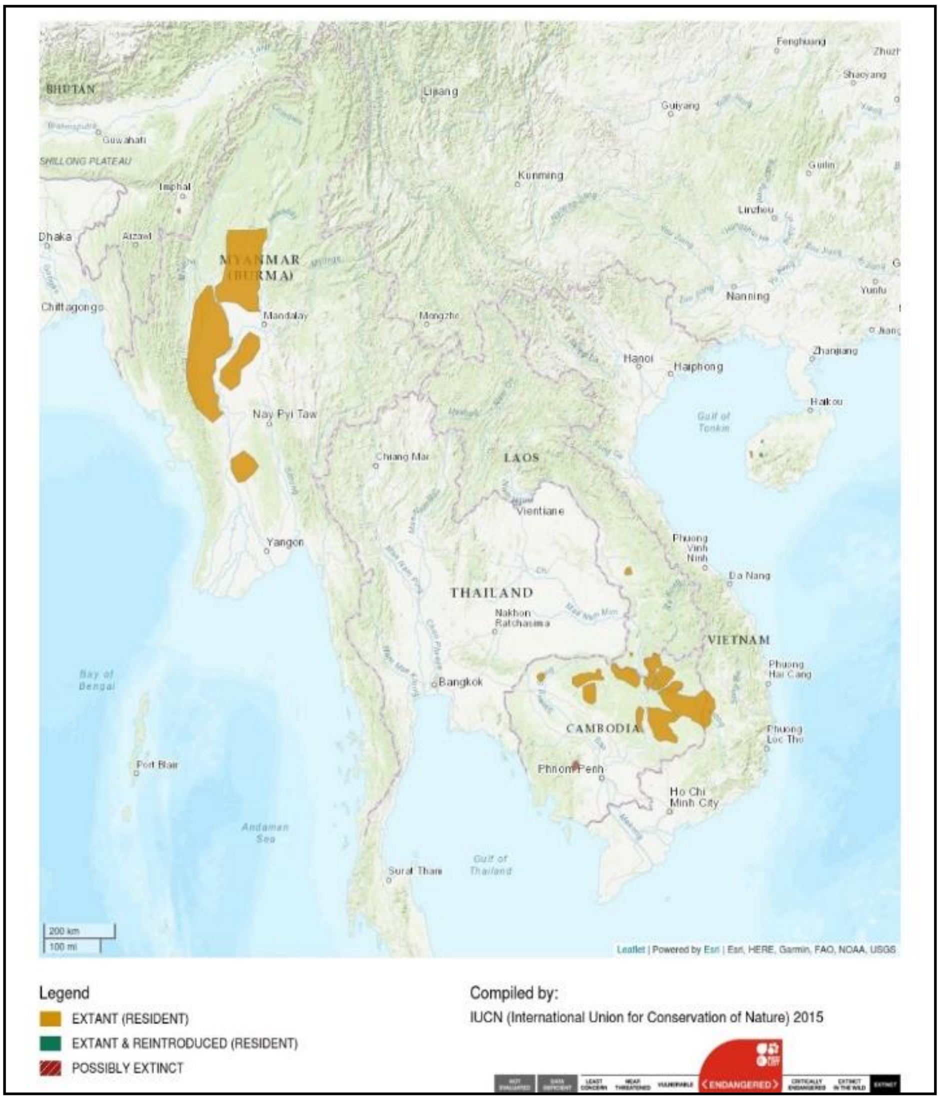

Figure 1. Geographical distribution of Eld's deer (*Rucervus eldii thamin*) (Source - IUCN Redlist, 2015)

Table 1. Taxonomic position of *Rucervus eldii thamin* (Eld's deer) (Gray *et al*., 2015)

Kingdom	*Animalia*
Phylum	Chordata
Class	Mammalia
Order	Antiodactyla
Family	Cervidae
Genus	*Rucervus*
Species	*R. eldii*
Subspecies	*R. eldii Thamin*
Common name	Burmese Brow Antlered deer or Eld's deer or Thamin

Table 2. Morphology or Physical measurement ranges of Eld's deer (Source: Wall and Hartley, 2017)

Head-Body Length	1.5 - 1.8 m
Shoulder height	114 cm
Antler Length	99 cm
Tail length	20 – 30 cm
Weight	Up to 150 kg
Mating Season	From Mid of February to May
Pregnant Period	220-235 days
Birthing Season	During October and December
Birth Rate	Individual born per annum
New Antler	August, September
Mating Potential	2 years old male deer, more than 456 days old female deer

Figure 2. Eld's deer (*Rucervus eldii Thamin*) Male and Female (Source: Field Photographs)

Both male and female reach sexual maturity at approximately 1.5-2.0 years of age and females remain fertile for 12-14 years (Wemmer and Grodinsky, 1988). Life expectancy of wild Eld's deer is 5.29 ± 3.57 years (Nie *et al*., 2011) in comparison to 5.07 ± 1.88 years in European zoos. There is no significant difference recorded in lifespan of wild males and females. Captive animals can live much longer than the average life expectancy however; one female recorded in the Endangered Species Programme (EEP) was over 18 years old (Wall and Hartley, 2017).

2. Objectives

The main objectives of the study are as followed;

- To generate the habitat suitability map of the Eld's deer in Chatthin wildlife sanctuary.
- To identify key variables associated with distribution of Eld's deer

3. Materials and Methods

3.1. Study Area

The study was carried in Chatthin Wildlife Sanctuary, Myanmar. The sanctuary was officially designated with the Notification No. 177 dated June 19, 1941, issued by Ministry of Agriculture and Forestry under the Wildlife Protection Act, 1936 and located in the Sagaing Region and lies between latitude 23° 30′ to 23° 42′ North and longitude 95° 24′ to 95° 40′ East.

The sanctuary covered a total area of 64,264.42 acres of two townships; Kanbalu and Kawlin. The dominant forest species in the study area is *Dipterocarpus tuberculatus*, locally known as "Indaing", with characteristics of slow growth, hardwood, and large leaves.

Figure 3. Location map of study area

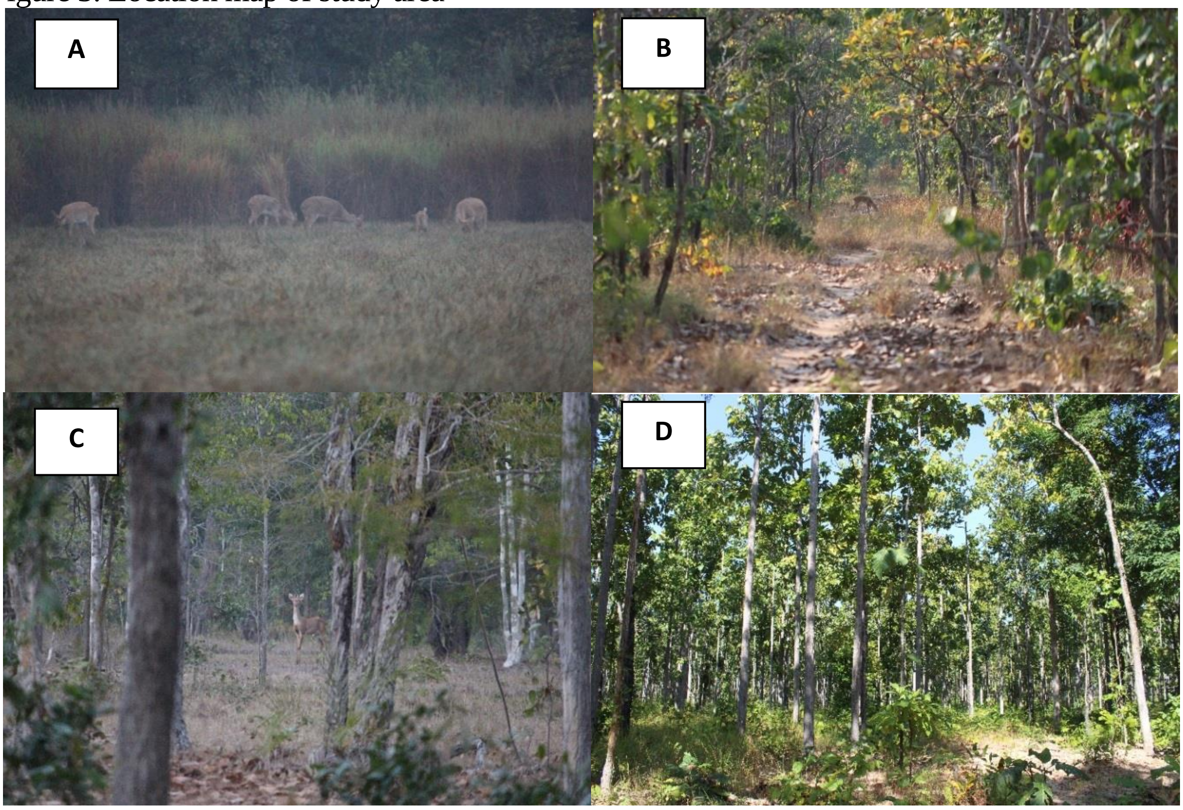

Figure 4. Eld's deer and its habitat in Chatthin Wildlife Sanctuary

3.2. Field Data Collection

Species occurrence location was collected during field (November 2019 to February 2020). A total of 113 (including direct and indirect sighting) occurrence locations of Eld's deer within the 22 permanant line-transacts were collected. SRTM Digital Elevation Model with spatial resolution 30 m was downloaded from http://earthexplorer.usgs.gov to generate the topographical layers (slope, aspect, elevation). Bioclimatic variables were downloaded from http://www.worldclim.org database (Version 1.4). These variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables for characterizing a species range. These are often used in species distribution modelling and related ecological modelling techniques. Both Mean Actual Evapo-Transpiration (ET) and Global-Aridity index are modeled using the data available from the WorldClim Global Climate Data as input parameters. The digital boundary shape file of the study area i.e. Chatthin wildlife sanctuary was obtained from Forest Department, Ministry of Natural Resources and Environmental Conservation, Myanmar. To compose the map of the study area and analyzing the data collected from the field a set of software's were used which are as follows:

- MaxEnt Version 3.3.3k (Species distribution modeling)
- ArcGIS Version 10.5 (GIS analysis)
- Erdas IMAGINE 2014 (image processing)
- DIVA GIS 7.5 (auto-correlation test)
- ENM Tools Version 1.3 (Multi-collinearity test)
- Google Earth Pro (data analysis)
- Microsoft Office (thesis writing)

Figure 5. Photographs of field survey and data collection in CWS

3.3. Methodology

DIVA GIS was used for the auto-correlation test of the species occurrence locations, and then converted the species occurrence location into .csv file for compatible with MaxEnt. 29 predictor variables were generated using ArcGIS from 19 bioclim variables, 3 topographical variables calculated from SRTM DEM, 3 anthropogenic variables obtained from field survey and 2 water sources variables. ENM Tool These predictor variables were used to test multi-collinearity using ENM Tool. The predictor variables were converted in ASCII files using ArcGIS in order to compatible with MaxEnt. The species distribution model was built using the MaxEnt.

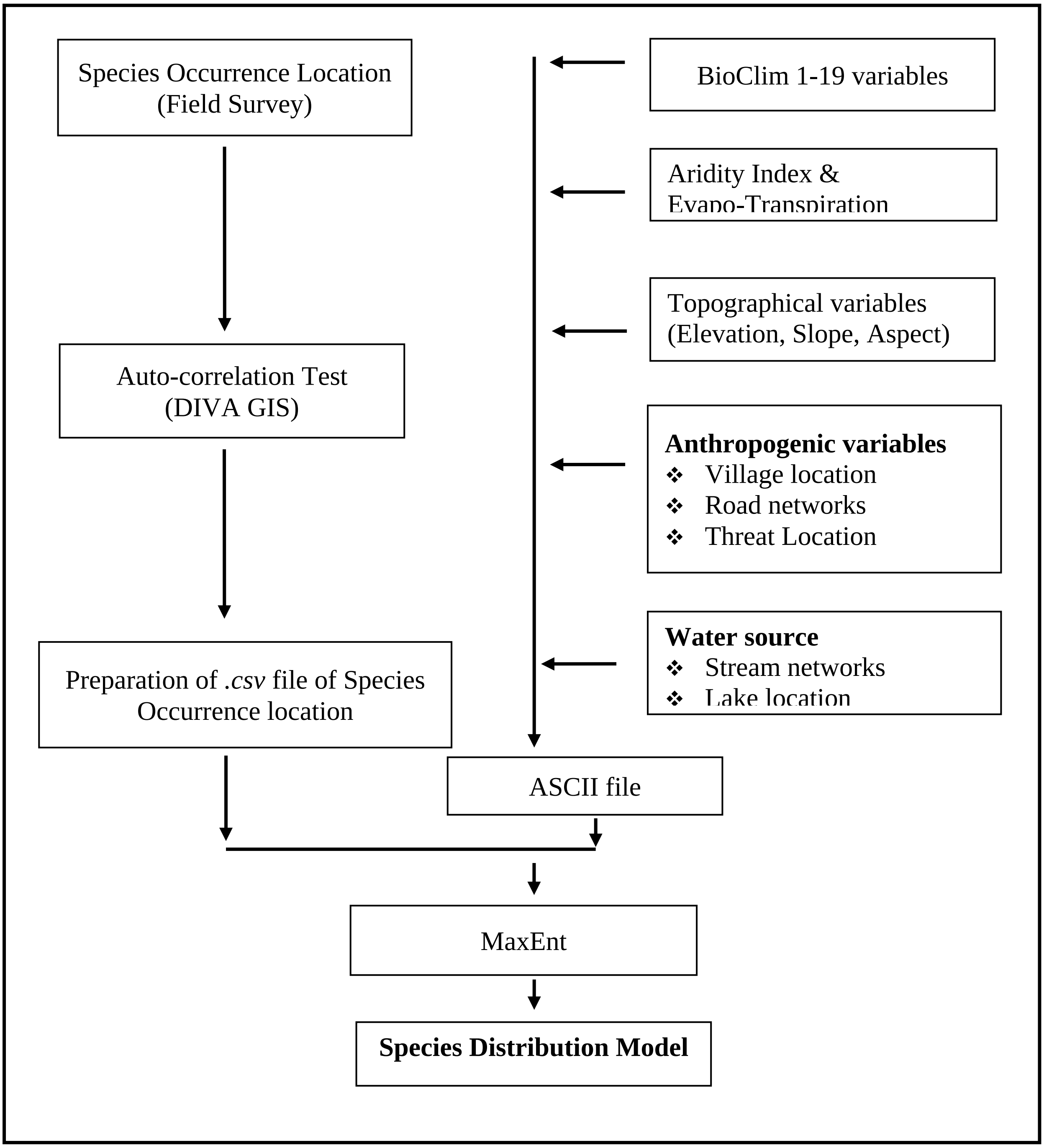

Figure 6. Flowchart of General Methodology

4. Results

In this study, 29 variables (elevation, Aspect, and slope) were gathered to generate the distribution model for Eld's deer. However, only 21 variables were used for habitat suitability model preparation and further analysis after multi-collinearity test in ENM tool. These predictor variables showed r value greater than 0.8 (r>0.8). As a result of this model with 100 replicates, 5000 iterations with 25% test data were found to be the best model with the training AUC 0.923, the value of standard deviation was 0.017. The model accuracy was measured using the AUC value which was 0.923 and shows that the model has moderate to excellent predictive ability in discriminating the highly and least susceptible areas.

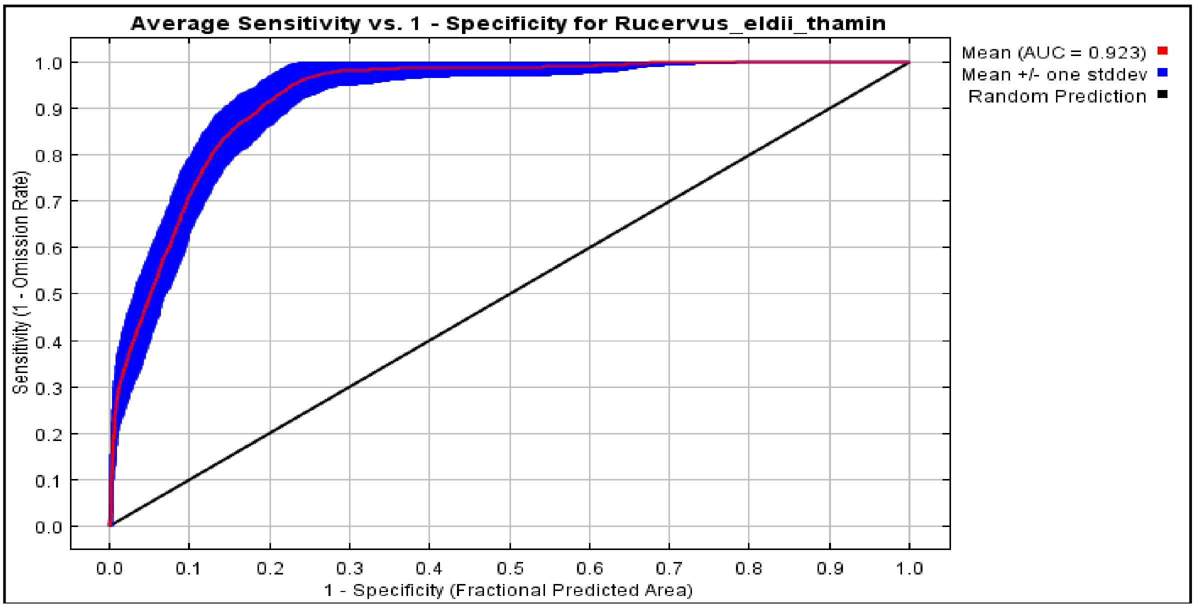

Figure 7. Average Sensitivity v/s Specificity for *Rucervus eldii thamin*

4.1. Predicted habitat suitability Map of Eld's deer

The habitat suitability map of the species was generated through this model. The map was classified into four classes i.e. highly susceptible (>0.6), moderately susceptible (0.6-0.4), marginally susceptible (0.4-0.2) and least susceptible (<0.2) based on the Yang *et al.* (2013). Out of total 26006.88 ha, 305.23 ha area is predicted to be highly suitable for Eld's, followed by moderately and marginally suitable i.e. 1264.89 ha and 2220.29 ha respectively, making it fairly possible for the species to spread to other areas easily with similar environmental conditions. Whereas, 22216.47 ha area was predicted as least suitable for Eld's deer. The area wise class percentage analysis for Eld's deer (*Rucervus eldii thamin)* shows that highly suitable area comprised of 1.0%, moderately suitable 5.0%, marginally suitable 9.0%, and least suitable 85.0%. The model predicted that the highly suitable habitat for *Rucervus eldii thamin* is located in the south-eastern part and central part of CWS.

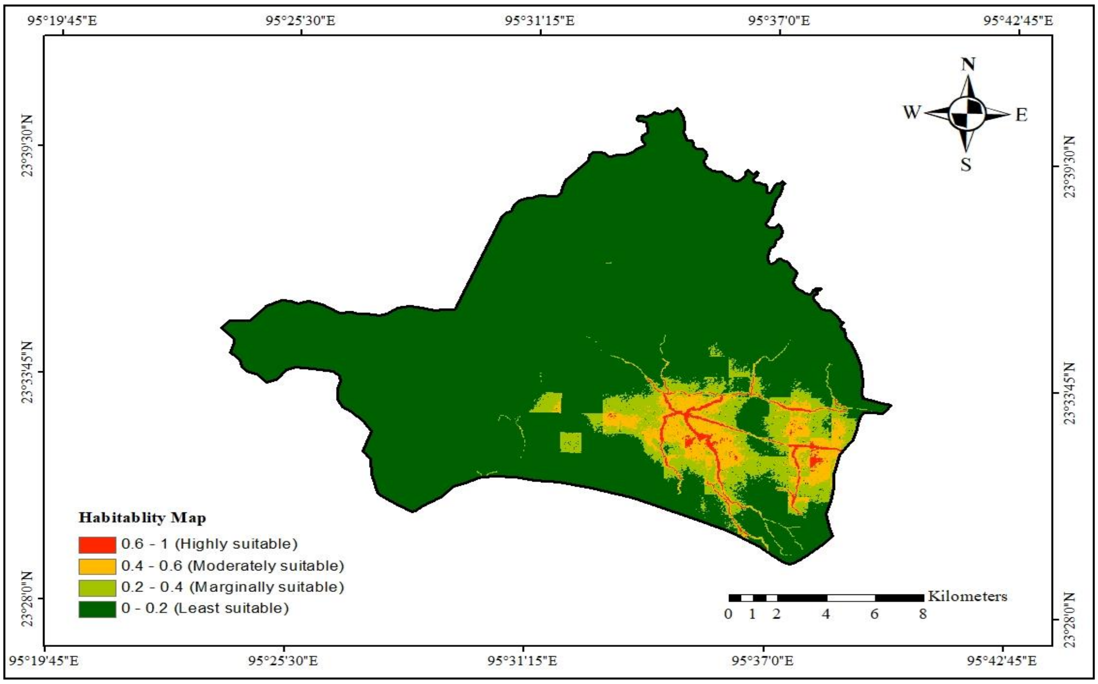

Figure 8. Habitat suitability map of *Rucervus eldii thamin*

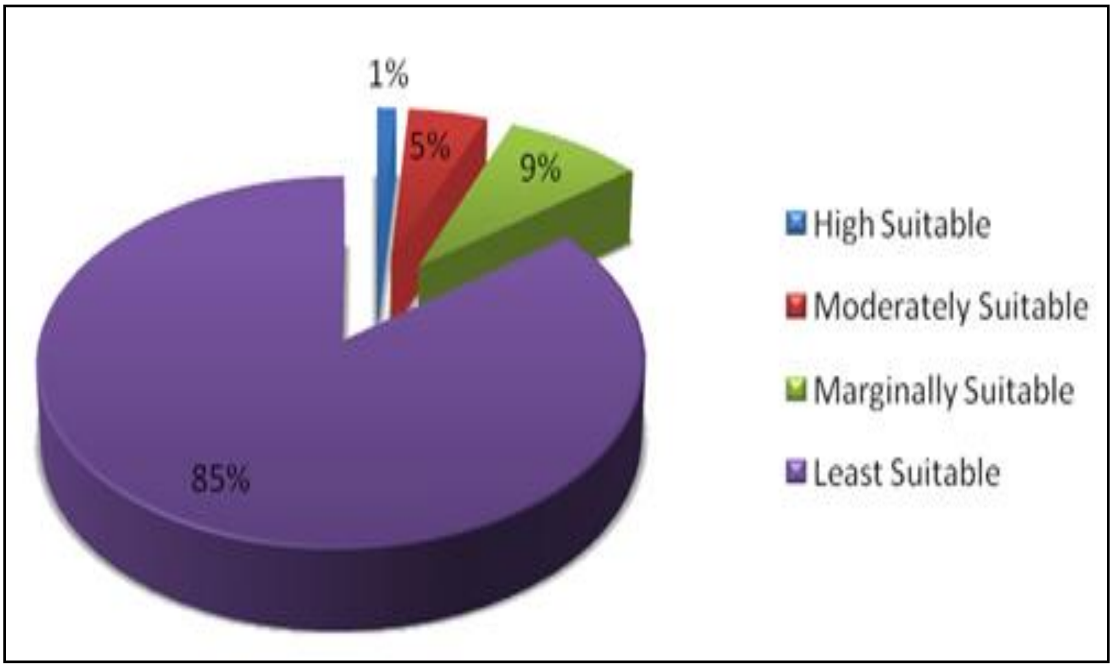

Figure 9. Percentage wise habitat suitability area of Eld's deer

During field survey, the species occurred patchy whereas water and food sources are available without threatened from hunting especially in the middle and eastern parts of the CWS. Females were occurred grouping with one or two males and each group has 2-7 individuals.

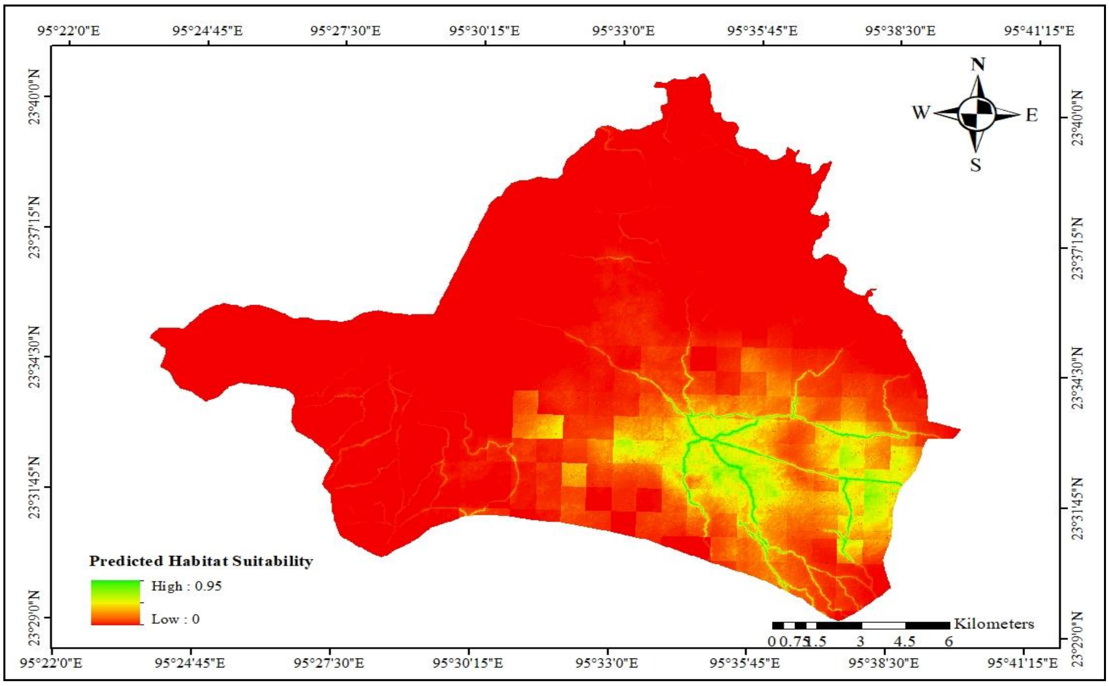

Figure 10. Predicted Eld's deer occurrence map from low to high probability values

The predicted probability map (figure 10) shows that the areas having probability value near to 1 is highly suitable whereas the areas having probability value near to 0 are least suitable for Eld's deer.

To identify the environmental variables having high influence on the distribution of Eld's deer, 19 bioclimatic variables were included in the model (Hijmans *et al.*, 2005) along with AI, ET, three topographical variables (elevation, slope and aspect), three anthropogenic variables (villages location, road network and threats) and two water sources lake and stream network. To reduce multi-collinearity among these 29 variables, highly correlated variables (r $\geq$ 0.8 Pearson correlation coefficient) were dropped from further analysis. This reduction of predictor variables resulted in the inclusion of only 21 variables for the model. The higher the contribution, the more impact that particular variable has on predicting the distribution of species.

Table 3. Percentage of contribution by environmental variables

Variable	**Percent contribution**	**Permutation importance**
Precipitation of Warmest Quarter	19.3	23.5
Distance from Road	18.5	9.9
Distance from Lake	15.7	5.5
Mean Diurnal Range	14.9	4
Distance from Stream	9.1	24.4
Annual Temperature Range	6	1.4
Distance from Lake	4	9.4
Mean Actual Evapo-transpiration	3.2	0.9
Precipitation of Coldest Quarter	2.8	1.8
Temperature Seasonality	2.3	3.8
Distance from Lake	1.3	2.6
Aspect	1.1	1.8

Mean Temperature of Coldest Quarter	0.7	5
Elevation	0.4	1.7
Slope	0.1	0.2
Min Temperature of Coldest Month	0.1	1.2
Precipitation Seasonality	0.1	0.2
Mean Temperature of Wettest Quarter	0.1	1.3
Isothermality	0.1	1
Mean Temperature of Warmest Quarter	0	0.1
Mean Temperature of Driest Quarter	0	0.2

The analysis result shows that the precipitation of warmest quarter (bio18), distance from road (L_DR), Distance from Lake(L_DL), mean diurnal range (bio 2) and Distance from Stream (L_DS) are the major contributors in predicting the distribution of *Rucervus eldii thamin* with 19.3%, 18.5%, 15.7%, 14.9% and 9.1% respectively. Based on permutation importance, distance from stream (L_DS), the precipitation of warmest quarter(bio18), distance from road (L_DR), distance from villages (L_DV) and distance from lake (L_DL) are the highest contributors with 24.4%, 23.5%, 9.9%,9.4% and 5.5% respectively. This shows that these factors are vital for the distribution and suitable habitat of *Rucervus eldii thamin* in natural conditions of CWS.

4.2. Response Curve

The response curves show that how each of the environmental variables affects MaxEnt predictions. These curves illustrate how the logistic prediction changes as each environmental variable is varied, while keeping all other environmental variables at their average sample value. The curves thus represent the marginal effect of changing exactly one variable. The response curves obtained from the MaxEnt Model explains the optimum conditions of each variable responsible for the spread of the species. The following graphs show the effect of individual environmental layers on the distribution of *Rucervus eldii thamin*:

1. **Response of *Rucervus eldii thamin* to Precipitation of Warmest Quarter (Bio18)**

Based on the analysis, the value of precipitation of warmest quarter varies from 624 mm to 671 mm as shown in figure 11 (a). The model result shows that the precipitation of warmest quarter (bio18) plays a significant role in the distribution of *Rucervus eldii thamin* i.e. 19.3%. The given response curve shows that the areas having a low value of precipitation of warmest quarter i.e., below 660mm are having a high probability of the species occurrence whereas the areas having a high value of the precipitation of warmest quarter i.e., above 660 mm are having a low probability of species occurrence. This resembles the ground situation as shown in figure 18 (b). During the field visit, it was observed that the maximum occurrence of the species is in the area having a low value of the precipitation of warmest quarter and the areas having a high value of the precipitation of warmest quarter are not suitable for *Rucervus eldii thamin.*

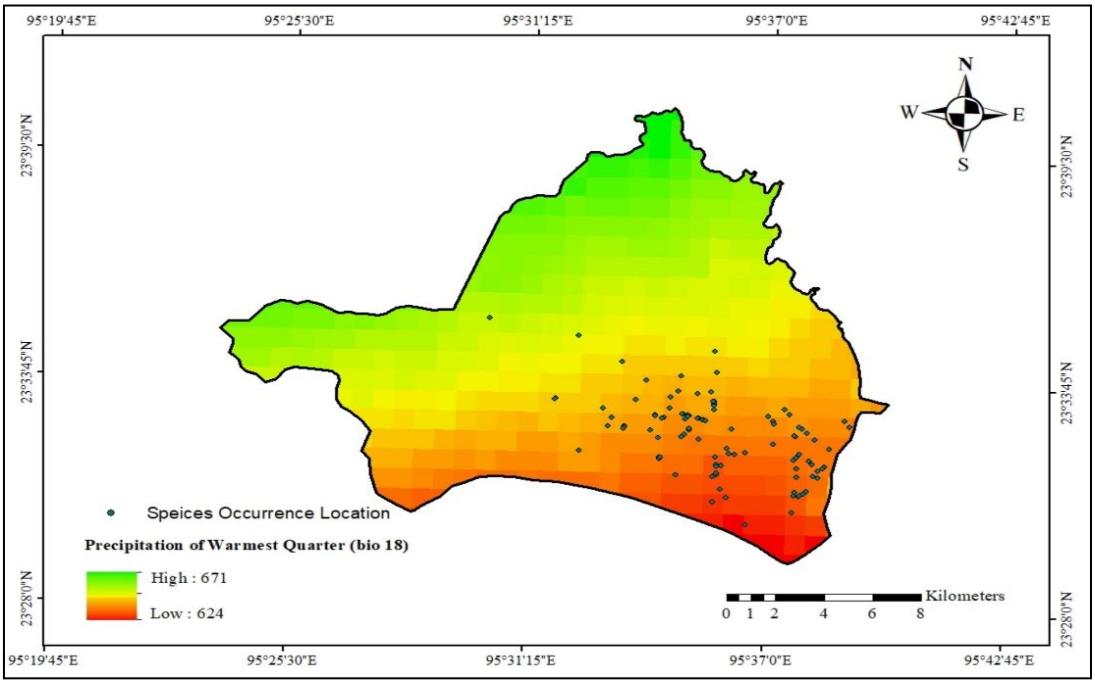

Figure 11(a). Rucervus eldii thamin presence locations overlaid on the precipitation range of warmest quarter (bio18)

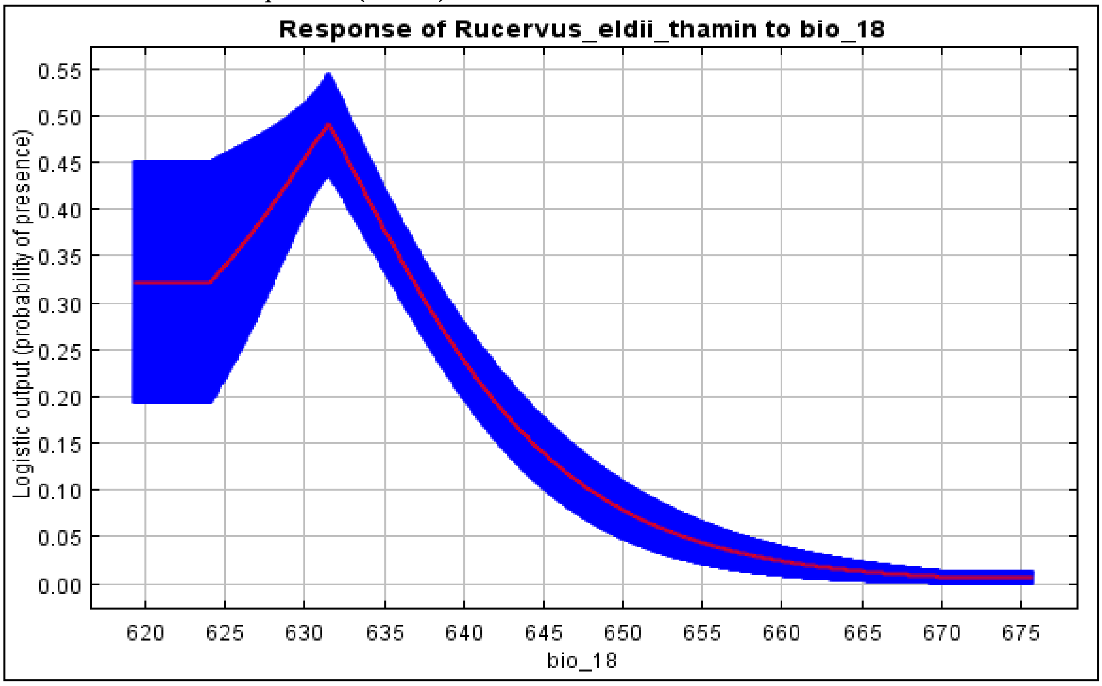

Figure 11(b): Response of *Rucervus eldii thamin* with bio18

2. Response of Eld's deer to Distance from Road (L_DR)

The model result shows that the distance from road (L_DR) plays a significant role in the distribution of *Rucervus eldii thamin* i.e. 18.5%. Based on the analysis, the distance ranges from the road network for the probability of species occurrence varies from 0 to 3233.47 m as shown in figure 12(a). The response curve shows that the areas having a low value of distance from the road network i.e., below 300m are having a high probability of the species occurrence whereas the areas having a high value of the distance from the road network i.e., above 300 m are having a low probability of species occurrence, but the probability of species occurrence is increased above 1000m.This resembles the ground situation as shown in figure 12(b). During the field visit, it was observed that the probability of the species occurrence is highest in the areas having a high value of distance from the road network and sometime on the roads.

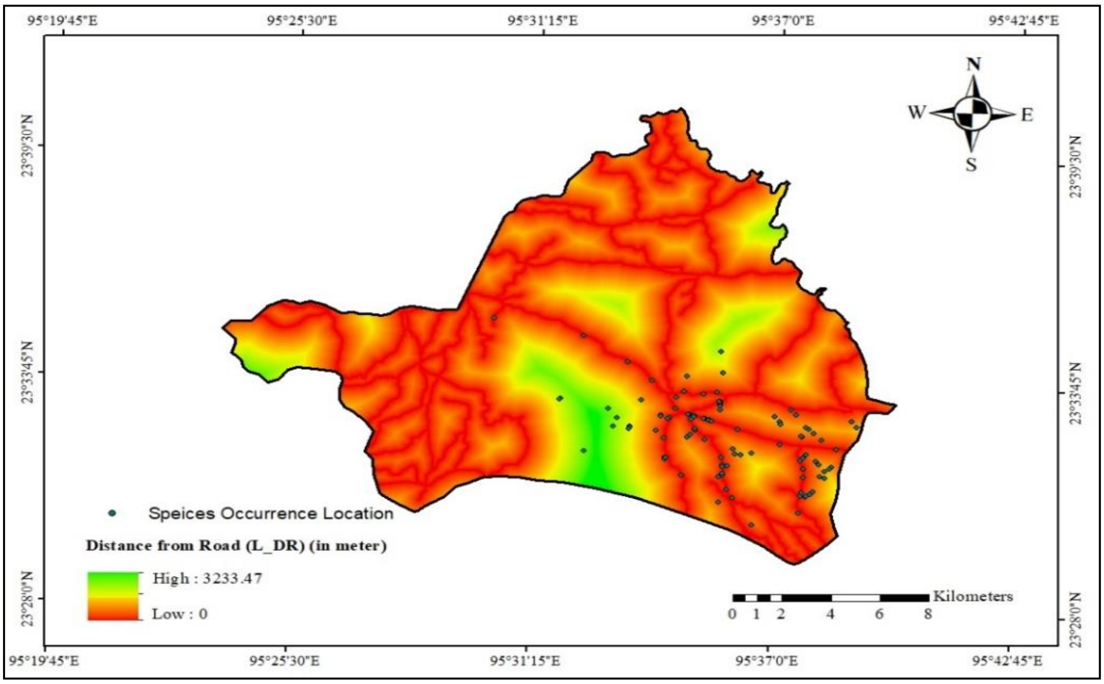

Figure 12(a). *Rucervus eldii thamin* presence locations overlaid on the road network

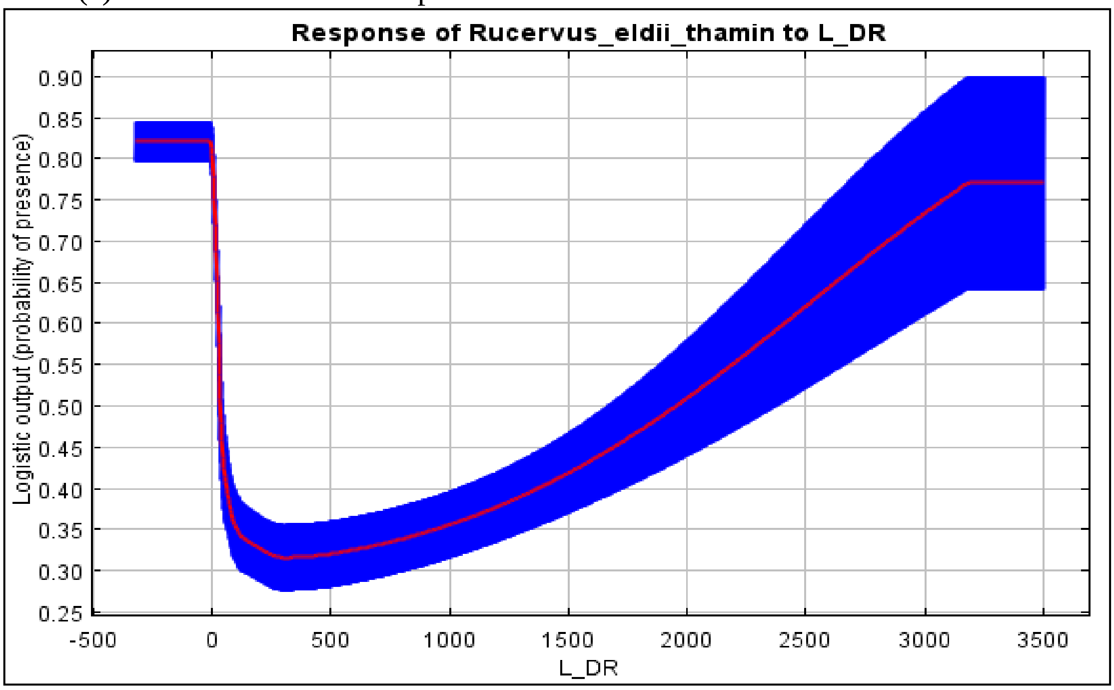

Figure 12(b). Response curve of *Rucervus eldii thamin* to road network

3. Response of Eld's deer to the distance from the lake (L_DL)

Based on the analysis, the distance ranges from lake (water source) varies from 0 to 8386.97m as shown in figure 13(a). The analysis result shows that the distance from the lake also plays a significant contribution in species occurrence i.e., 15.7%. The response curve of *Rucervus eldii thamin* with the distance from the lake shows that the areas having high value of distance from the lake i.e., above 3000m are having high probability of species occurrence whereas the areas having low value of the distance from the lake i.e., below 3000m are having low probability of species occurrence (Figure 13(b)). This resembles the ground situation as shown in the figure. During the field visit, it was observed that the probability of the species occurrence is in the areas having a high value of the distance from the lake, but the streams were more preferred by the species than the lake.

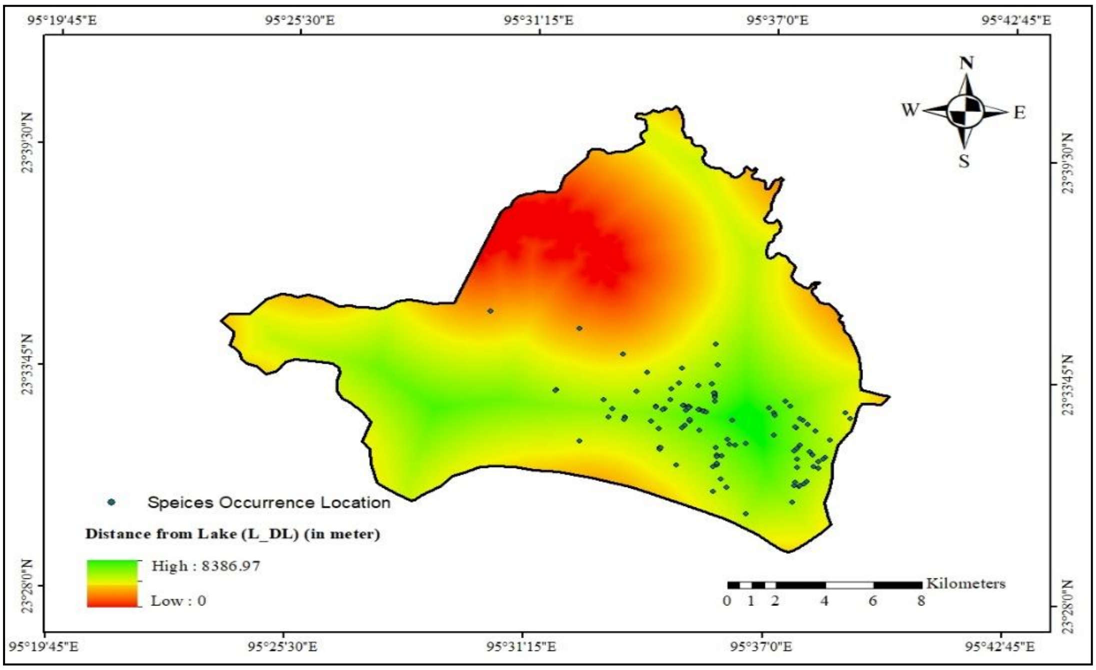

Figure 13(a). *Rucervus eldii thamin* presence locations overlaid on the water source (lake)

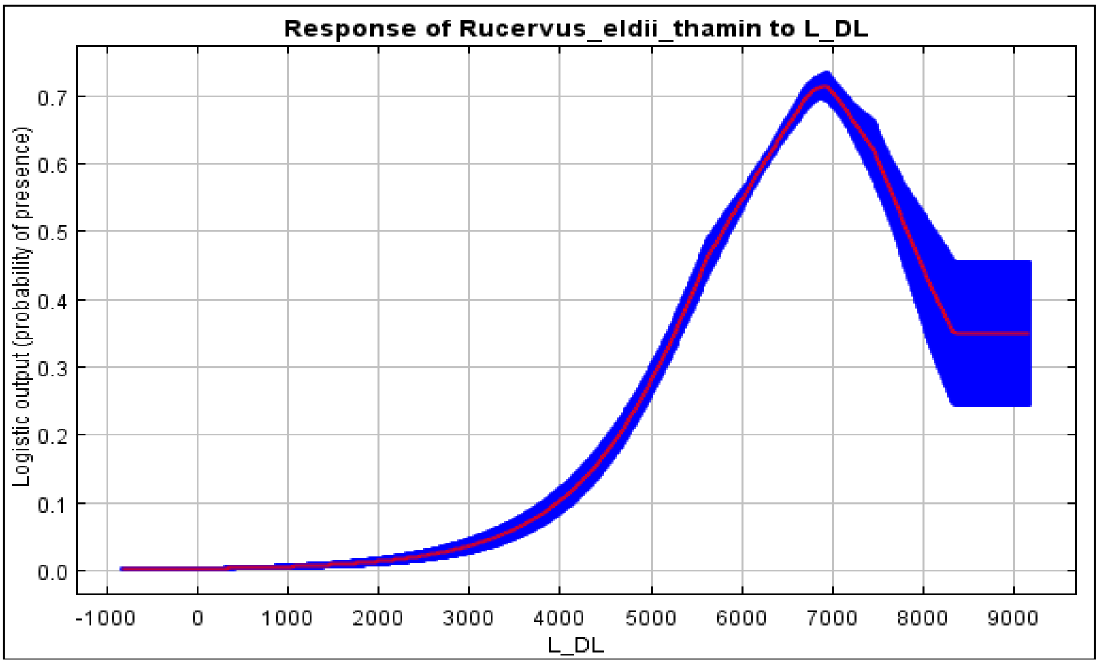

Figure 13(b). Response of *Rucervus eldii thamin* with L_DL (Distance from Lake)

4. Response of Eld's deer to BIO2 (Annual Mean Diurnal Range)

Based on the analysis, the value of the mean diurnal range varies from 11.2 to 11.3 °C as shown in figure 14(a). The analysis result shows that the mean diurnal range plays a significant contribution in species occurrence i.e., 14.9%. The response curve of Eld's deer with mean diurnal range shows the positive relationship that the areas having high value of mean diurnal range i.e., above 11.2°C are having high probability of species occurrence (figure 14(b)). This resembles the ground situation as shown in the figure. During the field visit, it was observed that the high probability of species occurrence is in the areas having a high value of mean diurnal range.

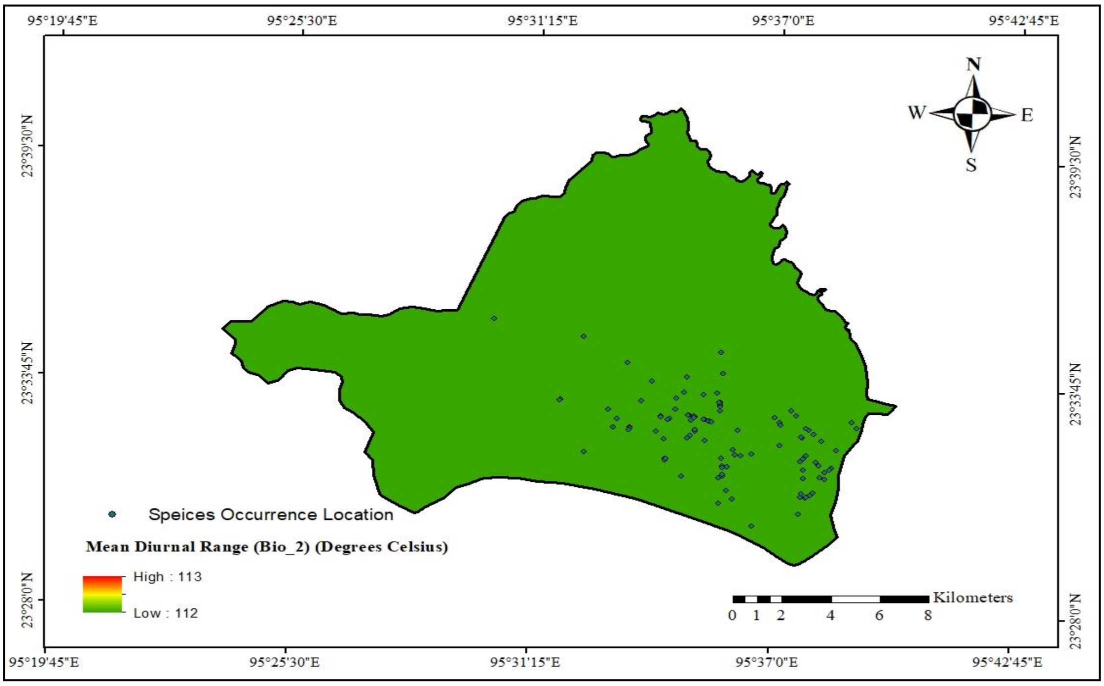

Figure 14(a). *Rucervus eldii thamin* presence locations overlaid on mean diurnal range (bio2) map

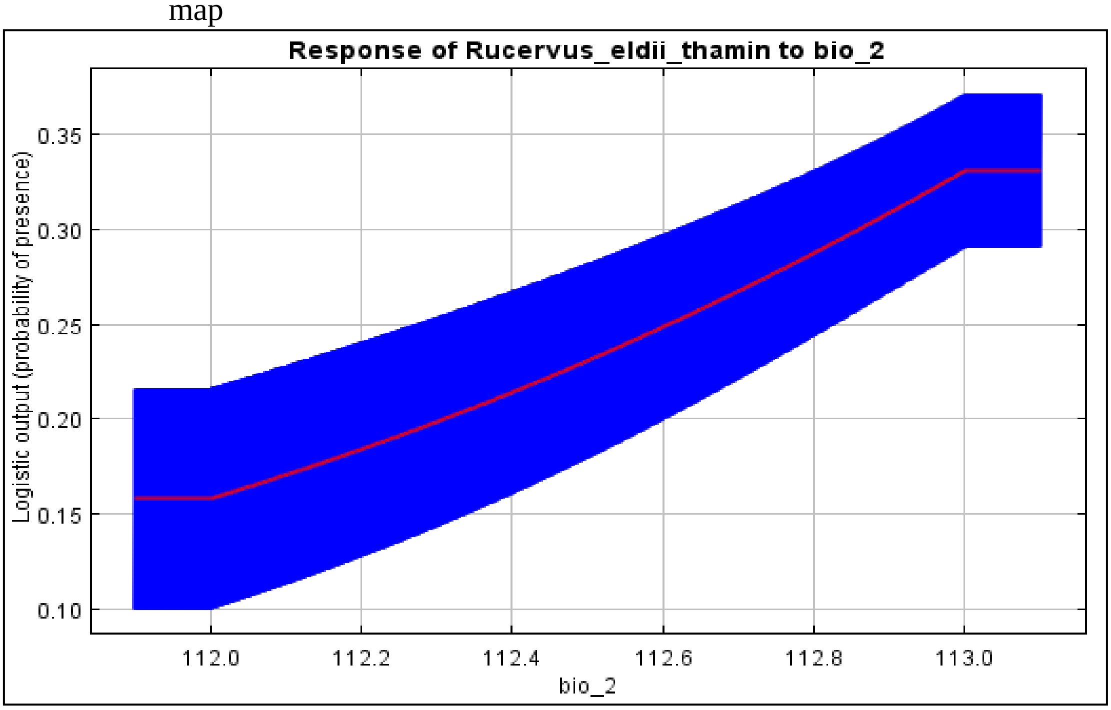

Figure 14(b). Response of *Rucervus eldii thamin* with bio2 (annual mean diurnal range)

5. Response of Eld's deer with L_DS (Distance from Streams)

Based on the analysis, the distance ranges from stream (water source) varies from 0 to 5983.85m as shown in figure 15(a). The analysis result show that the distance from the stream plays a significant contribution in species occurrence i.e., 9.1%. The response curve of *Rucervus eldii thamin* with the distance from the stream shows that the areas having high value of distance from the lake i.e., above 3000m are having a low probability of species occurrence whereas the areas having low value of the distance from the lake i.e., below 3000m are having a high probability of species occurrence (Figure 15(b)). This resembles the ground situation as shown in the figure. During the field visit, it was observed that the probability of the species occurrence is high in the areas having a low value of the distance from the stream, and the areas having a high value of distance from the stream are not suitable for *Rucervus eldii thamin*.

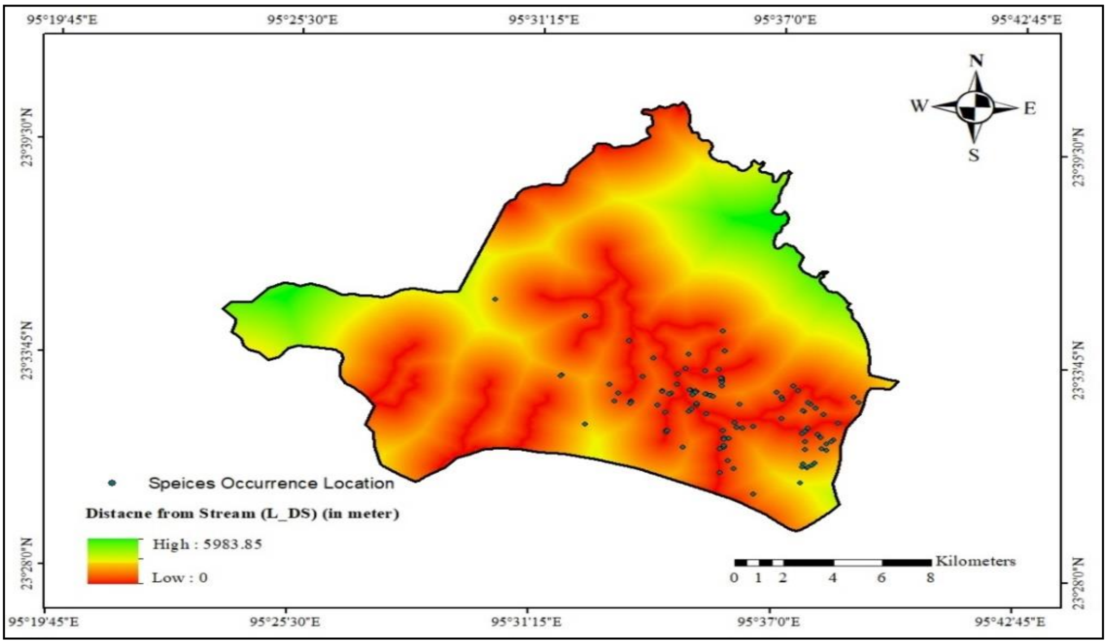

Figure 15(a). *Rucervus eldii thamin* presence locations overlaid on the stream network

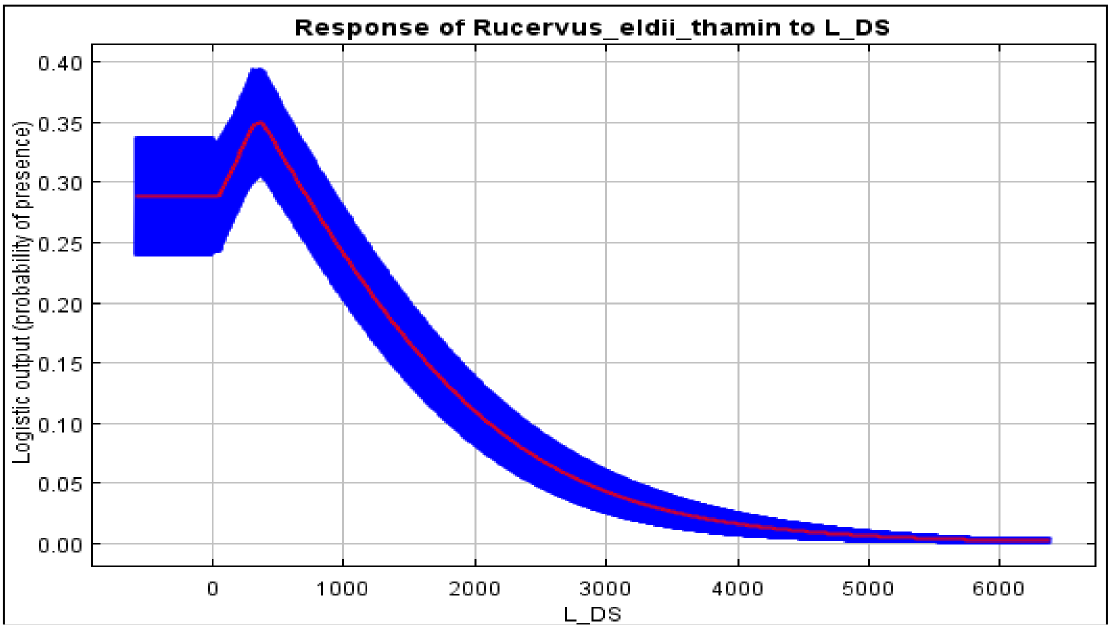

Figure 15(b). Response of *Rucervus eldii thamin* with L_DS (stream network)

6. Response of Eld's deer with Bio7 (Annual Temperature Range)

Based on the analysis, the value of the Temperature Annual Range varies from 24.2 to 24.4 °C as shown in figure 16(a). The analysis result shows that the Temperature Annual Range plays a significant contribution in species occurrence i.e., 6.0%. The response curve of *Rucervus eldii thamin* with annual temperature Range shows that the areas having a low value of annual temperature range i.e., below 24.25°C are having a high probability of species occurrence whereas the areas having a high value of annual temperature range i.e., above 24.25°C are having a low probability of species occurrence. This resembles the ground situation as shown in figure 16(b). During the field visit, it was observed that the the probability of speices occurrence is high in the areas having a low value of annual temperature range and the areas which are having a high value of annual temperature range are not suitable for *Rucervus eldii thamin.*

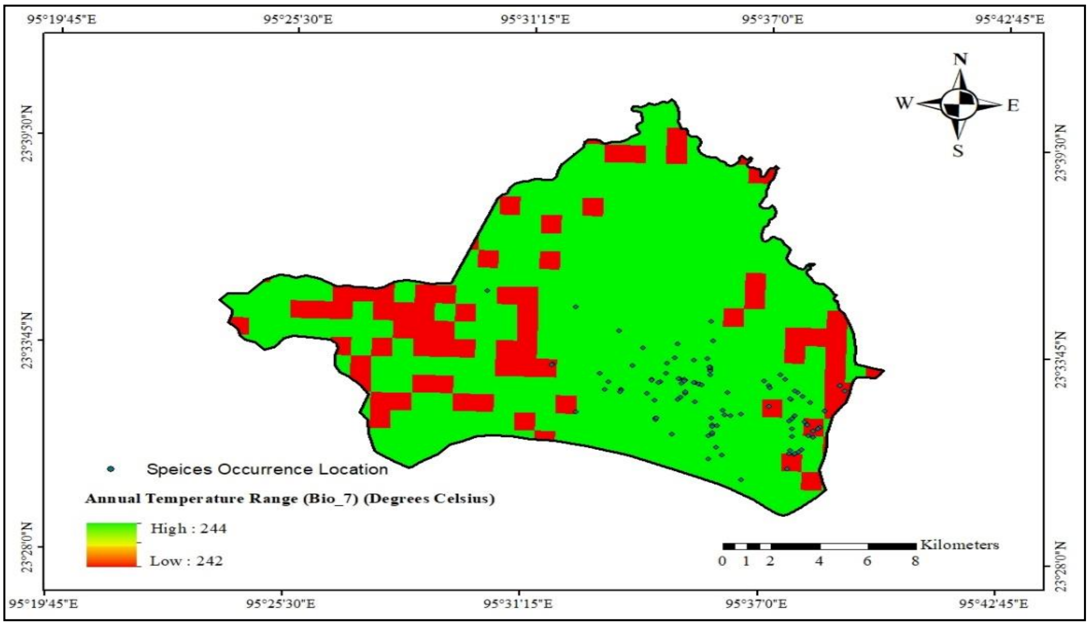

Figure 16(a). *Rucervus eldii thamin* presence locations overlaid on bio7 (annual temperature range)

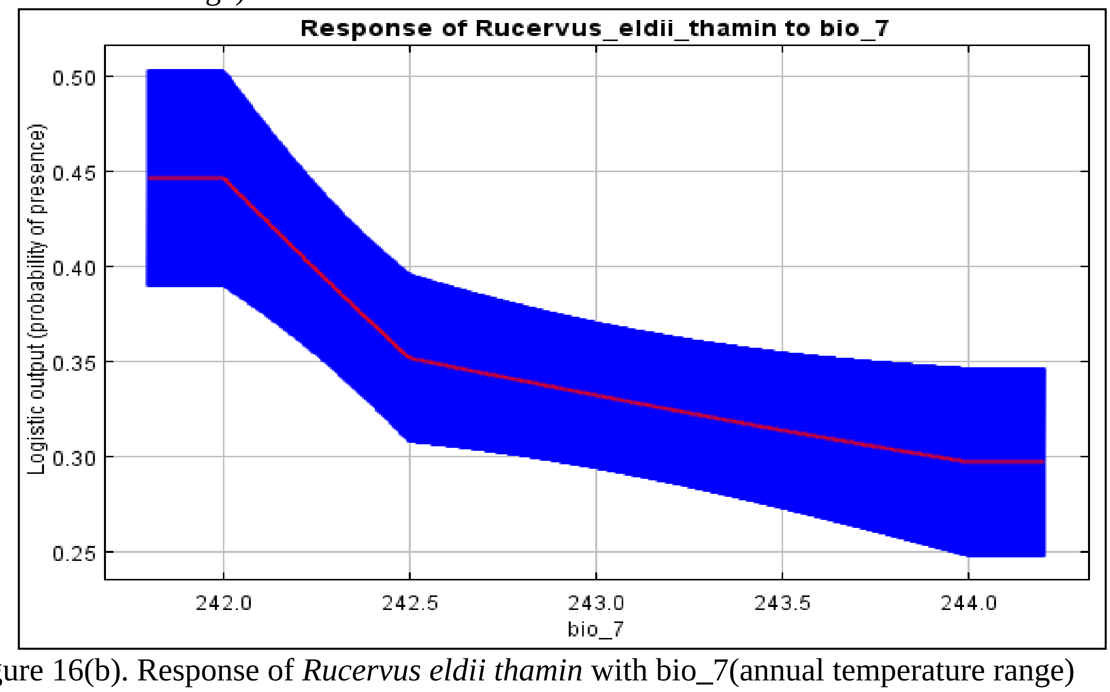

Figure 16(b). Response of *Rucervus eldii thamin* with bio_7(annual temperature range)

7. Response of Eld's deer to L_DV (Distance from Villages)

Based on the analysis, the distance ranges from villages varies from 0 to 8345.18m as shown in figure 17(a). The analysis result show that the distance from the stream plays a significant contribution in species occurrence i.e., 4.0%. The response curve of *Rucervus eldii thamin* with the distance from the villages shows that the areas having high value of distance from the lake i.e., above 1000m are having a high probability of species occurrence whereas the areas having low value of the distance from the village i.e., below 1000m are having a high probability of species occurrence (figure 17(b)). This resembles the ground situation as shown in the figure. During the field visit, it was observed that the probability of the species occurrence is high in the areas having a high value of the distance from the villages, and the areas having a low value of distance from the stream are not suitable for *Rucervus eldii thamin*.

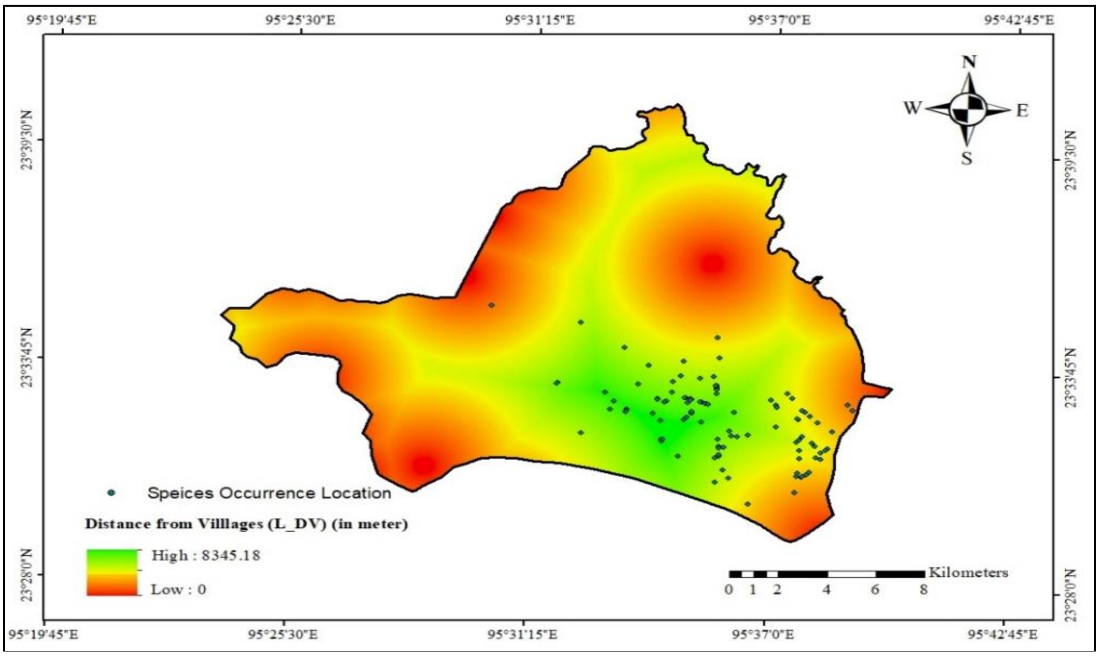

Figure 17(a). *Rucervus eldii thamin* presence locations overlaid on L_DV

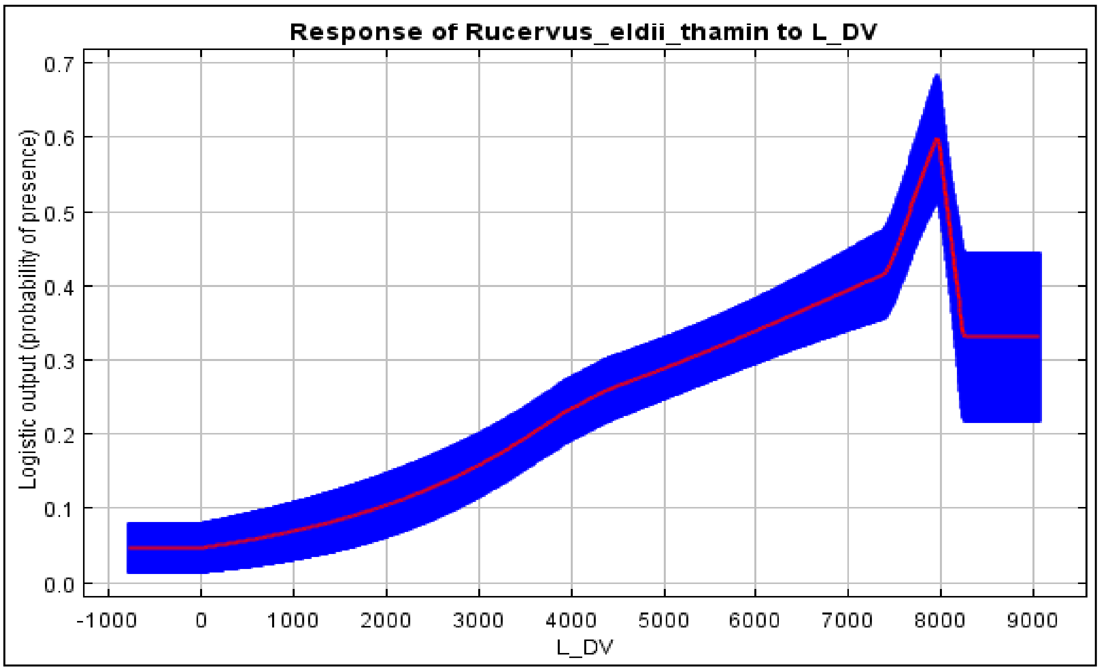

Figure 17(b). Response of *Rucervus eldii thamin* with L_DV

8. Response of Eld's deer to ET (Mean Actual Evapotranspiration)

The given map shows the range of mean actual evapo-transpiration value prevailing in the study area which ranges from 1601 to 1632 mm as shown in figure 18(a). It accounts for 3.2% variable contribution. The Evapotranspiration values shows the amount of evaporation and transpiration taking place from a given area in a given time. From the given map it can be inferred that high evapotranspiration values corresponds to areas with low temperatures thus rendering as favourable environment for the distribution of *Rucervus eldii thamin*. The given response curve also proves this negative interaction between the evapotranspiration values and the probability of species occurrence as it keeps increasing with decreasing values of mean evapotranspiration values below 1629mm (figure 18(b)). This resembles the ground situation as shown in the figures.

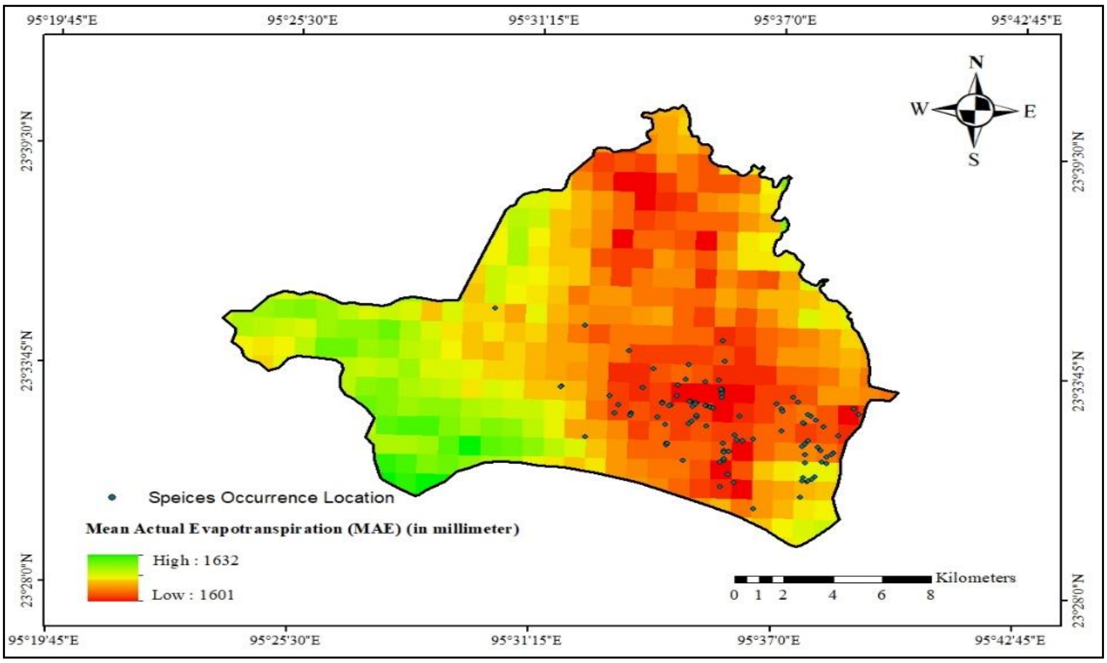

Figure 18(a). The actual evapo-transpiration range of the study area

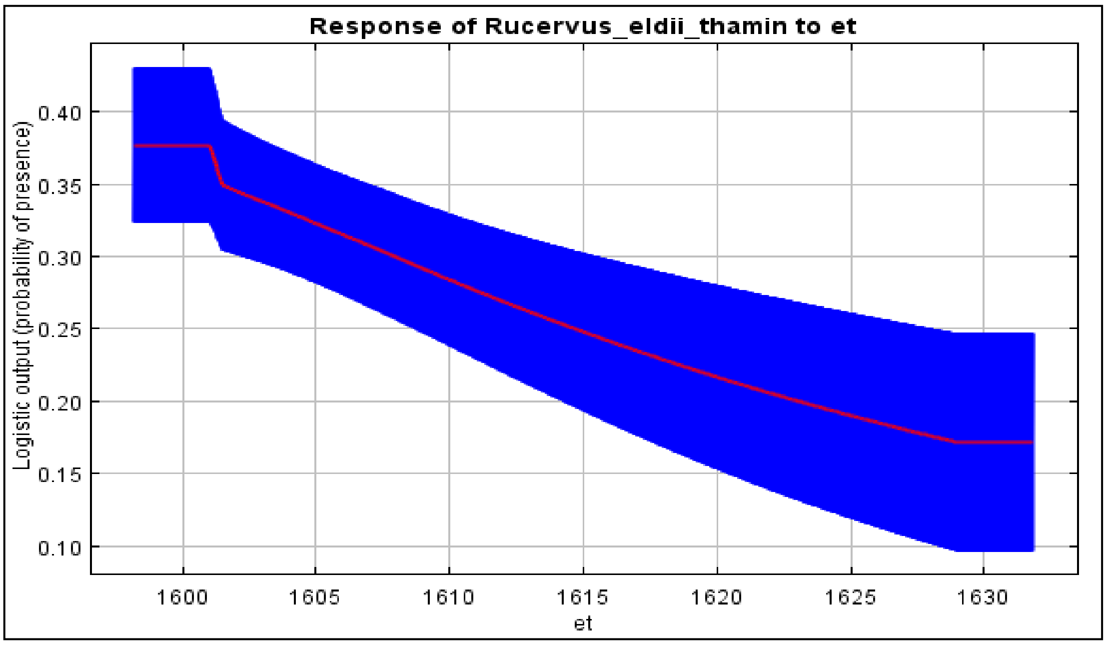

Figure 18(b). Response of *Rucervus eldii thamin* to ET (actual evapo-transpiration)

9. Response of Eld's deer to bio19 (Precipitation of Coldest Quarter)

The given map of the study area shows the range of variable bio19, i.e., the precipitation of coldest quarter, which varies from 19 to 23mm as shown in figure 19(a). The variable bio 19 shows the variable importance of 2.8%. The response curve shows that as the value of bio19 is increasing beyond 19.5mm the probability of the species occurrence is also increasing but only up to 21.5mm after which it falls drastically showing negative response with the value of the precipitation of coldest quarter. Thus, it can be said that the areas having the value of between 19.5 to 21.5mm the precipitation of coldest quarter, are suitable for *Rucervus eldii thamin* (figure 19(b)). This resembles the ground situation as shown in the figures.

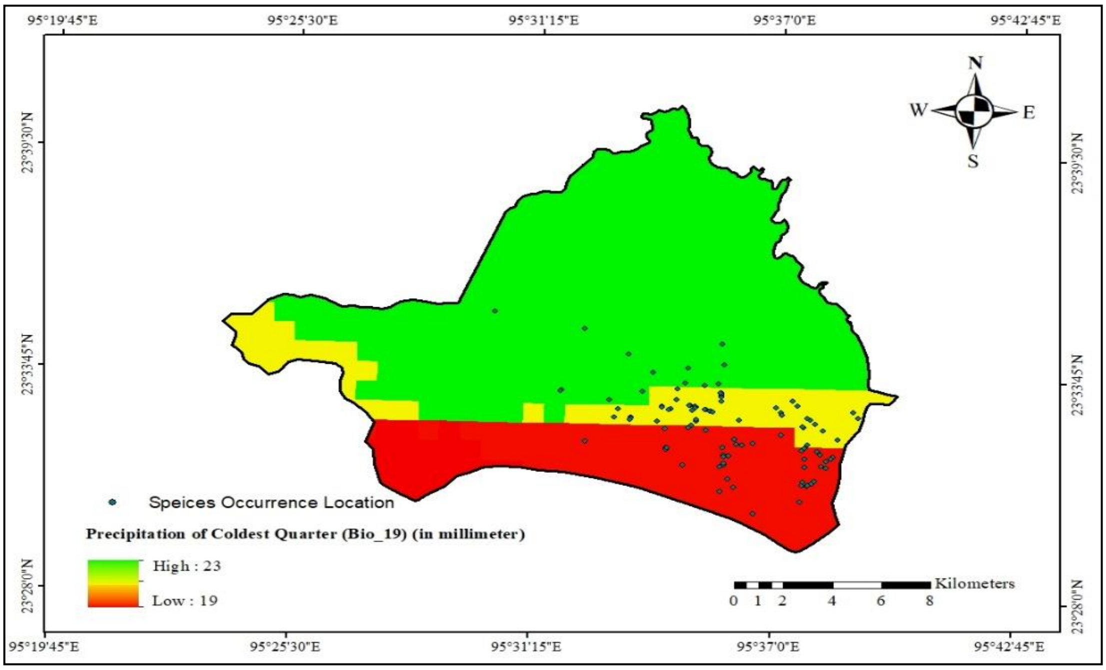

Figure 19(a). *Rucervus eldii thamin* presence locations overlaid on bio19 (precipitation of coldest quarter)

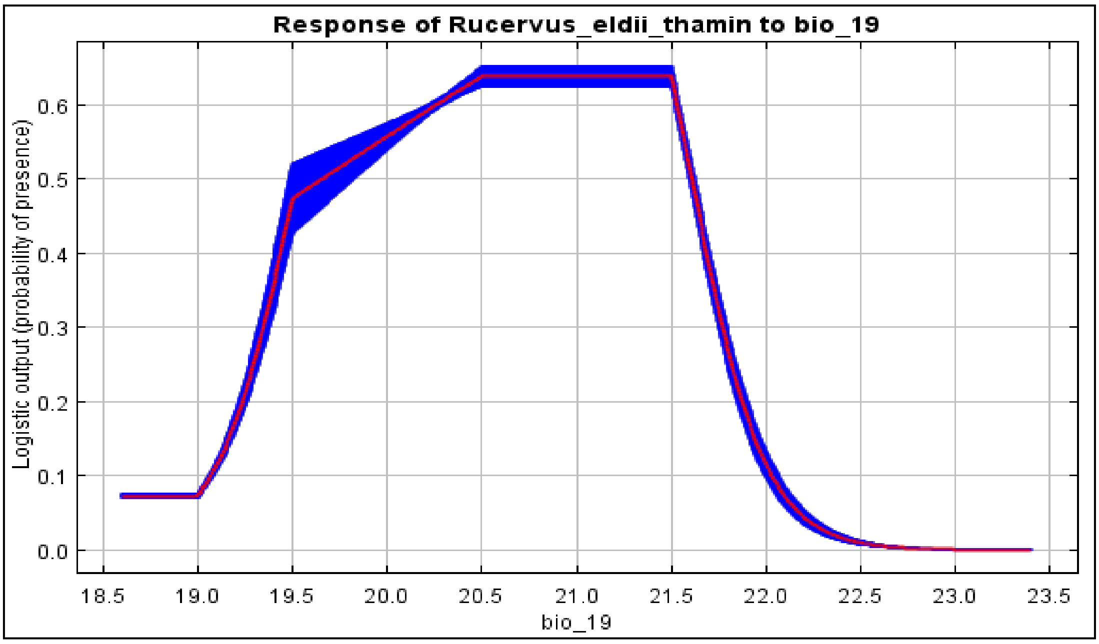

Figure 19(b). Response of *Rucervus eldii thamin* with the precipitation of coldest quarter

10. Response of Eld's deer to Bio4 (Temperature Seasonality)

Temperature seasonality is a measure of temperature change over the course of the year. Based on the analysis, it is ranging from 37.82 to 38.84℃ in the given study area (figure 20(a)). As per the response of *Rucervus eldii thamin* to the temperature seasonality, the probability of species occurrence is high in the areas having a low value of the temperature seasonality i.e., below 37.98°C whereas the areas having a high value of the distance from the road network i.e., above 37.98°C are having a low probability of species occurrence, but the probability of species occurrence is increased above 1000m again. This resembles the ground situation as shown in figure 20(b).

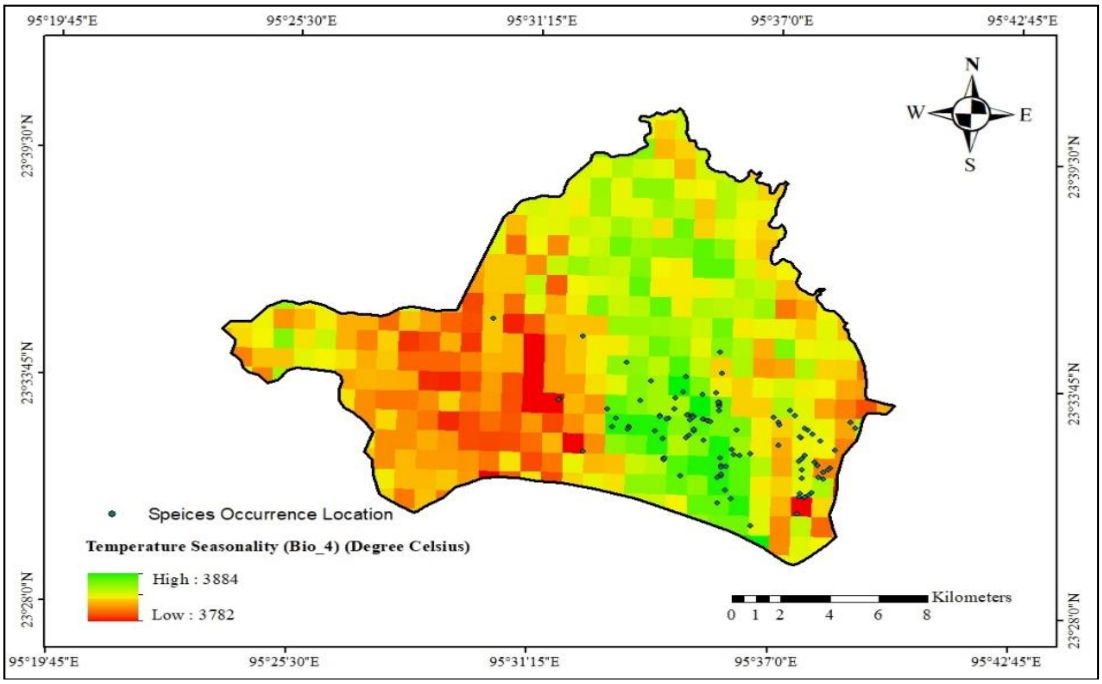

Figure 20(a). The map showing the temperature seasonality range of the study area

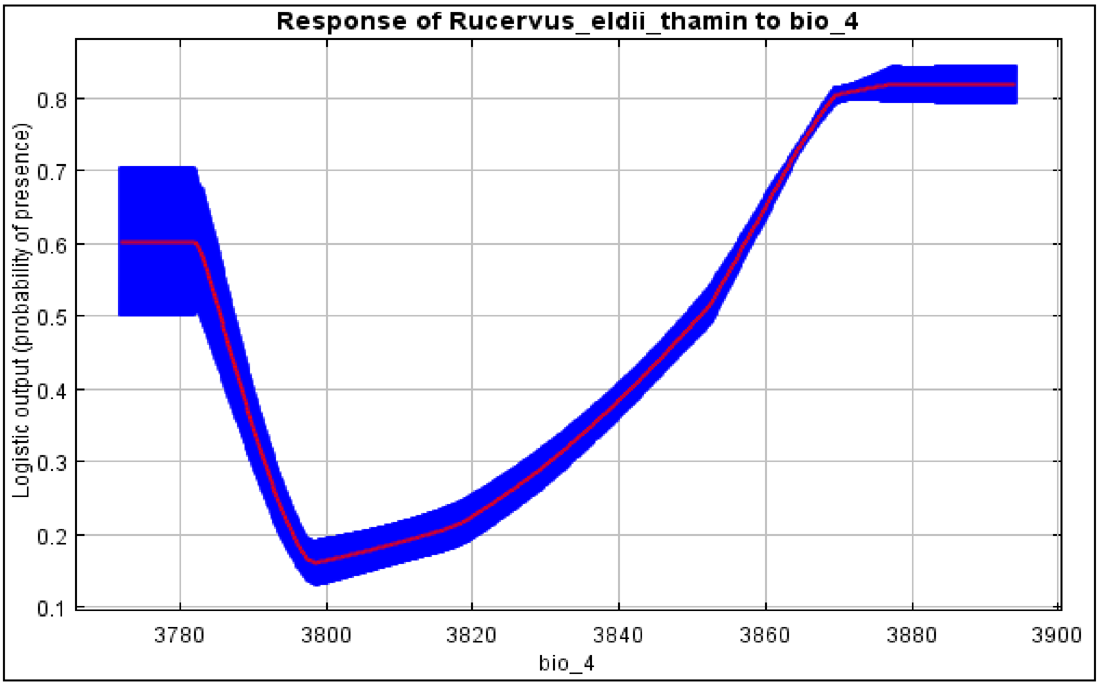

Figure 20(b). Response of *Rucervus eldii thamin* to the temperature seasonality

5. Discussion

Eld's deer, once distributed throughout much of Southeast Asia, from Manipur in Northeast India to Indochina and southern China, is now confined to small, fragmented patches (Wemmer, 1998; McShea *et al.*, 1999). Its historical range has been broken into four major parts, one of which is the Manipur region of India, inhabited by *Rucervus eldii eldii*, found in Keibul Lamjao National Park (Gee 1960; Ranjitsinh, 1975). Myanmar's Eld's deer, or *Rucervus eldii thamin* (Thomas, 1918), is found in the central plains of Myanmar and westernmost Thailand and along the eastern Downa Range and the upper Tenasserim Range in Thailand, near the Myanmar border (Bhumpakphan *et al*., 2003).

Although the nationwide Eld's deer surveys conducted in 1992 found that Eld's deer occurs in 28 townships, but only 23 out of the 24 surveyed townships in 1997. Similar investigations in 2007 indicated that Eld's deer were only found in 14 townships throughout the country (McShea *et al.,* 1999; Gray *et al.,* 2015). According to the investigation conducted by Myanmar Forest Department and Friend of Wildlife (FoW), in 2015 the species was found only in 13 townships. Thus, the distribution of the species has extirpated from its historical range in Myanmar within 23 years.

The Eld's deer is considered as a useful indicator of the condition of the sanctuary. Prediction of sizeable suitable habitat in CWS reveals is patched that the forest and habitat of Eld's deer is under the pressure of the anthropogenic activities. According to the field survey and MaxEnt results, the species was found in the young indaing habitat type, seasonally flooded indaing habitat type, mixed deciduous habitat type and grassland habitat type. Forage and water sources are sufficiently available in these habitat types and these areas are under intensive controlled and management. Most of the threats like land encroachment, human settlement, illegal logging, hunting and NTFPs collection were mostly found in other habitat types. Land encroachment and illegal logging were commonly found in the north, north-western and south-western parts of the CWS and hence, only a few of the specie occurrence locations were found in these parts. Thus, NTFPs collection, human settlement, land encroachment, hunting and illegal logging are the main drivers for the habitat loss, degradation, fragmentation and population decline.

MaxEnt can be used potentially for identifying suitable areas for Eld's deer species conservation. Highly and moderately suitable areas predicted in this study are the most potential areas for the species conservation, but also the marginally suitable areas should be considered as potential areas because the least suitable areas occupied about 85% of the area. Probability of occurrence of the Eld's deer is high in the southeast central part of the Chatthin wildlife sanctuary. Therefore, intensive management and conservation should be mainly implemented. The Probability of occurrence of Eld's deer is highest in Bio_18. Eld's deer was predicted to occur mostly in the young indaing, flooded Indaing and mixed deciduous forest in Chatthin wildlife sanctuary. The baseline information generated from the present study can be informative in the formulation of the future scientific management plan for the conservation of the endangered Eld's deer in Myanmar. This present study is the preliminary step for the habitat suitability for the Eld's deer in Chatthin wildlife sanctuary will contribute to better understanding of the Eld's deer and its habitats and conservation of the species and protected area management.

6. Conclusion

Due to the limited survey period, the collection of the distribution information in different seasons and in different parts outside PA and its range across the country was unable to conduct. This study is covered only the species habituated in CWS. Hence, future research on this species should focus on the distribution of Eld's deer throughout its range (not only CWS but also the countrywide) for the different seasons (both breeding and Non-breeding) in order to be ensured the intensive species conservation of the stable populations. This study is primarily based on my collected field data, relevant literatures and online databases.

7. Acknowledgements

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I humbly place my sincere thanks to Dean and Coordinator Forest Research Institute (Deemed to be) University, Dehradun. for helping me in more than one way during my stay here and offering me all sorts of facilities during the period of my study. I am also grateful to the MEA Scholarship Programm, India for giving me financial support throughout my study. I owe my sincere respect and thanks to FRI (Deemed) University for creating such platform for us to learn, understands, analysis and execute our idea and knowledge for the future research prospect.

I deeply thank Forest Department, Ministry of Natural Resources and Environmental Conservation, Myanmar, for giving me a great chance to pursue this master study. My sincere thanks also go to Park Warden and all staffs of the Chatthin Wildlife Sanctuary for helping facilitate the field survey. In addition, I feel thankful to everyone who helps me during my fieldwork in Myanmar.

Last but not least, my deepest gratitude to my parents for their encouragement throughout my studies and their countless love.

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