IMPACT OF THE WIND FARM ON SELECT FAUNAL COMPONENTS OF A DRY DECIDUOUS FOREST AT HARAPANAHALLI, DAVANGERE, KARNATAKA

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In

ZOOLOGY

By

ANOOP V

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October 2021

DECLARATION

I, ANOOP V hereby declare that the thesis, entitled "impact of the wind farm on select faunal components of a dry deciduous forest at harapanahalli, davangere, karnataka" submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology at Salim Ali Centre for Ornithology and Natural History is a record of original and independent research work done by me during November 2014 – October 2021 under the supervision and guidance of Dr. P R Arun, Department of Zoology and it has not formed the basis for the award of any Degree / Diploma / Associate ship / Fellowship or other similar title to any candidate in any University.

Signature of the Candidate

CERTIFICATE

This is to certify that the thesis entitled "**IMPACT OF THE WIND FARM ON SELECT FAUNAL COMPONENTS OF A DRY DECIDUOUS FOREST AT HARAPANAHALLI, DAVANGERE, KARNATAKA**" submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of **DOCTOR OF PHILOSOPHY IN ZOOLOGY** is a record of original research work done by **ANOOP V** during the period November 2014 - October 2021 of his study in the Department of Zoology at Salim Ali Centre for Ornithology and Natural History under my supervision and guidance and the thesis has not formed the basis for the award of any Degree / Diploma / Associateship / Fellowship or other similar title to any candidate of any University.

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CERTIFICATE OF GENUINENESS OF THE PUBLICATION

This is to certify that Ph.D. candidate Mr. ANOOP V working under my supervision has published a research article in the refereed journal named Journal of threatened taxa with Vol. No. 10 Page Nos. 11925-11927 and year of publication, 2018. The contents of the publication incorporate part of the results presented in his thesis.

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Research Supervisor

CERTIFICATE OF GENUINENESS OF THE PUBLICATION

This is to certify that Ph.D. candidate Mr. ANOOP V working under my supervision has published a research article in the refereed journal named Current science with Vol. No. 116 Page Nos.1587-1592 and year of publication 2019 published by Current Science Association, India. The contents of the publication incorporate part of the results presented in his thesis.

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CONTENTS

FIGURES

TABLES

PLATES

SUMMARY

A global shift from conventional energy to the more environment-friendly and pollution-free renewable energy sources is increasingly evident in recent years. However, the renewable energy sources too have its own share of impacts on environment and life forms, although to a lesser extent compared to the conventional energy resources. The major future source for energy generation in India is expected to be the wind energy. The wind turbine installation started in India in 1984, however there are very few studies on the negative effect of wind turbines on the environment. The current pace of wind energy development in India poses questions about the extent of potential impacts by the wind farms on the environment. This study focused on the impacts of wind energy production on birds, bats, and black-naped hare (*Lepus nigricollis*) at Harapanahalli, Karnataka with the following objectives.

(1) Study the Impacts of the wind farm on birds and bats of Hyrada reserve forest
(2) Study the Impacts of wind farm on Black-naped (*Lepus nigricollis*) hare at Hyrada reserve forest.
(3) Develop GIS-based model maps using distribution range information of select faunal species to evaluate the spatial variation in the impact potential of wind farm development.

The study area is located near Harapanahalli in the district of Davangere, Karnataka. Davangere district is located in Tungabhadra basin and lies between 14^{o} 25' north latitude and 75^{o} 50 east longitude. The Davangere district shares border with Shimoga, Bellary, and Chitradurga districts. The district has a geomorphology with the dry planes with agriculture lands and small patches of forests and hillocks. It lies in the Deccan Plateau around 100 km off the Western Ghats.

The prime objective of this study is the documentation of the negative impact of wind farms on birds, bats, and black-naped hare (*Lepus nigricollis*). Avian richness in the wind farm and adjoining areas were assessed by different methods such as the line transect and total count surveys, and all the opportunistic observations were added to the checklist. During the study, a total of 115 species of birds were observed from the wind farm and adjoining areas. The bird diversity and abundance are comparatively less in the wind farm area than in the control area (ie. adjacent habitat without turbines). Species like Bonneli's Eagle (*Aquila fasciata*), Brahmini Kite (*Haliastur indus*), Long-tailed Shrike (*Lanius schach*), and Sirkeer Malkoha (*Taccocua leschenaultii)* were seen only in the control areas. Whereas, Short-tailed Snake Eagle (*Circaetus gallicus)* was observed only in the wind farm site. Dominant species observed at the wind farm site were Red-vented Bulbul *(Pycnonotus cafer),* Purple Sunbird (*Cinnyris asiaticus),* and Indian Robin (*Copsychus fulicatus*). Dominant species at the Control site were Jungle Babblers (*Turdoides striata*), Red-vented Bulbul (*Pycnonotus cafer*), and Indian Robin (*Copsychus fulicatus*). Bird diversity was less in the wind farm (Shannon Index value (H') = 2.72) compared to control sites (H'= 3.02). Overall, the bird assemblage was significantly different (T-test: F= 2.69, P=0.1) between the sites. Similar pattern of difference was observed during the summer (T-test: F=6.59, P=0.01) and winter (T-test; F= 1.46, P=0.231) seasons as well. The nesting pattern of birds from opportunistic observations showed that many species of birds are using the wind farm and surrounding areas for nesting.

The activity pattern and flight height of birds were documented from vantage points. The data showed that the activity of raptors was more in the high-risk collision zone (ie. the height zone covered by the turbine blade sweep area), compared to other groups of birds.

To study the incidents of direct collision of birds and bats with the wind turbines, a carcass survey was conducted within 100 m radius around each wind turbine. All carcasses sighted at the turbine base attributable to direct collision with turbine blades were recorded. Twenty-five fatalities involving seven individuals of birds and eighteen individuals of insectivorous bats were recorded during the study. Out of the bird mortalities, three bird carcasses were not intact and could not be identified because of the unavailability of intact carcass (because of partial scavenging). The bird carcasses observed included Indian pitta (*Pitta brachyuran), White throated kingfisher (Halcyon smyrnensi),* Little swift *(Apus affinis),* one unidentifiable raptor species, and few unidentifiable passerines. Mean annual bird mortality per turbine was estimated as 0.47.

18 bat carcasses were found during the carcass sampling, and all of them were of single species, Tomb bat, *Taphozous melanopogon*. Tomb bats are insectivorous bats distributed all over the Indian subcontinent and are under the least concern category in the IUCN list. All recorded carcasses were found in the 60 m radius area from the base of the turbines. The estimated annual mortality rate of the Tomb bat was 12 bats/ turbine. The results showed that distance to the village from each wind turbine has a significant correlation with bat collision (P=0.04) on wind turbine (R^2 Value= 0.349, F=4.89). Other variables such as distance to natural water body and forest, altitude, NDVI had no significant relationship.

Besides, the changes in the population of Black naped Hare were studied using the pellet count method. During the study, the Indian Hare (*Lepus nigricolis*) was found to be more abundant in the wind farm area (3.34 individuals/ hectare) compared to the non-turbine area (1.37 individuals/ hectare) (t (df=56) =2.93, P=0.005).

Careful planning is very important to mitigate the impact of infrastructure development on biodiversity and the environment. As in other research fields, the scope of GIS and remote sensing as a tool is evident in environmental impact assessment studies as well. This study proposes using GIS based information to reduce the direct impact of wind farm installation on bats in the state of Karnataka, India. The potential areas for wind energy in Karnataka have already been documented by the National Institute of Wind Energy. This study has used this information superimposed with data on bat distribution in Karnataka to identify the areas with high-risk potential for bats from wind farms. The GIS analysis shows that the eastern part of Karnataka, the central part of the Western Ghat area in the state support maximum species of bats whereas some areas on the north side support a smaller number of bats. Even though this data is not an alternative for the individual impact assessment studies, it can provide the important baseline information to the policy makers and planners regarding the relative impact potential of various prospective windfarm sites. This study has developed a gradient map based on the bat species number and wind speed gradients. These maps can serve as a reference to visualize the spatial fluctuations in the impact potential of wind turbines on bats.

This study contributes to our knowledge on the impact of Indian wind farms on wildlife and related mitigation measures.

1 GENERAL INTRODUCTION

Traditionally, the non-renewable sources of energy have been the most extensively used energy sources worldwide, especially since the industrial revolution in Europe in 18th century. The widely available conventional and non-renewable sources of energy such as fossil fuels catapulted the advancement of machinery, energy technologies and innovations (John, 2004). Though the non-renewable sources currently remain as the dominant source of energy, renewable sources such as nuclear, hydroelectric and wind are expected to have an important role in energy production (WWEA, 2014) and expected to provide one third of the additional energy required worldwide by 2050 (IRENA, 2019).

Renewable energy, especially wind energy, is gaining attention and significance globally as it is considered environmentally benign, pollution-free and emission-free (Kuvlesky *et al.*, 2007). Consequently, wind power production has been increasing almost all over the world. India ranks fourth place in global wind energy production after China, USA, and Germany with an installed capacity of 27,151 MW (MNRE, 2016). India has renewable energy potential of 900 GW, of which wind energy could contribute about 102 GW (MNRE, 2016).

Although the energy generation from renewable sources is generally considered to be environment-friendly, recent studies have shown considerable impact of renewable energy generation on wildlife and their habitats (Hunteley, 2006, REN, 2014).The major reported impacts are: (1) habitat destruction (Larsen & Madson, 2000; Fox *et al.*, 2006; Larsen & Guillematte, 2007), (2) direct impact on aerial/flying fauna especially birds and bats (Nelson & Curry, 1995; Kunz *et al.*, 2007; Howe *et al.*, 2002; BNHS, 2013; Bernardino *et al.*, 2013; Barclay *et al.*, 2007; Arnett, 2008), (3) noise pollution, and (4) visual/aesthetic impacts on landscapes.

The unprecedented rate of wind farm installations in natural landscapes is raising concerns with regards to its impact on ecosystems and wildlife. In spite of India being one of the major global wind power generators and its faster pace of wind farm expansions (Madhu *et al.*, 2014), only few studies have been carried out in the country to assess the impacts of wind farms on wildlife (Kumar *et al*., 2013 and Pande *et al.,* 2013). While wind farms are rapidly expanding in India especially in five states namely, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra and Gujarat (Madhu *et al.*, 2014), studies from these regions, particularly from southern India, on the impacts of wind farm operation on the environment and living forms are very scarce.

Tools such as a map of bird sensitivity to wind farms were developed in certain countries based on the landscape and sensitivity of birds to wind turbines in order to mitigate the impact of wind turbines (Bright *et al.,* 2008). National Institute of Wind Energy (NIWE) has created a Wind atlas for India employing advanced modelling techniques with the help of National Clean Energy Fund (NCEF). The wind atlas serves as a major resource for planning the wind energy development in the country.

1.1 Literature review

Though wind was used as an energy source from very ancient times (Lovich & Ennen., 2013), it was only since the end of 1990s, the wind power generation became increasingly prevalent across the globe, especially in Europe, the USA, China, and India. Studies from elsewhere have shown the high negative impact of wind farms on different fauna especially on birds and bats (Drewit *et al.*, 2006, Erikson, 2001, Johnson *et al.*, 2003, Kerns *et al.*, 2004, Arnet *et al.*, 2005, Kunz *et al.*, 2007, Madhu *et al.*, 2014) which has raised serious ecological concerns. The major reported impacts of wind farms are as given below.

1.1.1 Direct collision of birds and bats in wind farms

Direct mortality at wind farm results from the collision of birds with the wind turbines. There are research evidences that birds are collapsing to the ground by the turbulence of wind turbine rotation (Winkelman 1992, Drewitt & Langston 2008). The factors that contribute to the direct collision of birds and bats may vary based on different factors such as weather conditions, landscape, species, species density, and movement frequency (e.g., migration routes, stop-over areas, and wintering areas of birds). Physical features of the landscape could affect the rate of mortality of birds at wind turbines. Since migratory birds usually select the coastal route, riverbank or area with a lot of lakes during the migration (Powlesl *et al.*, 2009), they are more prone to collision with wind turbines. Thus, wind turbines are considered as a significant cause of bird and bat mortality, along with other anthropogenic causes such as vehicles, buildings and windows, power lines, communication towers, electrocutions, oil spills and other contaminants, pesticides, predation, and commercial fish catching by-catch (Erickson *et al.*, 2005). Large number of raptors have collided with wind turbines in Europe and United States of America and most of them are long lived species with low reproductive outputs (Barrios & Rodriguez, 2004). Even though the number of bird mortality per turbine is low, the total number of collisions in a large wind farm will have significant deleterious effect on birds.

However, bird and other wildlife mortality due to anthropogenic structures are not well documented or estimated. Moreover, most of the studies published so far regarding the impact of wind farms on wildlife are from Europe and the United States of America.

The habitat types and local weather conditions where wind turbines are established may have strong bearings on bird and bat mortalities. The bird mortalities from wind turbines worldwide are estimated to be in a range of 0.01 to 23 birds/ turbine/ year. According to Lucas (2012), the chance for bird collision with the turbine will vary based on the local conditions of each turbine. A total of 221 Griffon vulture deaths (0.186 vulture deaths/ turbine/ year) were reported from 13 adjacent wind farms in Spain (Lucas D *et al.*, 2012). A mortality of 11 out of 45 bat species of the USA was reported in different wind farms of America (Kunz *et al.*, 2007, Arnet *et al.*, 2005). The bat mortalities were also reported from different wind farms in India (Ramesh *et al.,* 2013, Pande *et al.,* 2013). The major cause of the bat mortality in wind farms was found to be barotrauma, caused by the pressure difference around the rotating turbine blades (Baerwald *et al.,* 2008, Arnet *et al*., 2005).

1.1.2 Species displacement

A significant variation in population of different bird species before and after construction of turbines was reported in different studies (Higgins, 2012, Drewit *et al.,* 2006). Displacement of birds in a wind farm site is predominantly species and habitat-specific and might occur both during pre-construction and operational phases. The major reasons for bird displacement are noise, vibrations, human habitation, vehicle movements and the presence of wind turbine itself. Studies conducted before and after the wind farm construction could only examine the exact displacement rate because of wind farms (Drewit *et al.,* 2006). The displacement behaviour of birds from the wind farms are completely species specific, some studies quantified the changes in the distance of flight by different avian species from the periphery of the wind farms (Larsen & Guillemette, 2007). Masden *et al.,* 2009 reported that compared to other bird species in Denmark, Sea sucks (*Somateria mollissima*) fly far from the traditional flyway or path to avoid the wind farm area.

1.1.3 Barrier effect

The wind farms are known to cause alteration of migration pathways of birds. The barrier effect is a kind of displacement, caused when the birds will take a detour or diversion from their regular/ expected movement paths to avoid the wind turbine areas. In addition, there is a possibility of increased energy expenditure when birds fly in a route other than usual. The barrier effect depends on factors such as species, type of bird movement, flight height, wind turbine operational time, time of flight and distance from the turbine (Drewit *et al.,* 2006).

1.1.4 Habitat loss

Habitats could get altered due to the construction of wind turbines, which occur less frequently, becomes an issue depending on the habitat types and species distribution (Fox *et al.,* 2006). Previously, the wind farms were installed in the agricultural or human occupied areas but forest and wood lands are also being used for the construction of the wind farms in the recent years. The extent of land transformation for the wind farm installation will be minimum in already tilled or agricultural areas (Scholl & Nopp-Mayr 2021). The expansion of wind farms in to remote forest areas has negative impact on wildlife. Such expansion includes such as construction of new roads and which will make the area accessible for humans and predators. For, example, study by Siren *et al.,* (2017) reported that, up to the construction of roads in the wind farms, montane habitats were inaccessible for American red foxes (*Vulpes fulva*) and coyotes (*Canis latrans*) in winter due to snow cover. Additionally, the construction works including the blasts during the initial stage of wind farm construction is a disturbance to the wildlife, recent study by Sirens *et al.*, 2016 reported that American martens (*Martens americana*) are avoiding the wind turbine areas during the stage of construction.

1.1.5 Impact management

Many recommendations have been put forth to manage and mitigate the impact of wind farms on different fauna. For example, Bright (2008) developed a map of bird sensitivities to the wind turbines of Scotland. Another study employed Spatial Decision Support System (SDSS), where the land was divided into gradients based on the environmental and economic suitability of the land for installing the wind turbines with Multiple Criteria Analysis (Gorsevski *et al.*, 2013).

The literature review clearly suggests that the studies on impacts of wind farms on birds, bats, and other major wildlife in India are very scarce except for few studies (i.e. Pande *et al.*, 2013; Kumar *et al.*, 2013). These case studies examined the site-specific impact of wind farms on different fauna and provided regional perspectives. Similarly, The Rainforest Initiative had conducted a rapid survey in 2010 prior to installing wind turbines near Harapanahalli in the district of Davangere, Karnataka where the status of different fauna including birds, mammals and plants were assessed (Rain Forest Initiative, 2010). In the light of unprecedented and ever-expanding installations of wind turbines in different parts of India and scarcity of studies on its impact on different fauna, the present study was envisaged and carried out in a wind farm at Harapanahalli taluk in Karnataka with the objective of studying the impacts of wind farm and its management.

1.2 Objectives

The present research work was conceived with the following three major objectives.

1. Study the Impacts of the wind farm on birds and bats of Hyrada reserve forest,
2. Study the Impacts of wind farm on Black- naped hare at Hyrada reserve forest,
3. Develop GIS-based model maps using distribution range information of select faunal species to evaluate the spatial variation in the impact potential of wind farm development.

1.3 Thesis Organization

The thesis is divided into six main chapters, with two preliminary chapters on introduction and study area details followed by four technical chapters and a final summary chapter.

Chapter 1:

GENERAL INTRODUCTION

The first chapter discusses in detail the existing studies on impact of wind turbines on the environment and different faunas in Global and Indian scenario.

Chapter 2:
STUDY AREA

This chapter discusses the vegetation, geomorphology, climate, fauna and flora of the study area. This chapter also discusses the wind turbine structure, number and locations of wind turbines in the study area.

Chapter 3:
Avifauna Composition and Collision risk at Wind farms

This chapter describes the impact of wind turbines on birds in the study area of Davangere district of Karnataka. Three aspects of data used include bird diversity of the area, bird collisions on the wind turbine and bird nesting in and around the wind farm.

Chapter 4:

Impact of windfarm on bats

The impact of wind farms on bats are reported in this chapter. Different aspects of bat mortalities due to the wind turbine operations are discussed in this chapter.

Chapter 5:
Synanthropic behavior of black -napped hare in wind farms

This chapter discusses the observed variations in the abundance patterns of Black-naped hares in Turbine site and the adjacent control site. Higher black-naped hare population in the wind farm area than control sites are highlighted in the study.

Chapter 6:

Bat mortality risk prediction using Species distribution data and wind atlas

In this chapter, potential wind energy areas in the state of Karnataka are identified and categorized in to different gradients based on the risk from potential bat collisions on wind turbine. The data on potential areas of wind energy and the bat distribution in Karnataka were collated from secondary sources.

Chapter 7:

A detailed conclusion chapter is prepared based on the results from above four chapters. The major results and the significance of the study are highlighted in this chapter.

2 STUDY AREA

The study area is located near Harapanahalli in the district of Davangere, Karnataka. It is located in Tungabhadra basin at 14^{o}25’ North latitude and 75^{o}50’ East longitude. The Davangere district is nestled among Shimoga, Bellary and Chithradurga districts of Karnataka. The study area is 50 Km far from the Davangare city and well connected by road. Harihar and Hubli are the nearest railway station and airport respectively. The district has a geomorphology with plane, dry and agriculture lands with small patches of forests and hillocks. It lies in the Deccan Platue and around 100 km east of the Western Ghats.

2.1 Geomorphology

Davangare district has vast stretches of plains with few rocky hills in the eastern side of the district. The major soil type in the district is red sandy soil followed by black soil. Dalba Ranga Gudda (1013m above MSL) in Honnali taluk is the highest peak in the district followed by Jaikal Gudda (863m above MSL) and Anaburu (916mabove MSL). Deccan platue harbours many permanent and perennial ponds, lakes and marshy lands. The spatial and temporal changes in the wind energy potential of an area is governed by various factors such as geographic, topographic, and meteorological characters of area. The northern dry zone in Karnataka has good wind potential compared to other parts of the state (Ramachandra & Shruthi, 2003).

2.2 Flora & Fauna

Though the studies on birds, bats and other taxa are comparatively less from the central part of Karnataka, available literature have reported rich biodiversity. Both Western and Eastern Ghats lie as a boundary to the district. Forest type of the district varies from moist deciduous to scrub jungle through dry deciduous forest. The major plant species observed from the study area are *Ziziphus mauritiana, Terminalia crenulata, Phyllanthus emblica, Wendlandia thyrsoidea etc*.

A total of 524 species of birds are reported from Karnataka and 16 of them are endemic to Western Ghats (Praveen *et al.,* 2016). Great Indian Bustard (*Ardeotis nigriceps*) and Lesser florican (*Sypheotides indicus*) have been reported from different locations such as Ranebennur Blackbuck Sanctuary which is located 85 km from the study area. The major species of water birds recorded from the study area are Painted Stork *(Mycteria leucocephala)*, Wooly Necked stork *(Ciconia episcopus)*, and Red-naped Ibis *(Pseudibis papillosa)*, Asian Open Bill (*Anastomus oscitans)*, Indian Pond Heron (*Ardeola grayii)*, Purple Heron (*Ardea purpurea)*, Great Egret (*Casmerodius albus)*, Intermediate Egret (*Mesophoyx intermedia)*, Little Egret (*Egretta garzetta)* and Little Cormorant (*Phalacrocorax niger).*

Karnataka is located in the southwest part of India. The total area of Karnataka is 19.18 million hectares and it is 5.83 % of total area of the country. Physiographic ally, the area can be divided in to two regions such as hilly regions including the western Ghats and the plains. Many rivers flow through Karnataka including Cauvery, Tungbhadra and Krishna (Refer Figure 2.1).

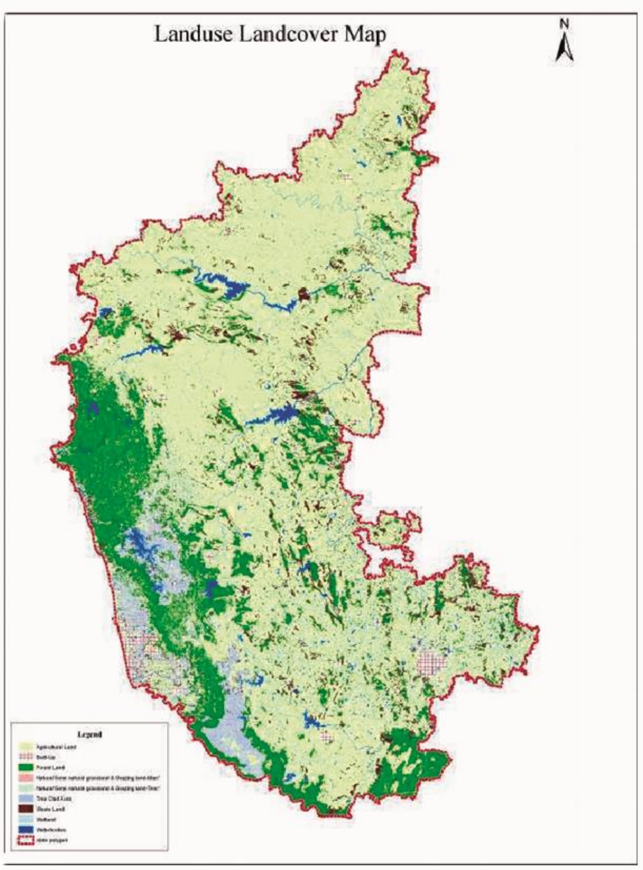


Figure 2.1. Land use land cover map (Source: Ramachandrappa and Thimme Gowda 2016)

The important large mammals reported from the study area are Leopard (*Panthera pardus*), Sloth bear (*Melursus ursinus*), and Jackal (*Canis aureus*). Out of 120 bat species in India, 59 species are reported from Karnataka (Srinivasulu, 2010).

2.3 Climate

The major seasons in the study area are monsoon (May to September), Post-monsoon (October to December), summer (March to May) and two months of winter (during December and January). The Davangere district gets an average annual rainfall of 639.9mm and temperature of 29.5^{o}C. The temperature varies from 17 to 35^{o}C in different seasons. May month is the hottest month whereas the temperature will be minimum in December.

2.4 Intensive Study Area

The intensive study area includes the wind farm and adjacent non-wind turbine areas. The windmill area belongs to Hyarada Reserve Forest. This 56.508 km^2 forest area is situated between latitudes $14^0$45'11.57" to $14^0$53'23.78" N, and longitudes $75^0$47'36.75" to $75^0$50'54.47" E. The area has a number of wetlands within the 5 km radius from the wind farm and the Tungabhadra river flows around 12 km west of the study area. All wind turbines are installed within the Harada Reserve Forest area. The study area has a mixed mosaic landscape with hillocks with small forest patches, agriculture lands, marshlands and dry barren lands. The wetlands in the study area harbour many water birds including the threatened bird species such as Painted Stork (*Mycteria leucocephala) and* Wooly-necked Stork (*Ciconia nigra).* A control site was selected in the non-wind turbine areas, 3 - 4 Km away from the wind turbine area. The selected control site has similar vegetation and geography of the wind farm area.

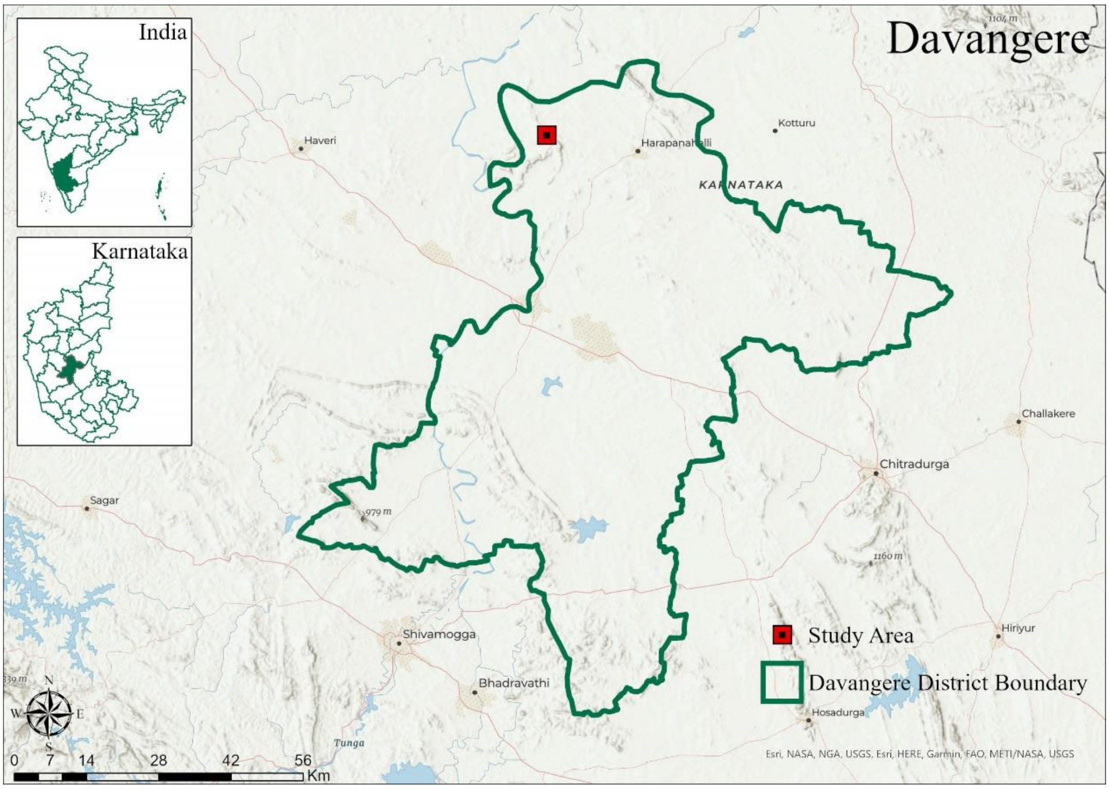


Figure 2. 2. Map of the study area with turbine locations

Plate 2.1: A distant view of the hillocks with wind turbines

2.5 Wind Farm & Turbine Structure

A total of 24 turbines were selected for the study. All turbines are tubular structures, active and maintained properly. The turbines were erected after levelling off the slopes and maintaining a distance of 50 to 200m between the turbines. The total height of a turbine was 119m, including the blade length of 41 m. The tower mounting the turbines measures 78 m from ground level to tip of the hub. The rotating blades cover a height zone of 82m between 37 to 119m above ground.

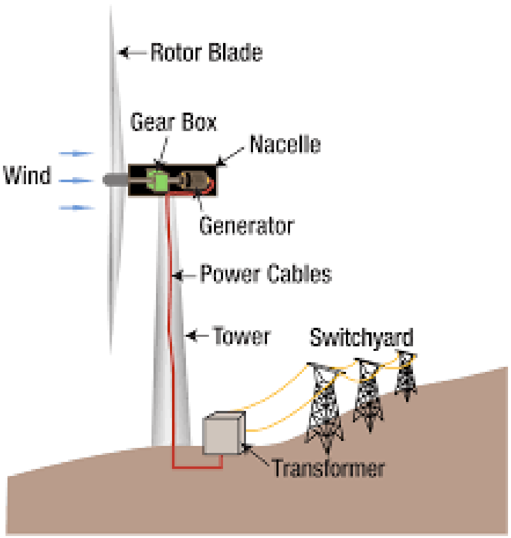


Figure 2.3. Wind turbine structure

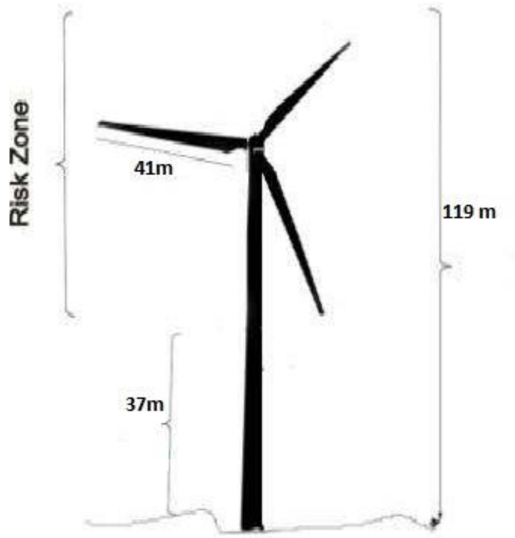


Figure 2.4. Risk zone for aerial fauna

2.6 Wind Energy in Karnataka

The renewable energy sector of Government of Karnataka targets 6000 MW of electricity by 2022 and wind will be the major contributor in that (Karnataka Renewable energy policy 2016-2022). The other renewable energy sources of the state are solar, wind-solar hybrid, small hydro, biomass, cogeneration, waste-to-energy and tidal, whereas the study area in Karnataka supports good flora and fauna.

The wind farm in the study area is placed in a reserve forest area, and it is rich with flora and fauna. Moreover, previous studies reported endangered mammals and birds from the study area, which consequently shows the significance of present study for conservation.

Plate 2.2: View of wind turbines from the study area

3 AVIFAUNA COMPOSITION AND COLLISION RISK AT WIND FARMS

3.1 Introduction

Geographically, Karnataka has three major zones namely, Western Ghats, Deccan Plateau, and the Coastline (Praveen *et al.*, 2016). The major forest types seen in the different landscapes of Karnataka are moist and dry-deciduous, wet, and semi-evergreen as well as small pockets of high-altitude montane forests and grasslands in the Western Ghats part of the state. Furthermore, secondary forest and several human-modified habitats including forest plantations, croplands, inland reservoirs, and degraded secondary forests also exist in this landscape (Alfred *et al.*, 2001). The Deccan Plateau has large expanses of dry/fallow grasslands, freshwater lakes, scrub forests, and barren rocky hillocks which support diverse species of fauna and flora (Alfred *et al.*, 2001, Praveen *et al.*, 2016). The diverse landscape of Karnataka supports 35% of total reported bird diversity from India, including 27 threatened species (Ali, 1938, Praveen *et al.*, 2016 & IUCN, 2020).

Even though the history of the ornithological expedition in Karnataka has more than a century of data from the time of Buteler (1881), A. O. Hume (1888) and Salim Ali (1938), specific information's on bird diversity of Davangere district of Karnataka is very scarce (Ali, 1938, Ali & Whistler, 1942 a, b., Praveen *et al.*, 2016). Davangare district is dotted with several water bodies including Tungabhadra River and multiple manmade wetlands that support diverse water birds.

Globally, avian habitats are degrading at an unprecedented rate mainly due to anthropogenic activities (Myers *et al.*, 2010). Electricity generation through conventional ways has been identified as one of the important human-made impacts on different groups of animals including birds (Kuvlesky *et al.*, 2007). The shifting of conventional to renewable sources of energy hasn't avoided the impact on wildlife completely.

Renewable energy sources such as wind energy have considerable impact on wildlife especially on bird communities (Orloff & Flannery, 1992). Such impacts involve several factors such as direct collision of birds with wind turbine blades, displacement of bird species, human disturbance, road construction and vehicular movements. The overall impact potential of wind farm sector has substantially increased in recent times due to large scale establishment and operation of wind turbines (Erickson *et al.*, 2001, Orloff & Flannery, 1992).

Bird collision on wind turbine towers, rotors, nacelles, and associated structures has become a recent issue of conservation concern in different parts of the globe (Krijgsveld *et al.*, 2009, Drewit & Langston 2006, Erickson *et al.*, 2001). The increased fatality rate of birds especially raptors and other threatened category have been reported elsewhere (Erickson *et al.*, 2001; Orloff & Flannery, 1992). The maximum number of studies on bird fatalities due to wind turbine operations have been reported from USA and Europe whereas few studies are from Australia, South America, Africa, and India (Hull *et al.*, 2013, Doty & Martin, 2013, Pande *et al.*, 2013 and Arun *et al.*, 2014).

This study compiled the baseline data on bird assemblage in the study area from various sources (Praveen *et al.*, 2016, ebird 2020) including primary data. The data on collision mortality of birds at the wind turbines were also monitored during the study period. The chapter addresses aim at (1) documentation of the bird assemblage of the study area and (2) to estimate the bird mortality rate caused by the wind farm.

3.2 Methods

3.2.1 Sampling strategies

Sampling was done in two habitats such as wind farm and control site. The control site was situated to 2-5 Km from the wind farm and has the same habitat characteristics of wind farms except for the wind turbines. Few control sites have roads similar to that of the wind farms, which were constructed for the future installation of wind turbines. The sampling effort was equally distributed in both the sites.

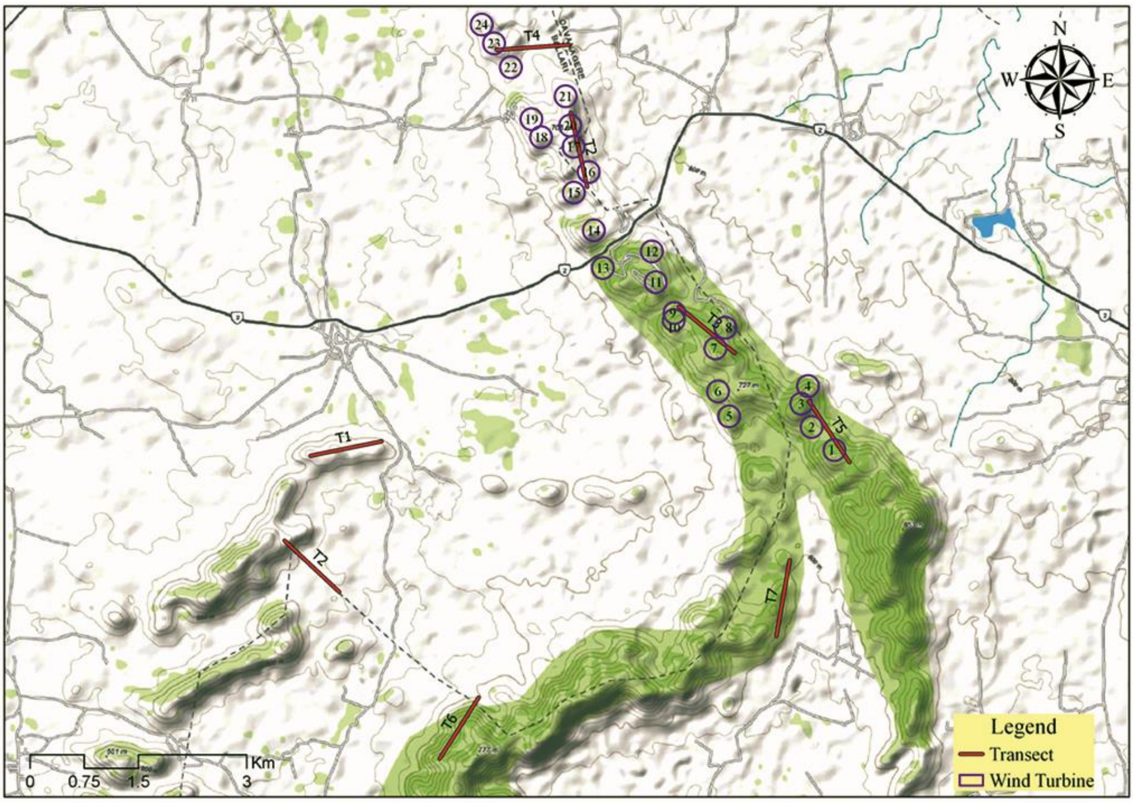


Figure 3.1. Map of the study area

3.2.2 Line transects

A total of eight bird transects (four in wind farms and four in control sites) of one km each were used for bird sampling following standard transect count method (Bibby *et al.,* 2000*)*. Bird counts were carried out by counting birds within fifty-meter on either sides of the transect. Sampling was done during the morning (07.00- 09.30 am) and evening time (04.00- 0700 pm) and eight replications were done in all the transects. The observer has walked at a slow pace along the transect wherein the species and the number of birds encountered were documented. This sampling was done from January 2014 to May 2015.

3.2.3 Vantage points

Eight vantage points were fixed in the wind farm to see the movements of birds through the wind farm. Each point was sampled for 40 minutes per point with eight temporal replications. Sampling was done during morning and evening from January 2014 to May 2015 by a single person.

3.2.3.1 Flight activities

The total height of a turbine is 119 m, including the blade length of 41 m. The tower mounting the turbines measures 78 m from ground level to the tip of the hub. The rotating blades cover a height zone of 82m between 37 to 119 m above ground. This zone is the maximal risk zone for the flight as far as the birds are concerned. For the convenience of the study this zone was termed as Zone B) the height level below this zone i.e. <37 m was termed Zone A and the height zone above 119 m was termed Zone C. Eight turbines were selected randomly after stratification ensuring maximum representation of all base height levels slopes and vegetation structure to minimize bias. We selected turbines located at different altitude categories (varies between 653- 776 m above MSL). Birds flying within in 300 m radius was observed with the help of binoculars and categorized into the respective height zones (A, B, or C). Fixed vantage points were used for flight height observation. Flight activities of birds near wind turbines including flight height, approximate distance from the turbine blade was recorded during sampling (Figure 2.3).

3.2.4 Total count

Wetlands and agriculture lands within a five-kilometre radius of the windmill project area were surveyed for water birds using total count method (Urfi *et al.,* 2005). The number of species and abundance were noted during the fieldwork. Five ponds were sampled by using the total count method. Sampling was done during the daytime varied between 7 am and 7 pm.

3.2.5 Opportunistic observations

Opportunistic observations of the birds were included in the species checklist. All opportunistic observations were documented and observation in a 5 km radius was considered for documentation. Other opportunistic observations on bird fauna like bird nests, bird roadkill, and congregation were documented. For a general comparison with the impacts of Wind farms, road kills of animals and birds on the nearby Davangere - Bellari state highway was observed on four different days in each field trip. This road survey was done on a 20 km stretch (between Harpanahalli and Hara wind farm) of the road.

3.2.6 Mortality monitoring of birds

Sampling was done for 24 wind turbines for the evidence of bird collisions or death-causing injuries for birds with 8 temporal replicates using systematic carcass searches.

3.2.6.1 Mortality/ Carcass Searches

To estimate the mortality of birds and bats, searches were conducted below all the 24 turbines by one person for carcasses spending forty minutes per turbine within a 100 m radial zone around the turbine base for remnants of birds and bats that might have died/ injured because of collision with the turbine. Whenever an injured or dead bird was detected, the species name, injury level, distance from the turbine, and approximate time of death/ injury (Orloff & Flannery, 1992) were recorded and was moved out of the counting zone to avoid repeat counting.

3.2.6.2 Scavenger removal rate

The scavenger removal rate at the wind farm area was estimated using field trials using dead birds. It was done to reduce the bias in mortality rate estimations because of the removal of a carcass by different scavengers from below the wind turbines. The widely used standard method was used for estimating the scavenger removal rate as in the other studies conducted elsewhere (Erickson *et al.*, 2000, 2004; Kerns *et al.*, 2005; Huso, 2010)

During the mortality survey two bird carcasses were left in the field and the length of time each carcass remained on the field before being naturally removed/ became undetectable was recorded. i.e., the number of days between the time the carcass was planted and the last search date on which it could not be detected. The mean length of time a carcass remained on a plot (T) was calculated based on the following equation Erickson *et al.*, 2003

$$\mathbf{T = \Sigma ti / S}$$

Where ti is the length of time a carcass remained on-site, S is the total number of carcasses planted for the study.

The estimated number of annual fatalities (m) per turbine was calculated using the following formula from Jhonson *et al.*, (2003)

$$\mathbf{M = N \times I \times C / k \times t \times e}$$

where ‘**N’** is the total number of turbines, ‘**I’** is the interval between searches in days, ‘**C’** is the total number of carcasses found ‘**k’** is the number of turbines sampled, t is the mean length of time carcasses remained on-site before being scavenged, and **e** searcher efficiency. Since the areas under the turbines were relatively plain with a high (100%) chance of delectability of the carcasses during the initial trials, the searcher efficiency was considered as 100% for the calculations.

3.2.6.3 Bird assemblage at wind farm and control site

The following analyses were used for estimating the bird diversity and richness in the wind farm and control areas.

The relative abundance (Abi = number of i^{th} species/Total number of individuals) of each species for all two assemblages (i.e. control and turbine site) were calculated. Species richness (S), Shannon diversity index (H’) for each assemblage was also calculated. An Independent T-test was used for comparing the species richness and abundance of both assemblages.

- Species Richness (S) = Number of species observed in each assemblage
- Shannon-Wiener Diversity Index (H') = $-\Sigma\, p_i \ln p_i$

where, *pi* = Proportion of individuals in the i^{th} species for the total sample, ln = Natural logarithm.

3.3 Results

3.3.1 Species Richness

A total of 115 species of birds belonging to 46 families and 18 orders were documented during the study.

Out of the 18 orders recorded from the study area, Passeriformes, Charadriiformes, Accipitriformes and Pelecaniformes were dominant with 49, 12, 10 and 8 bird species respectively. The following families had a maximum percentage of occurrence; Accipitridae (7.83%), Anatidae (6.96%), Motacillidae (6.96 %), and Ardeidae (6.09 %). Out of 115 species of birds, (72.17 %) were resident, (26.09 %) were winter visitor and (1.74 %) was passage migrant (Ali & Ripley, 2001, Grimmet *et al.*, 2011)

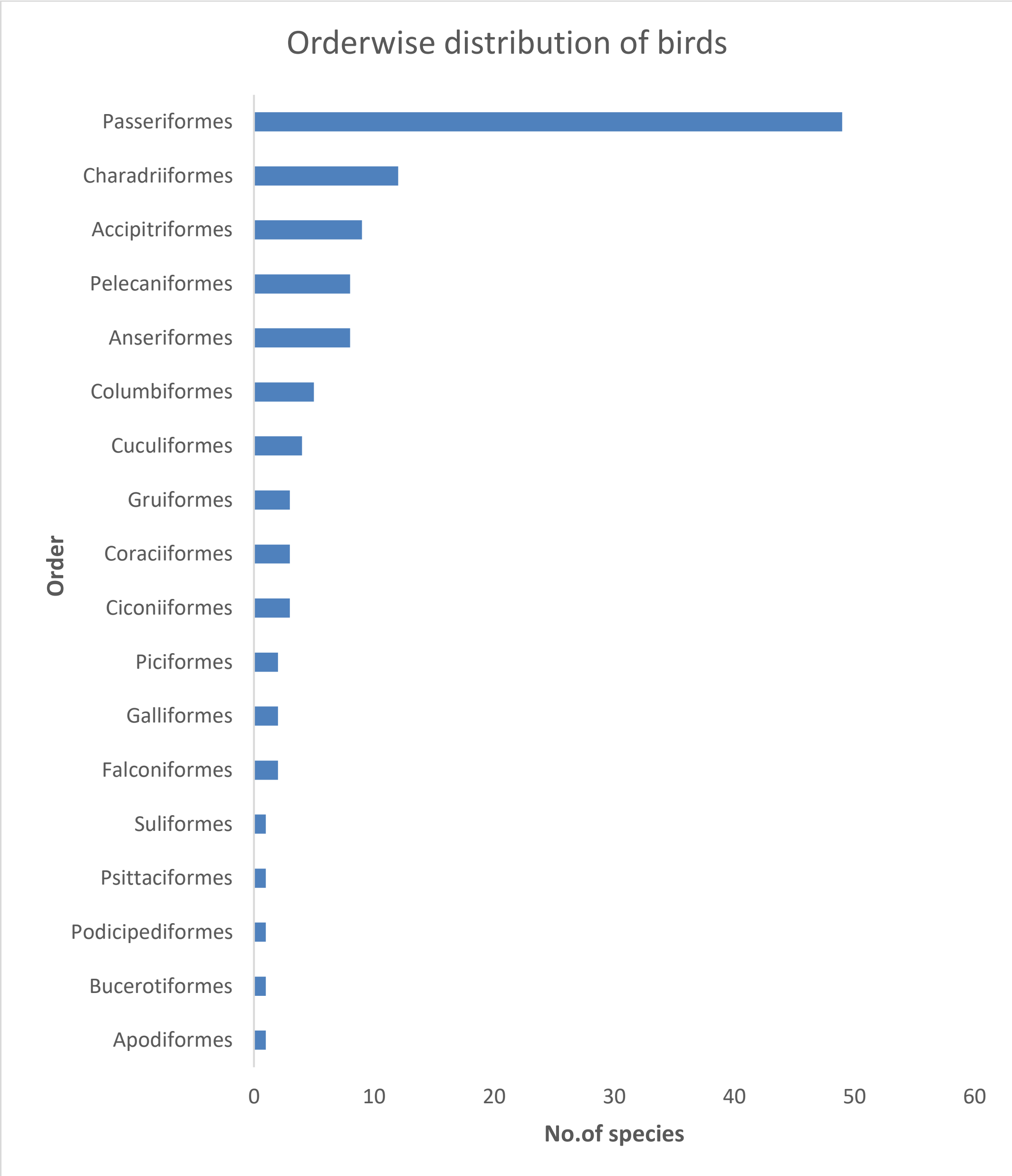


Figure 3.2: Order wise distribution of birds

Table 3. 1 - Family-wise species richness and migratory status of the avifauna recorded						
Sl. No.	**Family**	**Winter Visitor**	**Resident**	**Passage Visitor**	**Total**	**% Of each family**
1	Accipitridae	2	7	_	9	7.83
2	Acrocephalidae	1	0	_	1	0.87
3	Aegithinidae	0	1	_	1	0.87
4	Alaudidae	0	3	_	3	2.61
5	Alcedinidae	0	1	_	1	0.87
6	Anatidae	6	2	_	8	6.96
7	Apodidae	0	1	0	1	0.87
8	Ardeidae	0	6	1	7	6.09
9	Campephagidae	0	1	0	1	0.87
10	Charadriidae	0	2	0	2	1.74
11	Ciconiidae	0	3	0	3	2.61
12	Cisticolidae	0	3	0	3	2.61
13	Columbidae	0	5	0	5	4.35
14	Corvidae	0	2	0	2	1.74
15	Cuculidae	0	4	0	4	3.48
16	Dicaeidae	0	1	0	1	0.87
17	Dicruridae	0	2	0	2	1.74
18	Emberizidae	1	0	0	1	0.87
19	Falconidae	1	1	0	2	1.74
20	Hirundinidae	2	1	0	3	2.61
21	Jacanidae	0	1	0	1	0.87
22	Laniidae	1	2	0	3	2.61
23	Laridae	2	1	0	3	2.61

24	Leiothrichidae	0	2	0	2	1.74
25	Megalaimidae	0	1	0	1	0.87
26	Meropidae	0	1	1	2	1.74
27	Motacillidae	5	3	0	8	6.96
28	Muscicapidae	1	3	0	4	3.48
29	Nectariniidae	0	1	0	1	0.87
30	Paridae	0	1	0	1	0.87
31	Passeridae	0	2	0	2	1.74
32	Phalacrocoracidae	0	1	0	1	0.87
33	Phasianidae	0	2	0	2	1.74
34	Picidae	0	1	0	1	0.87
35	Pittidae	1	0	0	1	0.87
36	Podicipedidae	0	1	0	1	0.87
37	Psittacidae	0	1	0	1	0.87
38	Pycnonotidae	0	2	0	2	1.74
39	Rallidae	0	3	0	3	2.61
40	Recurvirostridae	1	0	0	1	0.87
41	Scolopacidae	5	0	0	5	4.35
42	Sturnidae	0	4	0	4	3.48
43	Sylviidae	1	1	0	2	1.74
44	Tephrodornithidae	0	1	0	1	0.87
45	Threskiornithidae	0	1	0	1	0.87
46	Upupidae	0	1	0	1	0.87
Grand Total		**30**	**83**	**2**	**115**	**100**

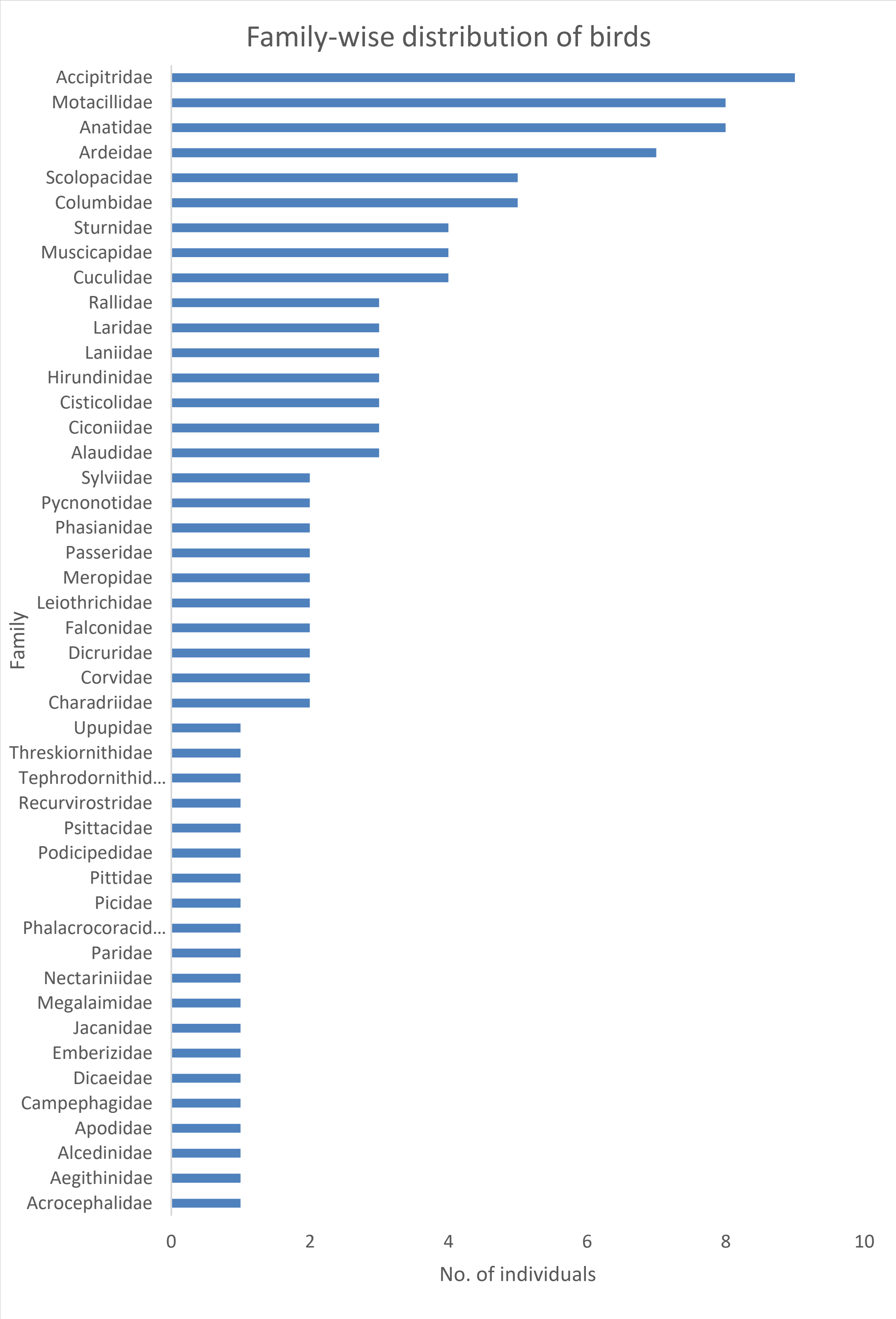


Figure 3.3. Family-wise distribution of birds

Table-3.2. Threatened species observed from the study site		
Common name	**Scientific name**	**IUCN**
Woolly-necked Stork	*Ciconia episcopus*	*VU*
Painted Stork	*Mycteria leucocephala*	*NT*
Pallid Harrier	*Circus macrourus*	*NT*
River Tern	*Sterna aurantia*	*NT*
Laggar Falcon	*Falco jugger*	*NT*

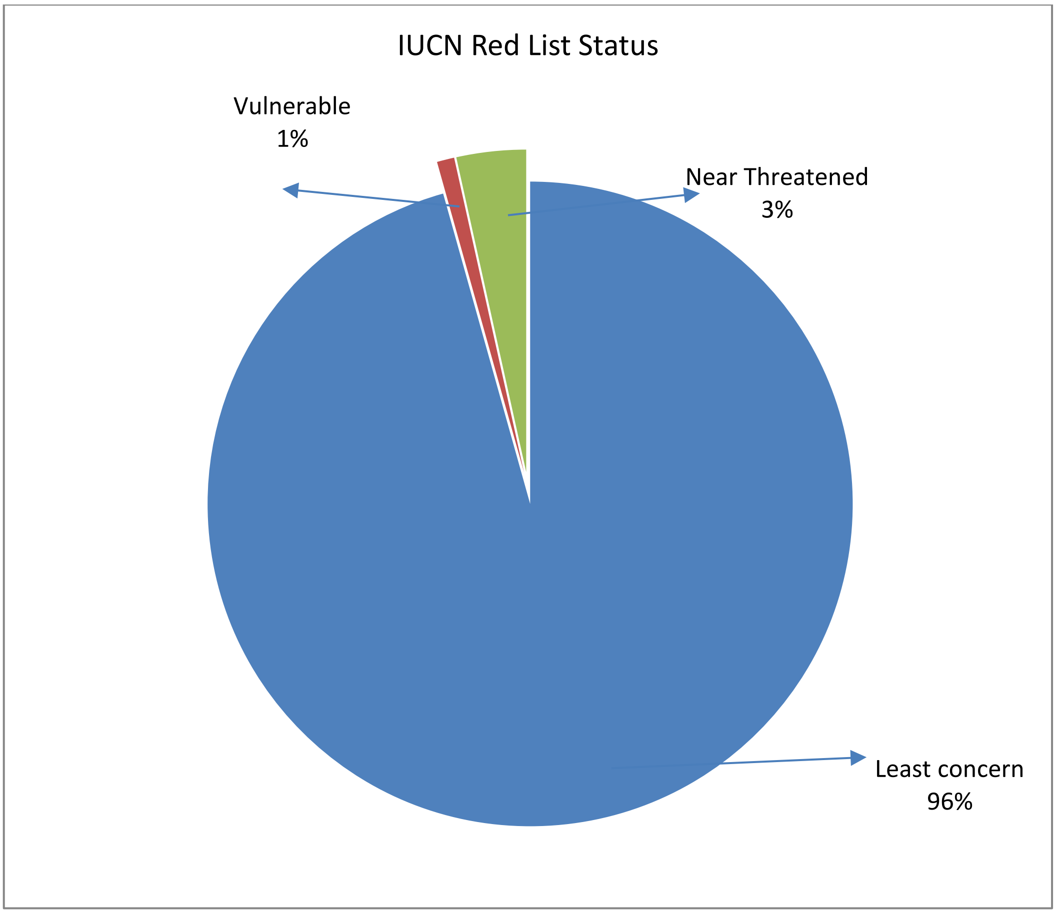


Figure-3.4. Proportion of birds under various IUCN Threatened Status

In all, only one species, the Indian peafowl (*Pavo cristatus*) was listed in Schedule I, and the other 114 birds were listed in Schedule IV under the Indian Wildlife Protection Act 1972(amended 2002).

3.3.1 Water birds

This study recorded 46 water birds from the 5 km radial distance around the wind farm area.

The major species of water birds observed from the study area are Painted Stork *(Mycteria leucocephala)*, Wooly-necked stork *(Ciconia episcopus)*, and Red-naped Ibis *(Pseudibis papillosa)*, Asian Open Bill (*Anasto musoscitans)*, Indian Pond Heron (*Ardeolagrayii)*, Purple Heron (*Ardea purpurea)*, Great Egret (*Casmerodius albus)*, Intermediate Egret (*Mesophoyx intermedia)*, Little Egret (*Egretta garzetta)* and Little Cormorant (*Phalacrocorax niger).*

3.3.2 Raptors

Nine species of raptors were documented from the study area including two near threatened species (IUCN 2018) namely Pallid Harrier (*Circus macrourus*) and Laggar falcon (*Falco jugger*).

3.3.3 Bird assemblage at wind farm and control areas

A total of 33 species of birds were recorded during the sampling from both the sites (25 species at the control site & 23 species at the wind farm). Bonnelis eagle (*Aquila fasciata*), Brahmini Kite (*Haliastur indus)*, Long-tailed Shrike *(Lanius schach)*, and Sirkeer Malkoha (*Taccocua leschenaultia)* were observed only in the control site. A short-toed snake eagle (*Circaetus gallicus)* was observed only at wind farms. Dominant species observed at the wind farm site were Red-vented bulbul (*Pycnonotus cafer)*, purple sunbird (*Cinnyris asiaticus)*, and Indian Robin (*Copsychus fulicatus*). Observed dominant species at Control site were Jungle babblers (*Turdoides striata*), Red-vented bulbul (*Pycnonotus cafer)*, and Indian Robin (*Copsychus fulicatus*).

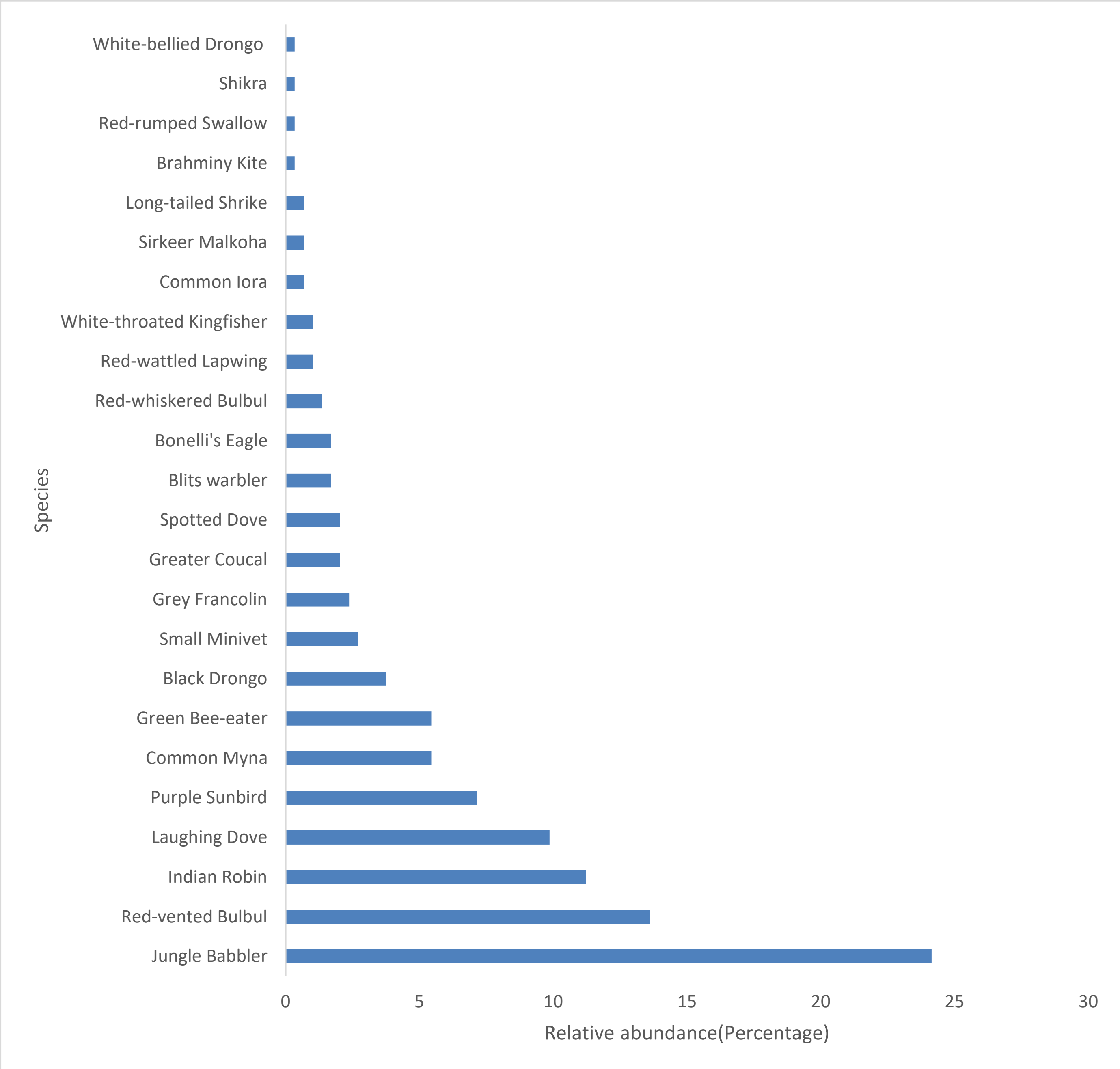


Figure 3.5. Relative abundance of birds in Control Site

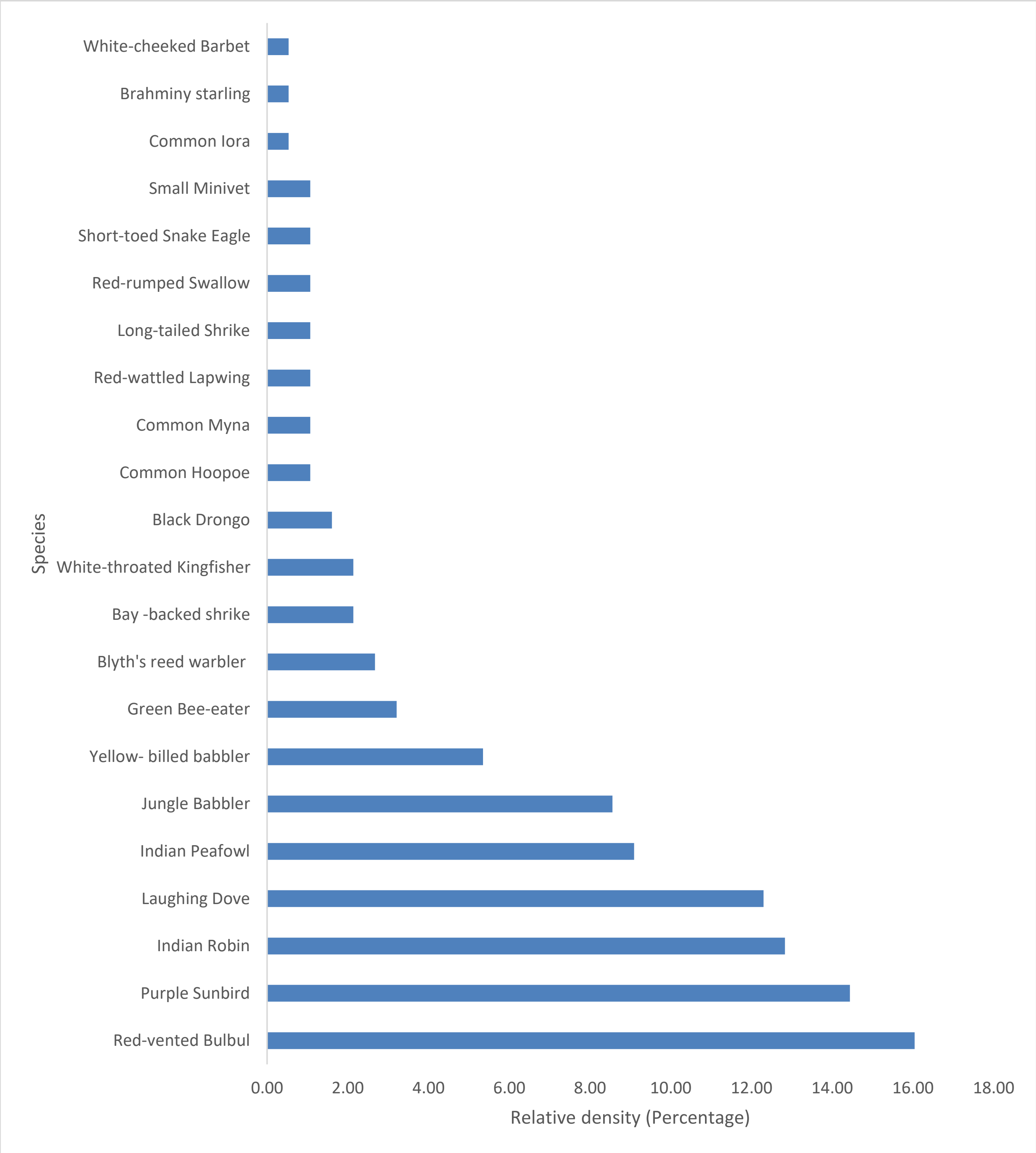

White-cheeked Barbet
Brahminy starling
Common Iora
Small Minivet
Short-toed Snake Eagle
Red-rumped Swallow
Long-tailed Shrike
Red-wattled Lapwing
Common Myna
Common Hoopoe
Black Drongo
White-throated Kingfisher
Bay -backed shrike
Blyth's reed warbler
Green Bee-eater
Yellow- billed babbler
Jungle Babbler
Indian Peafowl
Laughing Dove
Indian Robin
Purple Sunbird
Red-vented Bulbul
Species
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Relative density (Percentage)

Figure 3.6. Relative abundance of birds in Wind farm

Bird diversity was observed less in the wind farm (Shannon Index value (H') = 2.72) compared to control sites (H'= 3.02). Overall, the bird population of both the sites was significantly different (T-test: F= 2.69, P=0.1). The same pattern was followed during the summer season (T-test: F=6.59, P=0.01) and winter season (T-test; F= 1.46, P=0.231).

3.3.4 Nest Sites of birds

3.3.4.1 Grey Heron

During the survey of the wetlands around the wind farm, a nesting site of Grey Heron (*Ardea cinerea)* is comprised of three nests at a lake located at 14°49'53.70" N & 75°55'39.33" E. The chicks were in the fledgling stage and only one chick was there in one of the nests, while other two nests were empty. It is a wading bird of the family Ardeidae distributed throughout South East Asian countries, categorized as least concern by Birdlife International (Ali & Ripley, 2001, Grimmet *et al.,* 2011, Birdlife International, 2015).

3.3.4.2 Short-toed snake eagle

A short-toed snake eagle (*Circaetus gallicus)* nest also was observed inside the wind farm with one chick and it was 150 m far from the nearby wind turbine.

3.3.4.3 Red-rumped swallow

Houses and temples around the wind farms support nests of red-rumped swallows (*Cecropis daurica)* in the study area and opportunistic observations on nest locations were noted down. A total of 3 nests were recorded from the study area.

This data on nests are completely opportunistic records, only intensive nest search in the study area would give better information on nesting at this location.

3.3.5 Road Kills

The bird's carcasses observed on roads were of three species namely, Greater Coucal (*Centropus sinensis*), Large grey babbler (*Turdoides malcolmi*), and Laughing dove (*Spilopelia senegalensis*). The estimated bird road kill rate was 0.25 birds/ km/Year. The actual rate might be higher since the rate of removal of the carcass was very high from the roads because of the movements of the vehicles and the open accessibility for various scavengers including domestic dogs. (This could not be duly accounted for during the road mortality estimate). All the observations indicated that native granivorous birds were at maximum risk of mortality by road traffic.

3.3.6 The flight pattern of birds in wind farm

Fifteen species of birds belonging to fourteen families were sighted within the select turbines monitored during the study for the flight height. Among the three zones ('A', 'B' & 'C') monitored during the study, we observed a maximum number of birds in the lower zone ('A' zone) followed by 'B' zone and 'C' zone respectively. Flight height observations comprised of fifteen species of birds during the 112 hours of field observations in total. Only four species of birds were recorded using the 'B' zone (the risk zone) and they all were raptors (Bonneli's eagle (*Aquila fasciata*), Short-toed snake eagle (*Circaetus gallicus)*, Black kite (*Milvus migrans*), and Brahminy kite (*Haliastur indus*)). Eleven species of birds that flew through 'A' zone were Purple sunbird (*Cinnyris asiaticus*), Small minivet (*Pericrocotus cinnamomeus*), Black drongo (*Dicrurus macrocercus*), Sirkeer malkoha (*Taccocua leschenaultii*), Jungle babbler (*Turdoides striata*), Green bee-eater (*Merops orientalis*), Red-vented bulbul (*Pycnonotus cafer*), Bay-backed shrike (Lanius vittatus), Laughing Dove (*Streptopelia senegalensis*), Indian robin (*Saxicoloides fulicatus*), and red-rumped swallow (*Cecropis daurica*). Most of the birds kept a safe distance from turbine blades and raptors were often observed in shallow valleys among the hills where the turbines were absent.

Three different time slots during the day were monitored to record the temporal changes in the activities of birds at wind turbine sites. The three-time slots were 8-10 am, 10:30 am to 12:30 pm and 1:30 pm to 3:30 pm. The bird diversity in the wind turbine area was maximum in the first-time block (8:00 am to 10:00 am). However, unlike other avifaunal species, raptors were more active in second- and third-time blocks (10:30 am to 12:30 pm and 1:30 pm to 3:30 pm).

3.3.7 Observed bird mortalities

All carcasses sighted within 100 m of the turbine base were attributable to direct collision with turbine blades, as was evident from the injury marks on the carcass were recorded. Seven fatalities of birds were recorded during the study in the wind farm area. Out of the bird mortalities, three bird carcasses were not intact and could not be identified because of the unavailability of intact carcass (because of partial scavenging). The bird carcasses observed included Indian Pitta (*Pitta brachyuran),* White-throated Kingfisher *(Halcyon smyrnensis),* Little swift *(Apus affinis),* one unidentifiable raptor species, and few unidentifiable passerines.

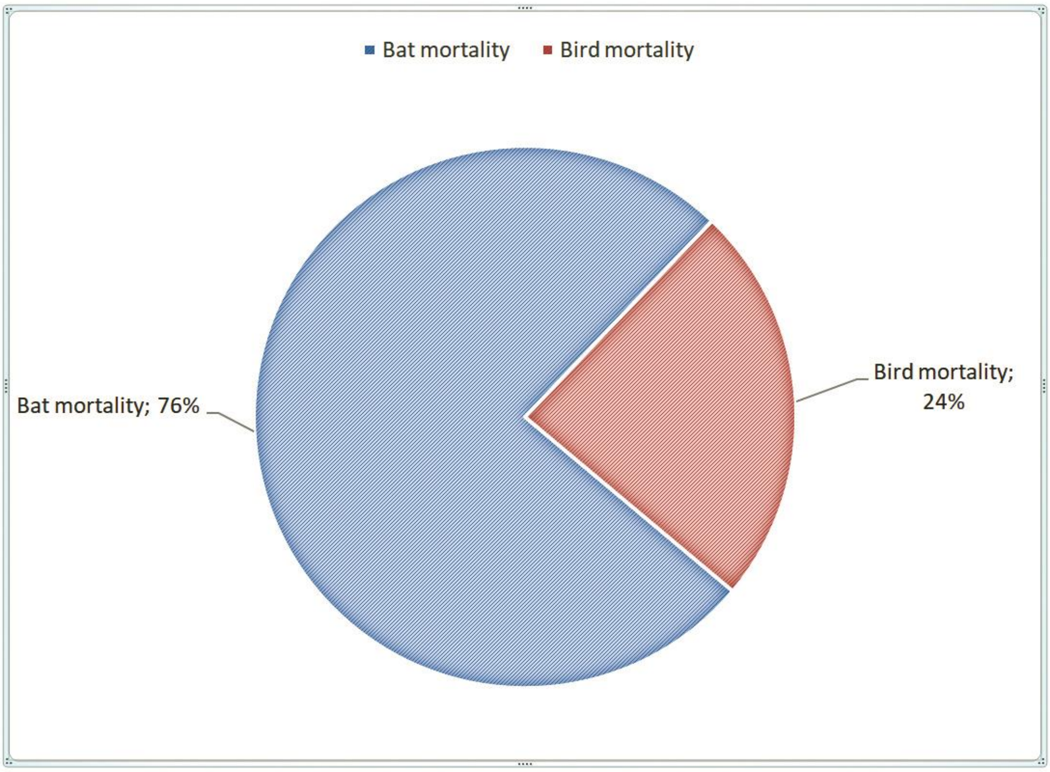


Figure 3.7.1 Bird and Bat Mortalities records

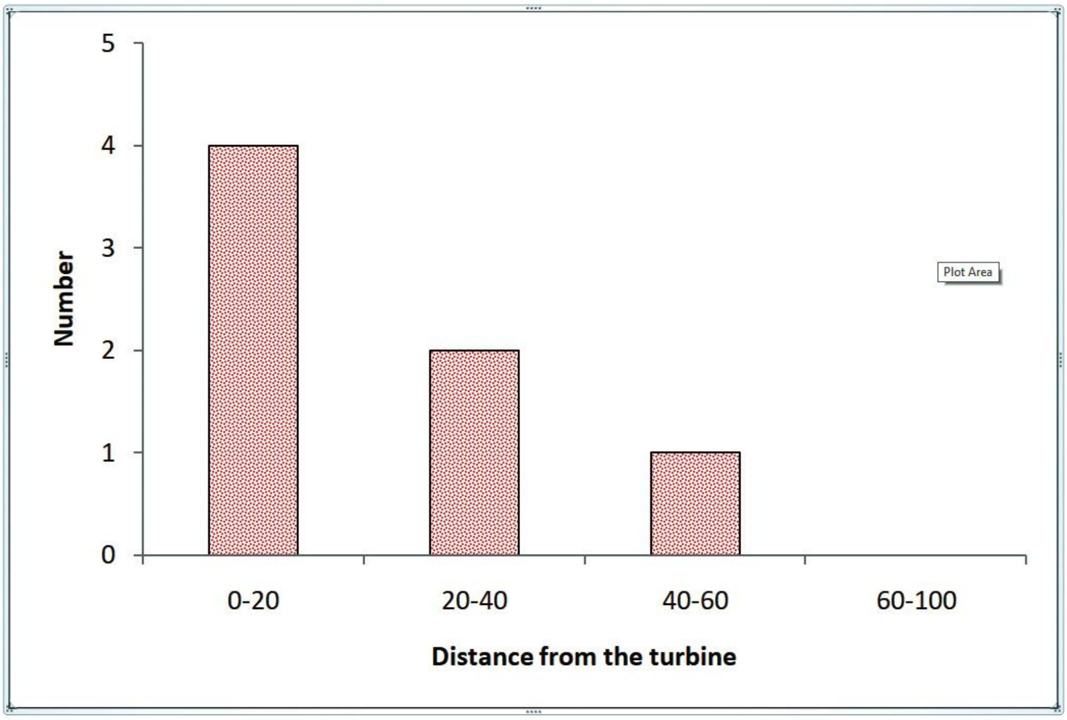


Figure 3.8. Distance of carcasses from the base of the turbine

3.3.8 Mortality Rate Estimation

During the entire study, seven bird mortalities were recorded from the Hara wind farm. In the case of Birds 'Σ ti' was 5 days. Hence the mean residence time of carcass in the field for birds was = 5/2 =2.5 days

The estimated annual mortality rate (M) at the wind farm during the study period from the farm was 11.2 birds per year

$\therefore$ Mean Annual Bird Mortality per turbine = 11.2/ (no. of turbines)
= 11.2/24 =0.47

$\therefore$ Bird mortality rate = 0.47 birds/ turbine/ year

3.4 Discussion

A total of 531 species of birds have been reported from the state of Karnataka (Praveen *et al.*, 2016) and 115 of them were documented in the present study. Many threatened and endemic birds reported from other parts of Karnataka were absent in the study area probably because of the vast geographical diversity of the state, for example, there are 16 endemic bird species in Karnataka part of Western Ghats.

In general, maximum birds are belonging to the order Passeriformes in Davengere. Besides the Passeriformes, birds belonging to the order Accipitriformes were common in different habitats of the study area including the wetlands and agriculture fields. Four species of birds that are documented from the study area comes under different IUCN threatened categories such as near threatened and vulnerable, highlighting the importance of the avifauna of the area. The widely dispersed lakes and good patches of dry forest in the Davangere district support a good number of birds. Though the number and area of water bodies are comparatively less in the study area, 46 water birds were documented during the study. Harisha *et al.*, 2011 had reported 53 species of waterbirds including three globally near-threatened birds, Oriental White Ibis (*Threskiornis melanocephalus*), Oriental Darter (*Anhinga melanogaster*), and Black-tailed Godwit (*Limo salimosa)* in Kundavadai Lake of Davangere which is about 41 Km from the present site (Harsha *et al.*, Praveen *et al*.,2016).

Even though the study area has good diversity of birds, bird collision on wind turbine was comparatively less than other Indian and global studies (Arun *et al.,* 2015, Pande *et al.,* 2013). Globally, various studies have reported a mortality range of 0 to 64.1 birds/ turbine/year (Lekuona, 2001; Hötker, 2006). However, the estimated annual bird mortality rate from the present study area, 0.47 birds per turbine is significant evidence that wind turbines do cause bird mortalities and it is a cause of concern for the conservation of avifauna in the area. Furthermore, the bird species affected by the wind turbine in an area is completely dependent on the species composition and population densities of the birds of an area (Kumar *et al.*, 2017). Even though the reported morality from the Harapanahalli area during the current study period is less, it is essential to conduct more studies in various parts of the country to understand the magnitude of impact in other areas and wind farms across the country.

Nesting of three species of birds such as grey heron (*Ardea cinerea*), Short toed snake eagle (*Circaetus gallicus*) and Red-rumped swallow (*Cecropis daurica*) was observed close to the wind farm during the study. Earlier studies from India reported the avoidance behaviour of raptors to the wind turbines but the observed raptor nest was within 150 m radius from the base of a turbine is contradictory to the available information (Kumar *et al.,* 2017). Furthermore, studies from Europe and North America reported many causalities of raptors including young ones (Watson *et al.,* 2018). Evaluation for spatial planning to install wind turbines based on nesting and distribution of many species such as Golden eagle (*Aquila chrysaetos*) in the United States was a great success (Miller *et al.*, 2014) and this study also highlights the importance of spatial planning in wind farm installation based on bird distribution to mitigate the impact of wind turbines.

Nesting sites of Grey Herons (*Ardea cinerea*) are reported to be rare in India and around 80 sites are recorded from all over the country (Subramanya, 1996). The Grey heron (*Ardea cinerea*) nest was observed near to a natural pond, 3Km away from the wind farm. The dry deciduous forest patches and adjoining agricultural fields with few wetlands support various wetland bird species, forms a special ecosystem (Mashiko & Toquenaga, 2014). Studies elsewhere have shown that the nesting sites of various colonial waterbirds in India are under serious threat due to anthropogenic pressure and natural calamities (Subramanya, 1996 & Basavarajappa, 2011). Reducing the pressure from anthropogenic disturbances around the wetland areas and protecting the nesting trees would be helpful for these water birds to establish and maintain their nesting colonies.

Future studies in wind farm operating areas at the entire Deccan plateau will only give the spatial changes in the impact of wind farms on birds. Studies on bird collisions at wind farms are important as India has very scarce information on wind farm-related bird collisions compared to European countries.

Red-wattled Lapwing (*Vanellus indicus)*

Woolly-necked stork (*Ciconia episcopus*

Painted stork (*Mycteria leucocephala)*

Little egret (*Egretta garzetta)*

Grey Heron (*Ardea cinerea)*

Black- winged stilt

Short- toed snake eagle (*Circaetus gallicus*

Red-rumped swallow (*Cecropis daurica)*

Plate 3.1. Some of the birds recorded during the study

Unidentified raptor

Little swift *Apus affinis*

Little swift *Apus affinis*

Indian pitta *Pitta brachyura*

Plate 3.2. View of some of the observed mortality records during the study

4 IMPACT OF WINDFARM ON BATS

4.1 Introduction

Several Studies on the potential impact of wind farms on wildlife are done in Europe and United States of America (Arnett *et al.,* 2005, 2008; Johnson *et al.,*2002, 2003; Kern & Kerlinger, 2004; Osborn *et al.,* 2000). Even though the installation of wind farms started in India in the early 80s, studies on the impact of wind farms on wildlife are scarce (Pande *et al.,* 2013; Madhu & Payal, 2014; Arun *et al.,* 2014, Arun *et al.,* 2015).

The operation of wind farms is a major threat for birds and bats. Globally, studies have concentrated mainly on birds, so that the knowledge on the impact of wind farms on bats in different habitat and landscapes are minimum (Arnet *et al.,* 2008). The major reported impacts of wind turbines on bats are, from direct collision of bats on wind turbines, displacement of the species, creation of movement barriers, and habitat alteration due to wind farm installation which in turn negatively affects their reproductive rate as well as hibernation (Kumar, S. R *et al.,* 2013, Pande, S *et al.,* 2013, Kunz *et al.,* 2007, Arnet *et al*., 2008, Max T. E., 2008, Larsen & Madson, 2000, Fox *et al.,* 2006, Larsen & Guillematte, 2007). A total of 128 bat species with 115 micro chiropterans and 13 mega chiropterans are reported from South Asia. Among the South Asian countries, India has 90% of the total bat diversity (Srinivasulu *et al.,* 2010). Understanding the cumulative effect of wind farms on bats is low in India as there is limited basic information on the bat population (Srinivasalu *et al.,* 2010). The bat population is declining all over the world due to anthropogenic threats and different diseases (Frick *et al.,*2020). Unprecedented installation of wind turbines is an additional threat to bats (Arnett, 2008). Large level installation of wind turbine is reported as a threat for bats as they have low reproductive life and long-life span (Barclay & Harder, 2003).

The identified consistent patterns of bat collision on wind turbines from Europe and North America are; migratory bats are more prone to the collision; there were no much changes in bat mortalities in individual wind turbines; bat collision has no relationship with habitat variables (Arnet *et al.,* 2008). Studies from Europe and North America shows that a greater number of bats are getting killed in wind farms than other anthropogenic structures (Arnet *et al.,* 2008). Few studies from North America identified that the height of the turbine and forest cover of the area are the important variables in the direct bat collision on wind turbines (Barclay *et al.,* 2007, Thompson *et al.,* 2017). Huso *et al.,* 2011 argued that bat mortalities are more site-specific. For example, the mortality of bats by the wind turbines in the United States of America varies from 15.3/MW/ year to 53.3/MW/ year (Kunz *et al.,* 2007, Arnet *et al.,* 2008, Fielder *et al.,* 2007). More studies are required in different landscapes to clarify the role of other unidentified habitat and climatic variables in the bat collision with wind turbine blades (Huso *et al.,* 2016).

Weather variables and turbine locations also play a role in the direct collision of bats on wind turbines, that varies based on the landscape (Baewarld, 2011). Compared to the wind farm locations in the developed countries, India has moderate and pleasant weather and the impact of this spatial specific variation in the bat mortalities at the wind farms has to be studied. From India, there are less available reports of the direct collision of bats by wind farms (Kumar, S. R., 2013). Our goals in the study were to identify the site-specific impact of wind farms on bats in the selected study area at Karnataka. In this study, I examined the impact of wind turbines on bats in the study area.

Following major questions are addressed in this chapter

1. What are the spatio-temporal patterns of bat collisions in the selected wind farm?
2. What are the major factors influencing the bat mortalities in the wind farm?

4.2 Methods

The major studies on the impact of wind farm operations on bats are done in Europe and North America and followed different methodologies based on the research questions and study area. Most of the research studies on wind farm-bat interactions are focused on the bat mortalities in wind farms. Arnet 2006 used trained dogs to search the carcasses and he found that dogs are tracing more carcasses in the field than humans. The ratio estimation of bat collision on wind turbines are done by different methods and statistical models. The bat mortality data for unsearched areas are estimated by using many models such as General Linear Models, ratio, weighted and non-parametric methods (Maurer *et al.,* 2020). Some studies shows that impact of wind farms on bats varies in pre and post construction of wind turbines (Santos *et al.,* 2010). Few studies covered large landscape to understand the spatial changes in bat collision on wind turbines (Arnet *et al.,* 2008). The methodologies used in this study are as follows.

4.2.1 Mortality / Carcass Searches

Searches were done for 40 minutes in a 100 m radial zone from the base of each turbine. A total of 24 turbines were selected for the sampling in the study area. The details on remnants of bats that might have died/ injured because of collision with the turbine were documented. Whenever an injured or dead bat was detected, the species name, injury level, distance from the turbine, and approximate time of death/ injury (following Orloff & Flannery, 1992; Christensen *et al.*, 2003) were recorded and was moved out of the counting zone to avoid repeated counting.

4.2.2 Scavenger removal rate

The scavenger removal rate at the wind farm area was estimated using field trials using dead bats. It was done to reduce the bias in mortality rate estimations because of the removal of a carcass by different scavengers from wind turbines sites.

During the mortality survey five bat carcasses were left in the field and the length of time each carcass remained on the field before being naturally removed or became undetectable was recorded, i.e., the number of days between the time the carcass was planted in the field and the last search date on which it could not be detected. The mean length of time a carcass remained on a plot (T) was calculated based on the following equation Erickson et *al.,* 2003.

$$T = \Sigma ti / S$$

Where ti is the length of time a carcass remained on-site, S is the total number of carcasses planted for the study.

The estimated number of annual fatalities (m) per turbine was calculated using the following formula from Jhonson *et al.,* 2003.

$$M = N \times I \times C / k \times t \times e$$

where N is the total number of turbines, ‘I’ is the interval between searches in days, ‘C’ is the total number of carcasses found ‘k’ is the number of turbines sampled, ‘t’ is the mean length of time carcasses remained on-site before being scavenged, and ‘e’ searcher efficiency. Since the areas under the turbines were relatively plain with a high (100%) chance of delectability of the carcasses during the initial trials, the searcher efficiency was considered as 100% for the calculations.

4.2.3 The role of bioclimatic variables in bat mortality at wind farms

The role of co-variables in the spatial pattern of bat fatalities in the study area was assessed through the analysis such as General Linear Models (GLM) (Mccullahgh & Nelder, 1983). Independent models are prepared with different variables by using the SPSS software. A total of 5 co-variables such as altitude, distance to the vegetation, distance to the village, distance to the water body, and NDVI were selected for the analysis. A correlation test was done with all available variables before finalizing the variables for GLM. NDVI data of each wind turbine have downloaded from the USGS website. Open source GIS software QGIS (https://download.qgis.org/) has been used for measuring, distance of sampling sites to the nearest village, vegetation, and water body. Altitude for each point was collected by using the GPS (Garmin etrex 20).

4.3 Results

4.3.1 Bat mortalities at the wind farm

18 bat carcasses were found during the one-year carcass search. Of which, 15 were of single species, Tomb bat (*Taphozous melanopogon)* and two were lesser mouse-tailed bat *Rhinopoma hardwickii* whereas the other one could not be unidentified. Tomb bats are insectivorous bats distributed all over the Indian subcontinent and the least concern in IUCN status.

All carcasses were found within a 60 m radius from the base of the turbine. The main scavengers here were Indian golden jackals (*Canis aureus)* and dogs *(Canis familiaris)*. The estimated annual mortality rate of the Tomb bat (*Taphozous melanopogon)* was 12 bats/ turbine (8 bats/ MW). Kumar *et al.,* 2013 data was considered along with the current data for estimating the fatality rate of bats in India, and it is 4.095 bats/ MW annually. Although the mortality rates across the country will not be uniform, if we take this as an indicative figure and crudely project the mortality of bats at wind turbines, the estimated potential of annual mortality of bats from the India's current installed wind capacity of 27151 MW would be about 111183 bats.

4.3.1.1 Spatial patterns in the bat collision on wind turbines

The number of bat collision was more in few wind turbines. Among the 24 turbines, 2 turbines had higher number of mortalities of bats (6 &2 no. respectively). A single carcass was found in another 9 wind turbines. No bat carcasses were found in the remaining wind turbine vicinities. The details are given below in the figure no.

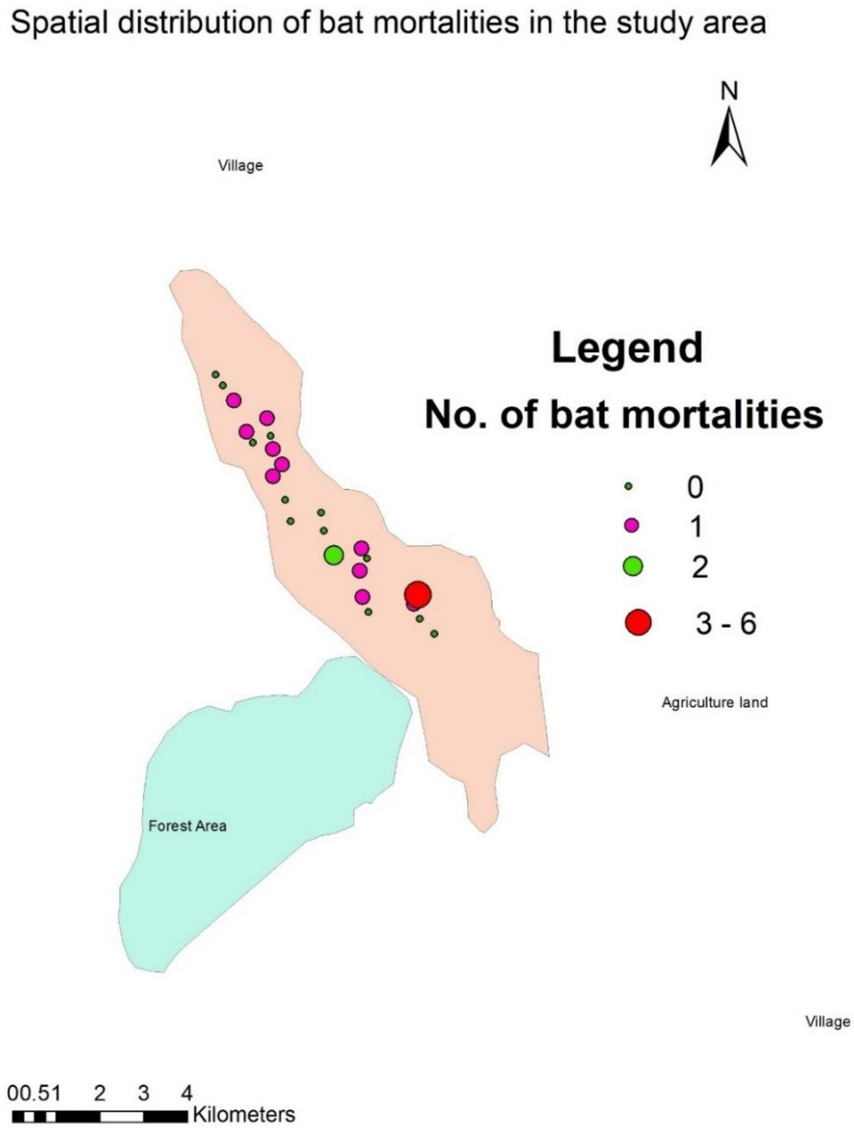


Figure 4.1. Spatial patterns in the bat collision on wind turbines

Table 4.2 Observed bat mortalities from the wind farm

No:	Date & Time	Common Name	Scientific Name	Turbine Number	Distance from the turbine (m)
1	Jan 24, 2014, 2.15 pm	Unidentified Bat		Turbine no. 10	35
2	Jan 27, 2014, 10.30 am	Tomb bat	*Taphozous melanopogon*	Turbine no. 3	50
3	May 6, 2014, 9.30 am	Lesser mouse – tailed bat	*Rhinopoma hardwickii*	Turbine no. 4	4
4	May 6, 2014, 9.40 am	Lesser mouse-tailed bat	*Rhinopoma hardwickii*	Turbine no. 4	7
5	May 6, 2014, 9.45 am	Tomb bat	*Taphozous melanopogon*	Turbine no. 4	5
6	May 6, 2014, 9.45 am	Tomb bat	*Taphozous melanopogon*	Turbine no. 4	5
7	May 6, 2014, 11.15 am	Tomb bat	*Taphozousmelanopogon*	Turbine no. 6	9
8	May 6, 2014, 3.50 pm	Tomb bat	*Taphozous melanopogon*	Turbine no. 20	6
9	May 7, 2014, 8.45 am	Tomb bat	*Taphozous melanopogon*	Turbine no. 9	8
10	May 7, 2014, 2.20 pm	Tomb bat	*Taphozous melanopogon*	Turbine no. 16	11
11	June 18, 1: 40 pm	Tomb bat	*Taphozous melanopogon*	Turbine no. 17	9
12	October 15, 2014	Tomb bat	*Taphozousmelanopogon*	Turbine no. 4	9
13	October 15, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 10	8
14	October 16, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 07	12
15	October 16, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 22	7
16	December 02, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 4	20
17	December 03, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 15	15

18	February 11, 2014	Tomb bat	*Taphozous melanopogon*	Turbine no. 21	7

4.3.1.2 Seasonal patterns in the Bat collision

There was a significant variation in bat mortalities at the wind farm among different seasons. Summer season had the maximum number of bat mortalities (44.44%) followed by monsoon (27.78%), winter (16.67%) and post monsoon (11.11%) (Figure no. 4.1). Moreover, out of 25 carcasses found in the wind farm, 18 were bats and remain 7 were birds (Figure 4.2).

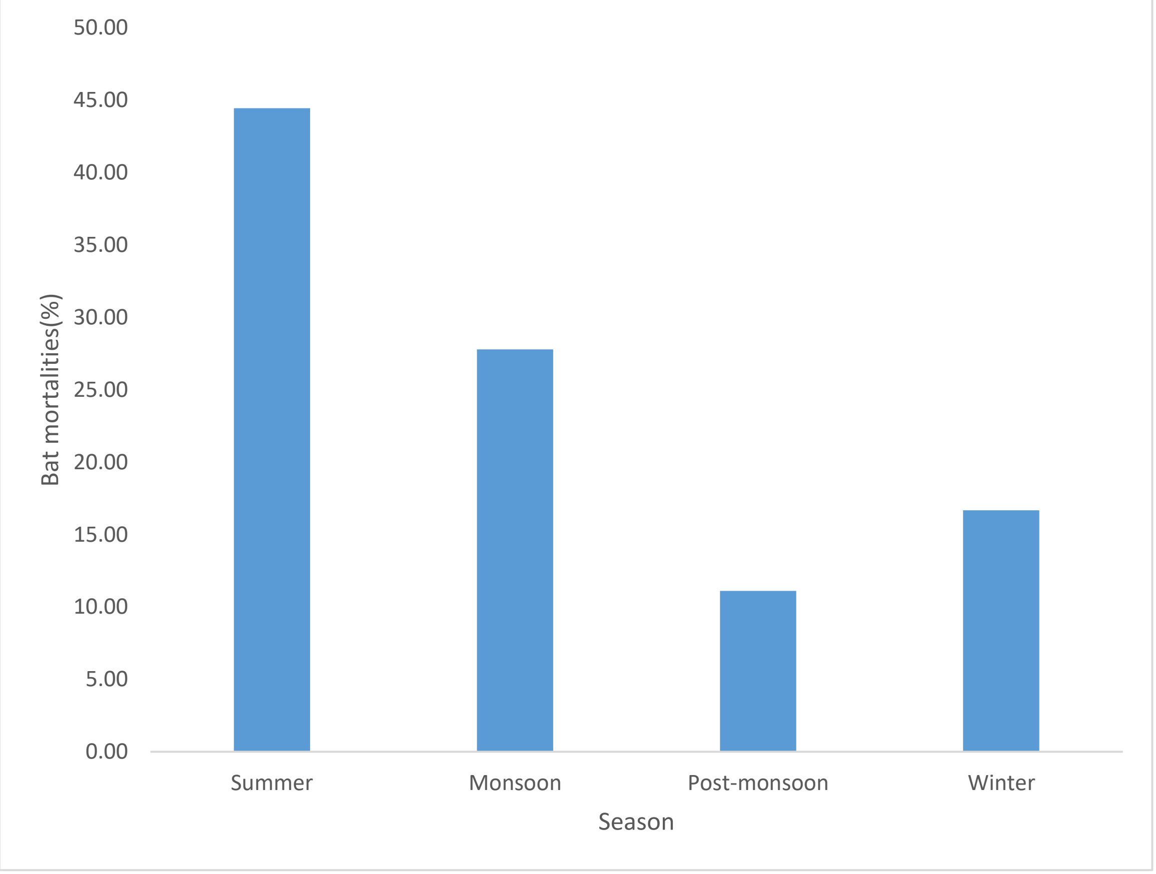


Figure no. 4.2: Seasonal pattern of bat mortalities in the wind farms

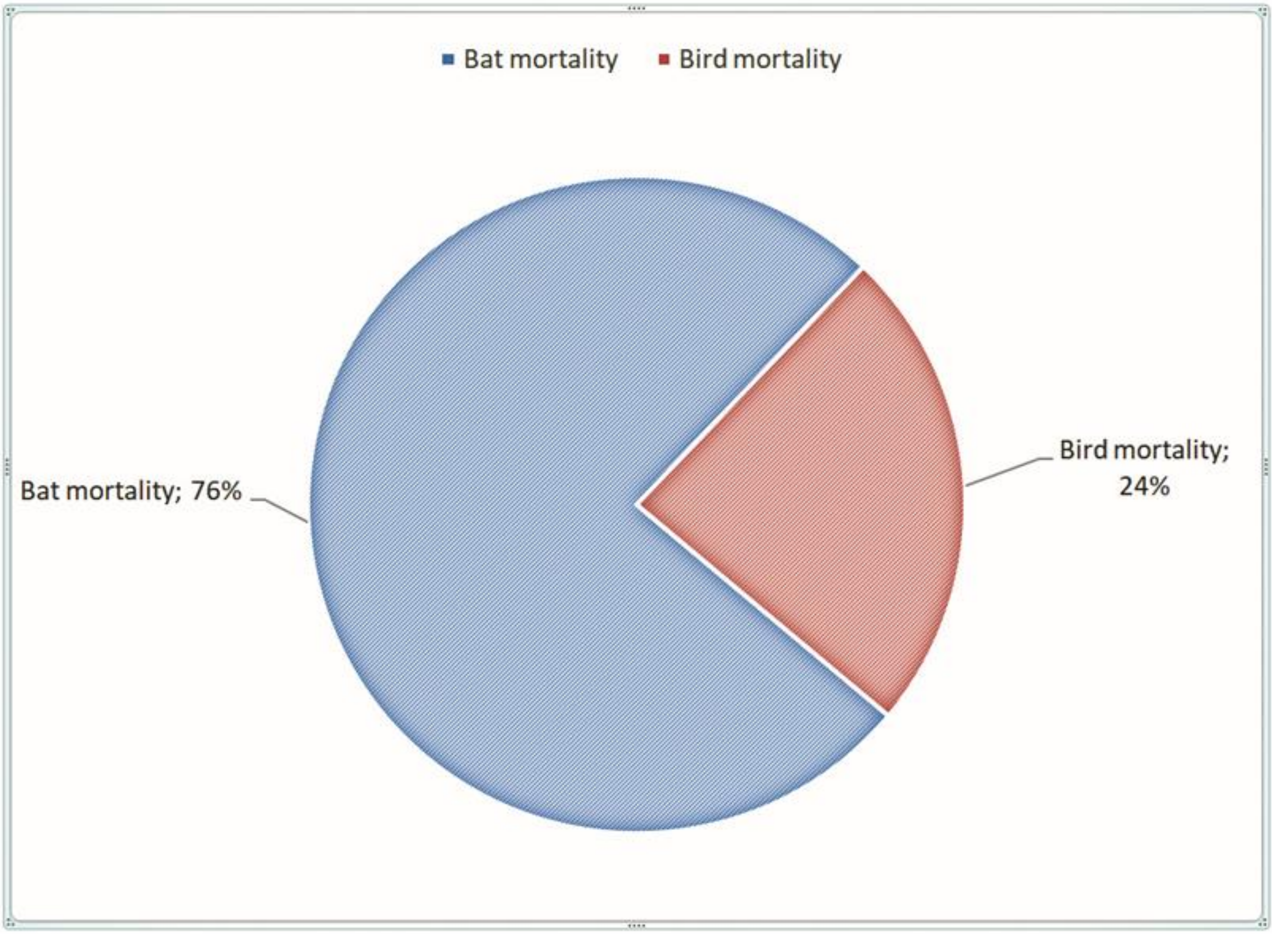


Figure 4.3 Recorded bat and bird mortalities from the study area

4.3.1.3 Role of covariables in bat collision

Among all the covariables, distance to the village from the turbine base has a significant correlation with bat collision (P = 0.04) on turbines in the study area (R^2 Value = 0.349, F = 4.89). Other variables such as distance to natural water body and forest, altitude, NDVI had no significant relationship. The range, minimum, maximum, mean, std. error and the deviation of the independent variable used for GLM analysis are given in the Table 4.2.

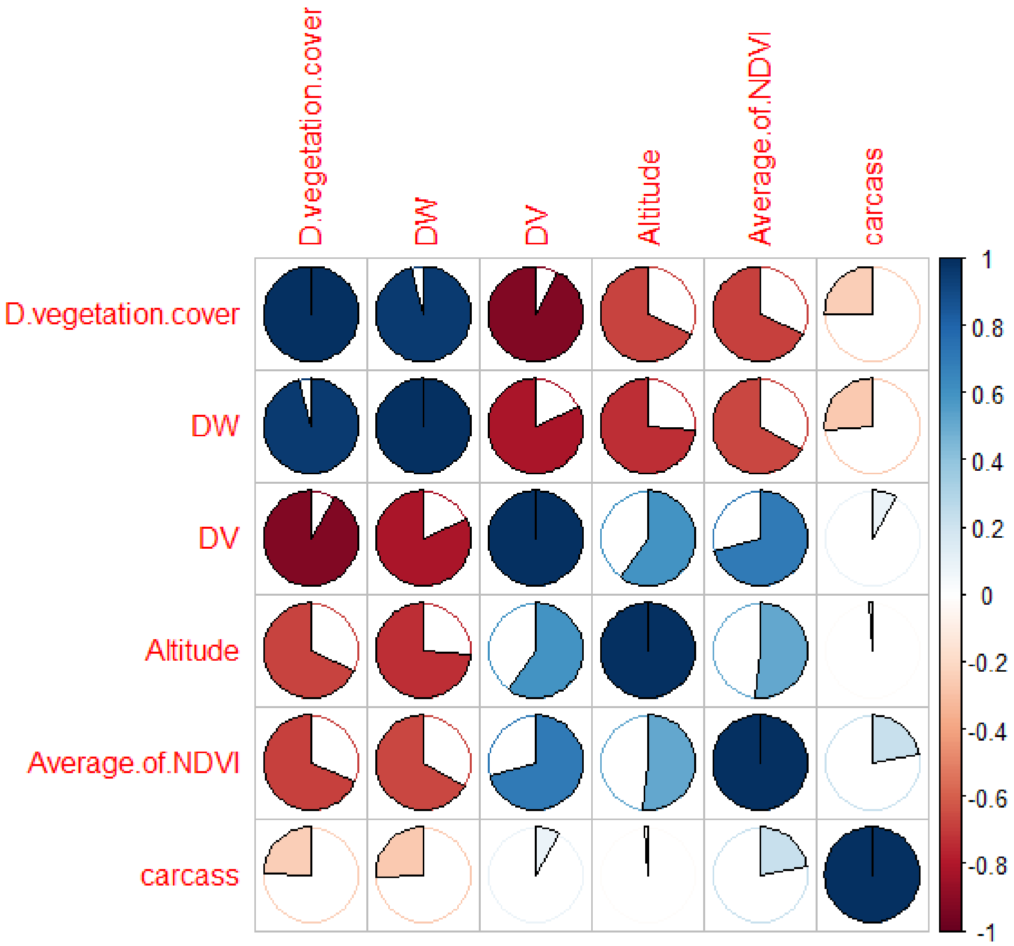


Figure 4.4. Correlation matrix of selected variables

Table 4.2 Results of GLM analysis

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20.906[a]	5	4.181	1.927	.140
Intercept	4.065	1	4.065	1.874	.188
Distance to waterbody (DW)	1.202	1	1.202	.554	.466
Distance to village (DV)	10.614	1	10.614	4.892	.040
Altitude	2.724	1	2.724	1.255	.277
NDVI	3.819	1	3.819	1.760	.201
Error	39.052	18	2.170		
Total	75.000	24			
Corrected Total	59.958	23			

4.4 Discussion

Studies from Europe and North America reported high rate of bat fatalities at wind farms, for example, a study reported 15.3 to 53.3 mortalities of bats per megawatt in the United States (Kunz *et al.,* 2007, Arnet *et al.,* 2008, Fielder *et al.,* 2007). In India, very few studies documented the bat fatalities at wind farms and the range of mortality of bats may vary if the sampling is extending to more different habitats because of the heterogeneity of land and the large size of the Country (Kumar *et al.,* 2013, Pande *et al.,* 2013). Among the studies in India, the maximum bat mortalities (8 bats/ MW/year) at wind farms are reported in this study. Kumar *et al.,* 2013 reported 2 bat collision incidents at a wind farm in Gujarat and the species was Greater mouse -tailed bat (*Rhinopoma microphyllum)*. There are very few reports of bat mortalities from India so that the estimated bat mortality estimation for entire India is an approximate figure and best with the available data. Different statistical models were used for the estimation of bat mortalities at wind farms in the large landscape (Maurer *et al.,* 2020). The estimation of bat mortalities at wind farm based on the annual electricity production (MW) is a customary methodology in the windfarm-bat interaction studies (GWPF report 2019).

Compared to the studies conducted outside India, the bat mortality rate in India is low. However, it is very high compared to other studies in India (Kumar *et al.,* 2013). The scavenger removal rate of bat carcass in the field varies from 1 to 2 days with an average day of 1.5 days.

The role of different habitat characteristics in bat mortalities at wind farms was also studied. Among the different co variables in the study area, distance to the village has a significant positive correlation with bat mortalities at the wind farm. The major variables influencing bat mortalities in Europe and North America are turbine height, season, and grassland in the wind farm proximity (Arnet *et al.,* 2008). In the current study, the turbines are with equal height and vegetation is dry deciduous so that both of these variables are not considered for the analysis. Moreover, Karnataka has no complete winter season as in tropical countries.

Wind turbine operation impacts each mammal species differently (Arnet *et al.,* 2008). A study from Europe shows that few species of mammals are avoiding wind farms to reduce the predator risk (Santos *et al.,* 2010). The study from Portugal (Santos *et al.,* 2010) showed a decline of vertebrate populations in wind farm sites. The reasons for the decline included direct disturbances, structural habitat changes, and behavioral segregations. The impact of wind farms is an additional threat to bio-diversity (Santos *et al.,* 2010).

India has rich diversity of bats and therefore the knowledge on the impact of wind turbine installation on different species of bats has a significant application in conservation policy development. This current study gives important data on bat mortalities due to wind turbines in India. As a high number of mortalities of bats due to wind turbines are reported from India, precautionary measures are necessary to mitigate the bat mortalities.

Plate 4.1. Bat mortality records from the wind farm

5 SYNANTHROPIC BEHAVIOR OF BLACK -NAPPED HARE IN WIND FARMS

5.1 Introduction

Incidentally, several countries are becoming more dependent in wind as a major source of energy. Many countries are promoting wind energy as part of their energy policy (Karydis, 2013; Mann & Teilmann, 2013). Countries such as Spain and Denmark generate more than 20% of total electricity from wind energy, and United State of America is aiming to achieve 30% of energy generation from wind by 2030 (Winder *et al.*, 2014 a, b; REN 21, 2014).

The rapid increase in establishment of wind farms has the potential to impact the wildlife. Most of the studies focused on the collision risk of birds and bats on wind turbine (Kunz *et al.*, 2008, Pearce-Higgins *et al.*, 2012). The major reported impact of wind farm on terrestrial mammals are habitat alteration, noise pollution, aesthetic impacts, vibration and shadow flicker effects, macro- and micro-climate change, predator attraction, fire incidents, and increase of direct mortality on wind farm (de Lucas *et al.*, 2005; Santos *et al.*, 2010; Lovich & Ennen, 2013). Few studies argue that the major impacts of wind energy production on mammals happens only during the construction phase and the mammals will get acclimate to the wind farms and other infrastructure after the construction phase (Helldin *et al.,* 2012). There are few studies with significant evidence for the negative impact of wind farms on small and large sized mammals. More research in the future will add more information on the direct and indirect impacts of wind farms on mammals.

Studies on the response of mammals, other than bats and marine mammals to wind farms are very scarce (Lopuck *et al.*, 2017). The behavioral responses of animals to the wind farm are completely species-specific (Lopuck *et al.,* 2017). Studies from Europe shows that few species of mammals such as Roe Deer (*Capreolus capreolus)* and European hare (*Lepus europaeus)* are avoiding interior and proximity of wind farms. The same study shows that the common pheasant (*Phasianus colchicus)* shows a positive response to wind farms and the red fox (*Vulpes vulpes)* is neutral in wind farm and control areas (Lopuck *et al.*, 2017). Another study shows that the survival rate of Agassiz's desert tortoises (*Gopherus agassizii)* is more in the wind farm facilities than the neighboring tortoises in the wilderness area and farther to the wind farm (Agha, M *et al.*, 2015).

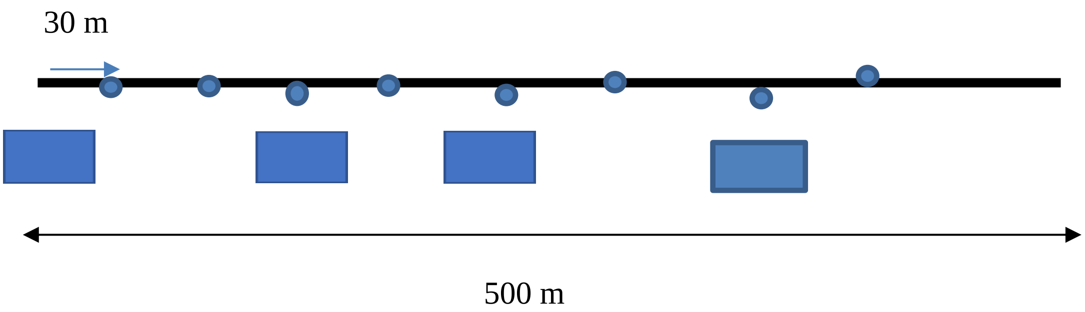
Recent studies have shown that birds and mammals adapt to adjust with development through synurbization (the process by which animals adjust to human-made habitat changes (Luniak, 2004, Lopucki *et al.*, 2013). This study examines whether the habitat use of the Indian hare (*Lepus nigricollis)* in the interior and proximity areas of wind farms shows any evidence of synanthropism (the propensity of an organism to associate with humans or altered habitats ecologically). Few studies suggest that the wind farms reduce the predator activities in the wind farm and which helps for the population hike of small mammals in the wind farm proximities.

The Indian hare (*Lepus nigricollis)*, also called Black-napped hare, and is a common species of hare in the Indian subcontinent, categorized as the least concern by the International Union for Conservation of Nature (IUCN) (Maheswaran *et al.*, 2008*)*. The species is also introduced in many of the islands like Andaman through human agency (IUCN, 2016). During the field survey for studying the impact of wind farm on birds and bats, the indirect evidences from wind farm and control sites showed a big change in Black-napped hare (*Lepus nigricollis)* population and a study was designed. I have tested the null hypothesis of no effect (Positive and negative) of wind turbines on the Black-napped hare population.

5.2 Methodology

5.2.1 Pellet count method

The main method used to document the activities of black -napped (*Lepus nigricollis)* hare was 500 m linear transects. Pellet count survey was done along all the transects. Four transects were laid in the Harada Forest reserve where two transects were within the wind farm and the other two were in the non-turbine areas of the forest (Control transects). Control transects were laid in such a way that the topography, vegetation, altitude and nature of the surroundings were similar to the wind farm area. A total of 16 quadrats were sampled in each transect, each quadrate has 2-inch width and 10 feet length perpendicular to each transect approximately at 30 m intervals (Krebs *et al*., 1987, 2001). The thin quadrates were sampled effectively by two persons and the number of all fresh pellets of hare found inside the quadrates was recorded. The new and old pellets were distinguished based on their colour. Only yellow colour pellets were considered as new.



The hare density at the study area was calculated from the pellet counts using the following equation (Krebs, 1989).

Hare density / ha = 1.567* EXP ((0.888962* (LN (mean no. of pellets per quadrate)))- 1.203391)

5.3 Results

5.3.1 Black-napped hare (*Lepus nigricolis*) population

Independent samples t-test was used to compare the pellet count data in the two sites. Since the data set did not follow a normal distribution (Kolmogorov-Smirnov value- 0.00), we transformed the data to log 10 which confirmed normal distribution (Kolmogorov-Smirnov value - 0.190). During the study, the Black-napped hare (*Lepus nigricolis*) was found to be using the wind farm areas more (3.34 individuals/ hectare) than the non-turbine area (1.37 individuals/ hectare) (t (df = 56) = 2.93, P = 0.005).

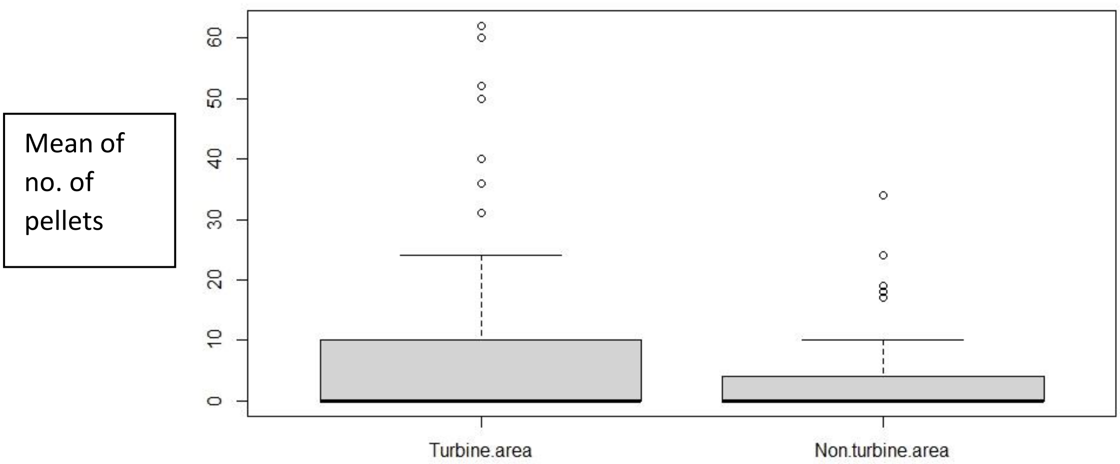


Figure 5.1: Pellet count data

5.4 Discussion

Terrestrial animals are also in a threat by the wind farm installation (Ennen *et al.*, 2012) whereas few studies shows that animals are adjusting to the wind farm during the operational stage of wind farm. Moreover, the impact of wind turbine operation impacts each mammal species differently (Lopuck *et al.*, 2017), and this study showed that the habitat alteration influences the habitat use of mammals in the wind farms. A study from Europe shows that few species of mammals are avoiding wind farms to reduce the predator risk. However, this result throws up a lot of new questions on the response of mammals to wind farm sites. The study from Portugal (Santos *et al.*, 2010) showed a decline of vertebrate populations in wind farm sites. The reasons for the decline included direct disturbances, structural habitat changes, and behavioral segregations. The Mediterranean region is known to be fire-prone and the impact of wind farms is an additional threat to bio-diversity (Santos *et al.*, 2010). Behavioural changes of California ground squirrels (*Spermophilus beecheyi)* in terms of their anti-predator call and displacement of European Hare *(Lepus europaeus)* and Roe Deer (*Capreolus capreolus*) because of predatory pressure in the presence of the background noise from the wind turbines are also reported elsewhere (Rabin & Owings, 2006, Kikuchi, 2008, Lopuck *et al.*, 2017). Studies from elsewhere show that the absence of predators especially raptors in the wind farm favours some of the prey species. Whereas, some species of herbivores shows a neutral response to wind farms (Lopucki *et al.*, 2017)

Wind turbine at Hyrada forest reserve was found as a significant factor influencing the Black-naped hare (*Lepus nigricolis*) population. When the black-naped hare (*Lepus nigricolis*) population estimates in the wind turbine area and control site were analyzed using an independent t-test, a significantly higher number of Black napped hare (*Lepus nigricolis*) was found in the wind farm area than in control sites. The role of predatory pressures, competitors, and forest fire regimes will be worth looking into in future studies for understanding the dynamics of mammal populations using wind farm areas. The role of various possible determinant variables that might have caused this difference was not examined during this study, however, this result throws up a lot of new questions on the response of mammals to wind farm sites. A detailed investigation is needed on this aspect to identify the factors which help the population of hares thrives in wind farm areas. Long term studies can provide more insights into the role of wind turbines and associated factors in the habitat selection of such faunal species. The present result indicates that apart from the well-known negative impacts of wind farms like mortality from the collision of birds and bats with turbines, there are other ecological phenomena like synanthropic associations fostered among other faunal groups such as small mammals that need further scientific attention. Moreover, studies should be carried out to confirm whether the predator pressure and age of the wind farms have a role in the behavioural changes in animals at wind farms (Lopuck *et al.*, 2017).

6 BAT MORTALITY RISK PREDICTION USING SPECIES DISTRIBUTION DATA AND WIND ATLAS

6.1 Introduction

Global warming and climate change affects the environment and living forms worldwide leading to threats such as famine, disease, drought, floods, regional insecurity and population displacements (IPCC, 2007). In addition, climate change and global warming will lead to global extinction of 15-37% species by 2050 (Thomas *et al*., 2004). Measures to mitigate global warming through a decarbonisation approach is carried out by governmental agencies all over the world (REN, 2019). Incidentally, the usage of conventional energy sources is one of the major reasons for the green-house gas emissions due to which countries are shifting to renewable sources of energy. Several countries are installing wind turbines in large scale because of its pollution free nature. India targets 175 GW energy from renewable sources by the year 2022. The potential areas of wind energy in India are documented by National Institute of Wind Energy (NIWE, 2014). Five states in India such as Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra and Gujarat have the maximum area of wind energy potential (NIWE, 2014). Despite its positive sides, the negative impacts of wind farms on environment and wildlife need to be addressed (Arnet *et al*., 2008; Kerns & Kerlinger, 2004). Development of wind farm facilities in the wildlife sensitive areas will have negative impact on threatened species. The small number of mortalities due to wind turbine operations are significant for the rare, endangered and long-lived species with relatively low annual productivity (Langston & Pullan, 2003), bats have low reproductive rates as well as low natural mortality (De Lucas *et al.*, 2012). The wind farms affect bats especially through collision with turbine blades and associated powerlines (Arnet *et al.,* 2008). Bat fatalities are reported recently in wind farms from Europe and North America (Kerns & Kerlinger, 2004; Arnet *et al.*, 2008; Barewald & Barclay, 2009, Rydell *et al.*, 2010). The other threats to bats by wind turbine operations are loss of foraging habitats, roosting sites and commuting corridors (Rodrigues *et al.,* 2008). Although reports on the direct collision of bats on wind turbine are scarce in comparison to other taxa such as birds, it is imperative to assess the long-term impacts of wind turbines on the bats to better understand the real risk potential. Studies on bat mortalities have been reported mostly in Europe and North America during their migratory season. As there are no reported migration of bats in India, the areas with rich species diversity are likely to have higher risk of bat collision with wind turbines (Arnet *et al.*, 2008; Rydell *et al.*, 2010).

The former research works documented the negative impacts of wind farms on wildlife, whereas the recent studies address measures to reduce the negative impacts of wind farm on environment and wildlife (Gartman *et al.,* 2016; Arnet *et al.,* 2016). The curtailment of wind turbines in the specific season was proposed by a few researchers to minimize the bird and bat collision on wind turbines (Marques *et al.*, 2014). Macro-siting and Micro-siting involve the selection of location for wind farm and subsequent selection of sites for wind turbines within the wind farm. Studies suggest this measure to mitigate impact of wind turbines (Garter *et al.*, 2016; Arnet & May, 2016). Ensuing mitigation measures on wind farms at pre-construction phases drastically minimizes the impact of wind farm on environment through following the different protocols (Arnet, 2015). Low bird collision on wind turbine was reported after the replacement of smaller turbines with larger turbines (i.e., repowering) in Europe and North America (Smallwood & Karas, 2009; Dahl *et al.,* 2015).

Studies from Europe suggests that mapping of threatened species distribution in the wind potential areas will be used as a 'spatial model' for predicting the threat of wind turbines on the species (Madders & Whitefield, 2006; Bright *et al.,* 2008; Morkūnė, *et al.,* 2020). Identification of bat sensitive areas will ensue the reduction in direct collision of bats on wind turbines (Arnet & May, 2008). The major measures to overcome the negative impact of wind farms on environment and living forms are the systematic data collection on wildlife in all potential areas for wind farm development and avoidance of wind turbine installation in the sensitive areas (Arnet *et al.,* 2016). All the environmental variables and wildlife distribution also should be considered while identifying the potential areas for wind farm operations, whereas only wind speed was considered in many former studies, which will help to formulate strategies to conserve wildlife in potential wind farm sites (Cellura *et al.,* 2008; Cowell, 2010).

Bats are one of the least studied taxa worldwide due to difficulties in sampling and identification. Globally, population data on bats are lacking so that it impedes the impact assessment of collision risk of bats on wind turbines (O'Shea *et al.,* 2003; Carrete *et al.,* 2009). The Karnataka landscape supports many species of bats of conservation importance, including three threatened species (IUCN, 2014, Srinivasulu *et al*., 2010). Data on spatial distribution of bat species is in a preliminary stage in Karnataka. Out of 120 species of bats reported in India, 59 species are distributed in Karnataka (Srinivasulu *et al.,* 2010). The impacts of wind turbines on bats are area-specific, for instance the bat mortality rates ranged between 15.3/MW/year to 53.3/MW/year in the USA. Though the installation of wind turbines has been started in India since 1984, the information on the spatial impacts of wind farms on different faunal species is very limited (Madhu *et al.,* 2014). The location of the wind farm is very important in bat conservation as even small increase in bat mortalities has serious conservation implications (Drewitt & Langston, 2006; Langston *et al.,* 2006; Stewart *et al.,* 2007). Even though studies in the past attempted to map the sensitive areas for bird collision on wind turbines, studies pertaining to bats in the same aspect are scarce (Bright *et al.,* 2008; Morkūnė *et al.,* 2020).

From India, only a few reports are there on bat collision with wind turbines but the increasing acceptance of wind farms and installation in different states of the country needs a proper selection of wind farm locations for safeguarding the species of conservation concern (Kumar *et al.,* 2013). This study presents to do an approach to prepare a baseline data to mitigate the bat-wind farm conflict in Karnataka.

In this chapter the following two major aspects are addressed

a. Estimation of the areas where the wind turbine installation might affect bats in the potential areas of wind energy development at Karnataka.

b. Use of GIS and remote sensing as a tool to help mitigate the negative impacts of wind energy production on bat species.

6.2 Methodology

6.2.1 Species selection

All the species of bats within the political boundary of Karnataka were considered initially for the study whereas selected species were considered for the analysis based on their conservation priorities and distribution (Bright *et al.*, 2008). Bat distribution data in Karnataka was collected from the online source, International Union for Conservation of Nature and Natural resources (IUCN) website. IUCN data is the only available uniform spatial data on bat distribution for Karnataka. Extensive literature survey was done before finalizing the species list for the study.

6.2.2 Wind Speed data

The spatial distribution data for wind speed in Karnataka state was collected from the National Institute of Wind Energy (NIWE), Chennai. There are seven different categories of areas based on the wind speed data. The seven categories of wind speed (Miles/ Hour) gradients in Karnataka are 0-5.4, 5.4-5.6, 5.6-6.00, 6.0-6.4, 6.4-6.7, 6.7-7.00 and >7.00 (Data source: GIS department, National Institute of Wind energy, 2015).

6.2.3 Mapping the risk potential for bats

The map was prepared using the software namely ArcGIS and ArcGIS Pro for each individual species of bat. The global data layer was clipped and intersected with the Karnataka political boundary in GIS software. The intersected layers of all the species were overlaid on wind speed data of Karnataka through the GIS plug-in called "Union". Gradient layers were prepared for each map using the tools from plug-in symbology. In addition, a composite map of bats in Karnataka was made with colour gradient based on the number of species present in each area to identify the areas with high bat diversity. In the composite map of bats in Karnataka, distribution data of 30 species were excluded as they have a wide distribution in all over the Karnataka State.

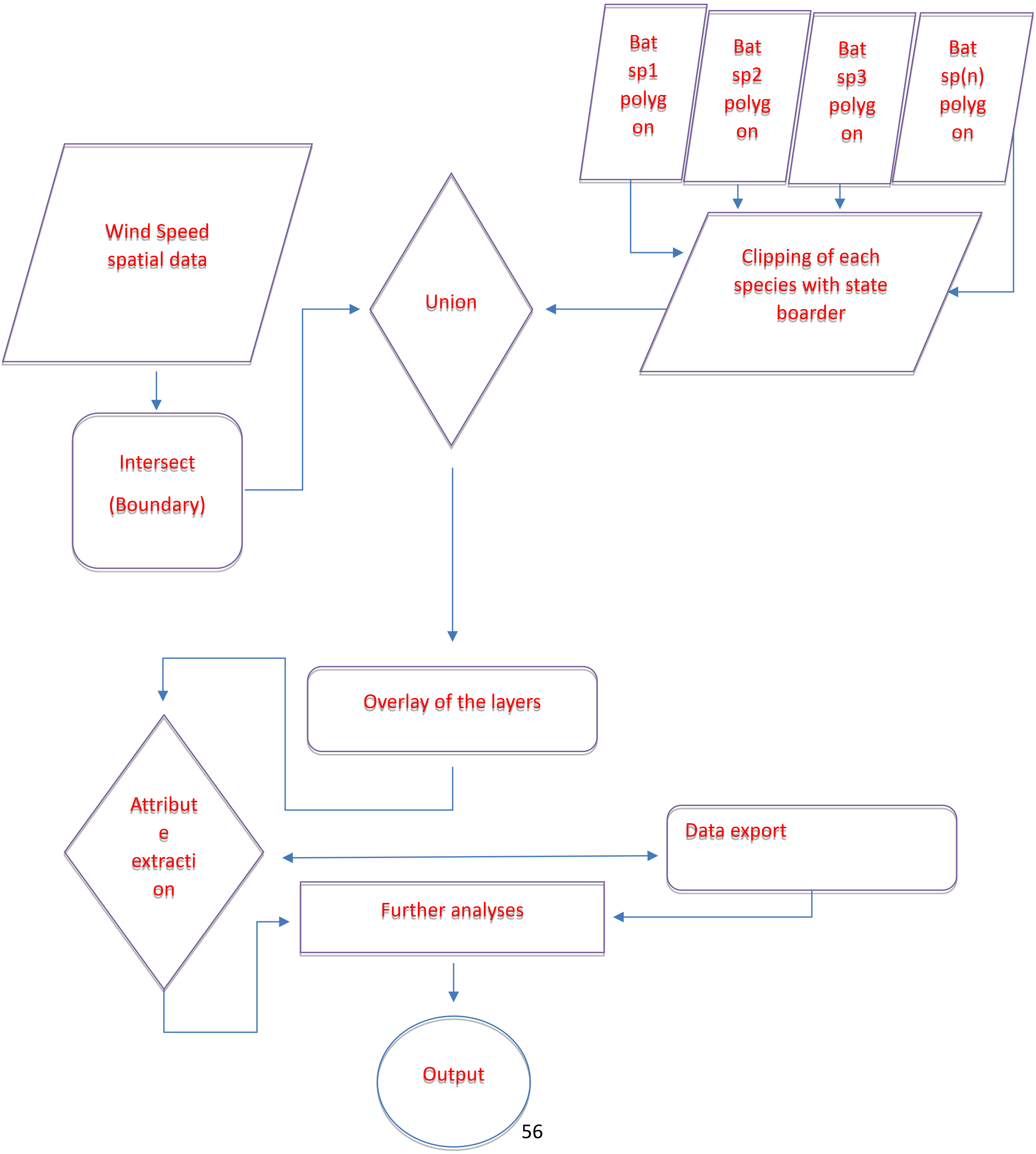

Bat sp1 polyg on
Bat sp2 polyg on
Bat sp3 polyg on
Bat sp(n) polyg on
Wind Speed spatial data
Union
Clipping of each species with state boarder
Intersect (Boundary)
Overlay of the layers
Attribut e extracti on
Data export
Further analyses
Output

FIGURE 6.1. FLOWCHART OF OVERLAY ANALYSIS

6.3 Results

Out of 59 bat species in Karnataka, 30 have wide-spread distribution in Karnataka whereas 29 has only restricted area of distribution. Out of the 7 categories of wind speed areas, a total of 42 species of bats are reported from the first category (0-5.4) followed by 41, 40, 40, 32, 27 and 17 in the other categories such as 5.4-5.6, 5.6-6.0, 6.0-6.4, 6.4-6.7, 6.7-7.0 and >7.0 respectively.

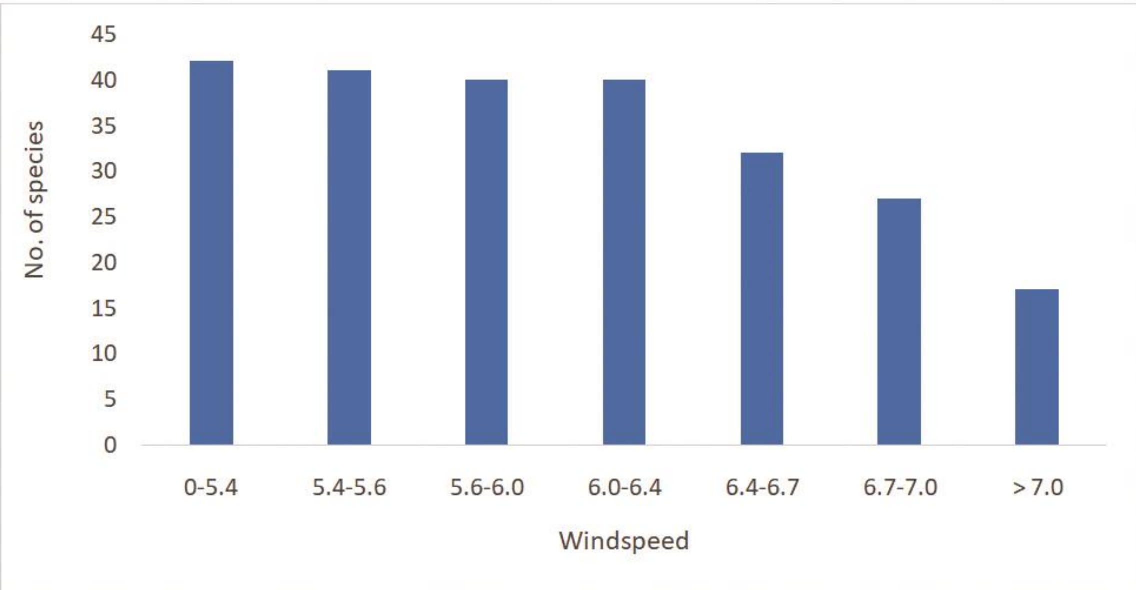


Figure 6.2 Bat species distribution in the wind speed gradients of Karnataka

6.3.1 Composite map of bat species in Karnataka

Compared to other part of the state, central Karnataka has the maximum potential areas of wind energy. The gradient map (Figure 6.3) presented below shows the spatial changes in bat distribution at Karnataka. The high species density of bats is in the western sides of Karnataka including the Arabian sea cost and Western Ghats. Less number of bat species are reported from the northern part of the state.

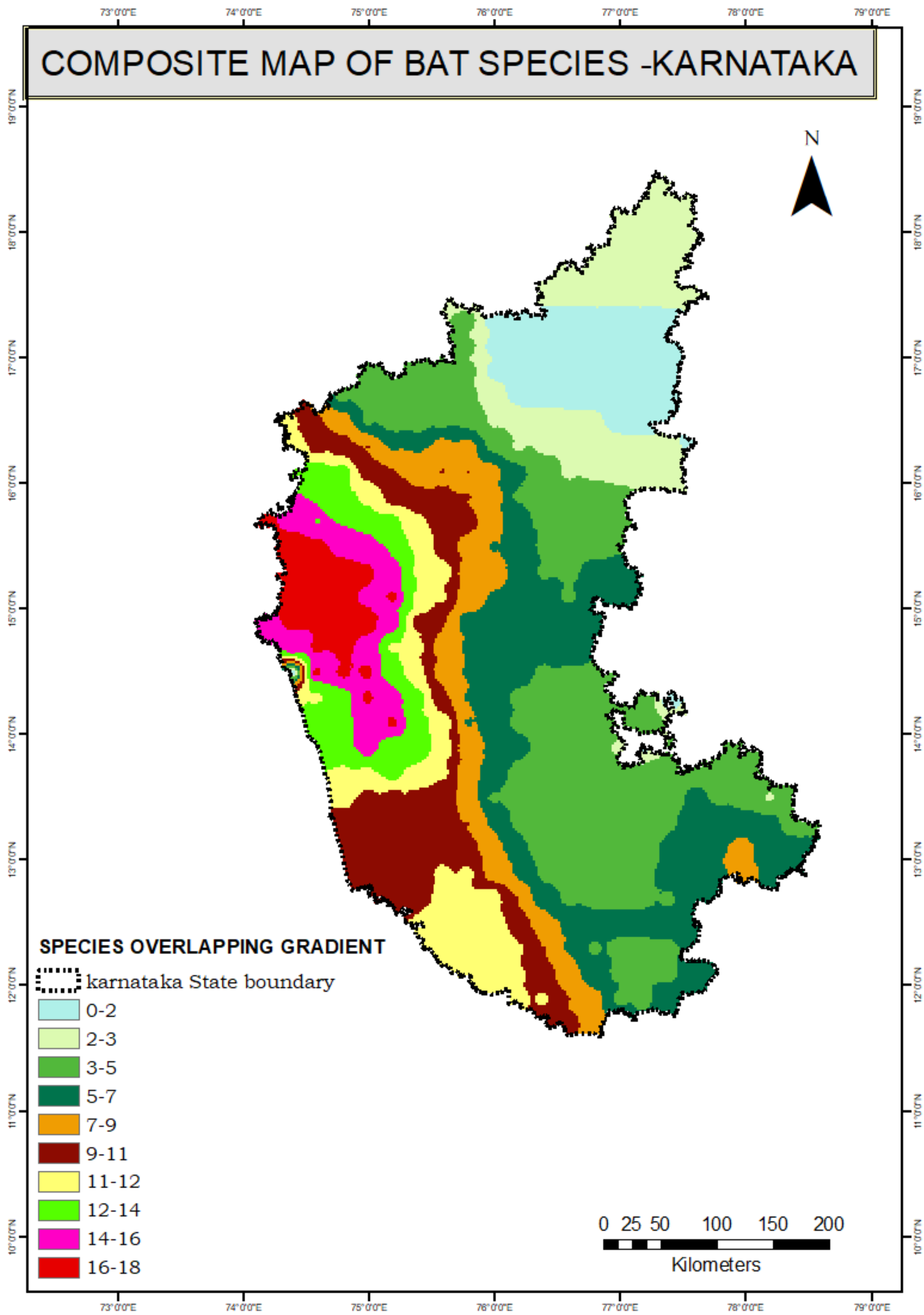


Figure 6.3 Composite map of bat species in Karnataka

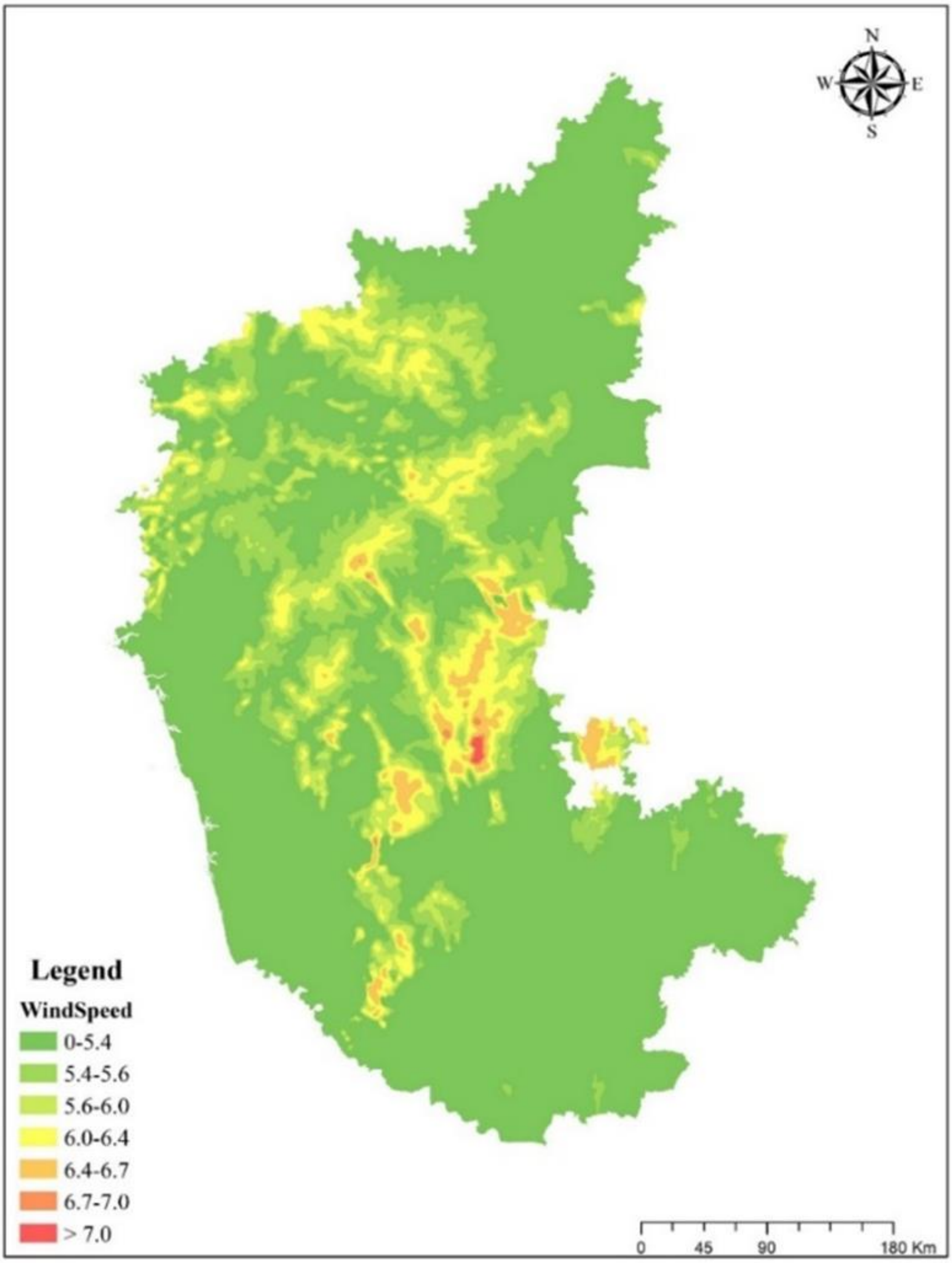


Figure 6.4. WIND SPPED PATTERN AT KARNATAKA

6.3.2 Overlay analysis

The details on the global distribution of each species used for the analysis are given below.

a. *Scotophilus kuhli*: *Scotophilus kuhli* is found in south and south East Asia and the data on the distribution, ecology and behaviour of the species are very scarce. They communicate through echolocation and are able to detect the objects at long distances in open areas. Whereas, studies reported that the bats cannot exactly detect the blades during the rotation (Zhu& Zhang 2012).
b. *Scotophilus kuhli*: The distribution of *Chaerephus plicatus* is in the coastal areas of Karnataka and are overlapping with the high potential areas of wind energy (Mcfarlane *et al.*, 2015).
c. *Saccolaimus saccolaimus*: This species is locally rare in many places like Sri Lanka, they prefer to occupy in the rocks, old trees and buildings. This species is found in a few locations in Karnataka.
d. *Taphozous nudiventris*: This species is distributed in two continents such as Asia and Africa covering many countries including the countries Egypt, Sudan, Somalia, Senegal, Eritrea, Congo, Kenya, Israel, Palestine, Jordan, Syria, Iraq, Iran, Yemen, Oman, United Arab Emirates, Bahrain, Afghanistan, and India (Asan & Albayrak 2007).
e. *Taphozous melanopogon:* This species is distributed in South Asia, South East Asia and Southern China.
f. *Megaderma spasma*: This species is distributed widely in South Asia and South East Asia.
g. *Hesperoptenus tickelli:* This species is distributed in many countries such as India, Sri Lanka, Nepal, Bhutan, Myanmar, Thailand, and in Southwest China
h. *Cynopterus brachyotis*: This species is distributed in Sri Lanka, India, southern Burma, Thailand, southern China, Indochina, Malay Peninsula, Sumatra, Java, Kangean Islands, Borneo, Bali, Sulawesi, and the Philippines
i. *Megaderma spasma*: This species has distribution in India and Sri Lanka to Indochina, Malaysia, Indonesia, and the Philippines.
j. *Pipisrerellus coromandra*: This species is distributed in Afghanistan, Bangladesh, Bhutha, Cambodia, India, Myanmar, Nepal, Pakistan, Srilanka, Thailand and Vietnam.
k. *Hipposideros durgadasi*: This species is endemic to India and reported only from Madhyapradesh and Karnataka (Kaur *et al.*, 2014).
l. *Hipposideros ater*: It is widely distributed in Sri Lanka and India in South Asia. In India, this species is known from Andaman & Nicobar Islands, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa and Tamil Nadu (Molur *et al.*, 2002).
m. *Scotozous dormeri*: This species is distributed in India, Pakistan and Bangladesh.
n. *Rhinolophus beddomei*: This species is endemic to South Asia (India and Sri Lanka).
o. *Rhinolophus rouxi*: This species is distributed in South Asia including India.

p. *Rhinolophus luctus*: This species distribution is restricted to South Asian countries such as Bangladesh, Cambodia, China, Indonesia, Loas, Malaysia, Myanmar, Nepal, Singapore, Thailand and Viet Nam (Baniya *et al.,*2019).

q. *Hipposideros galeritus*: The global distribution of the species is restricted to South Asian countries such as Bangladesh, India, Sri Lanka, Southeast Asia, Java, and Borneo (Debata & Palita 2017).

r. *Tadarida aegyptiaca*: This species is distributed different continents such as Africa and Asia.

s. *Myotis horsfieldi*: This species is distributed in South Asia and South East Asia.

t. *Miniopterus pusillus*: This distribution of the species is recorded from the countries India, Nepal, Hong Kong, Indonesia, Loyalty Island and New Caledonia.

u. *Tylonycteris pachypus*: It is found in Bangladesh, India, Myanmar, South China, Thailand, Laos, Cambodia, Vietnam to peninsular Malaysia, Philippines, Sumatra, Java, Borneo, Bali (Indonesia).

v. *Chaerephon plicatus*: The global distribution of the species is restricted to South and South East Asia. It is widely distributed in India.

w. *Eonycteris spelaea:* It is distributed in South and south east Asia (Acharya *et al.*,2015).

x. *Rhinolophus pusillus*: This species is distributed in South and South East Asia and India has a wide distribution of the species.

y. *Taphozous theobaldi*: This species is distributed in central and South India, and it is also reported from Cambodia, Myanmar, Thailand and Viet Nam.

z. *Myotis montivagus*: China, India, Myanmar, Malaysia and Indonesia have the distribution of *Myotis montivagus*. In India it is distributed in the states of Andhra Pradesh, Karnataka, Kerala, Maharashtra, Mizoram and Tamil Nadu

aa. *Kerivoula hardwickei*: This widely distributed species is recorded from South and South East Asian countries. In India, it is recorded from the states of Meghalaya, Nagaland, Jammu and Kashmir, Madhya Pradesh, Karnataka, West Bengal.

bb. *Otomops wroughtoni*: This species is restricted to India and Cambodia and In India It is recorded only from Karnataka and Meghalaya.

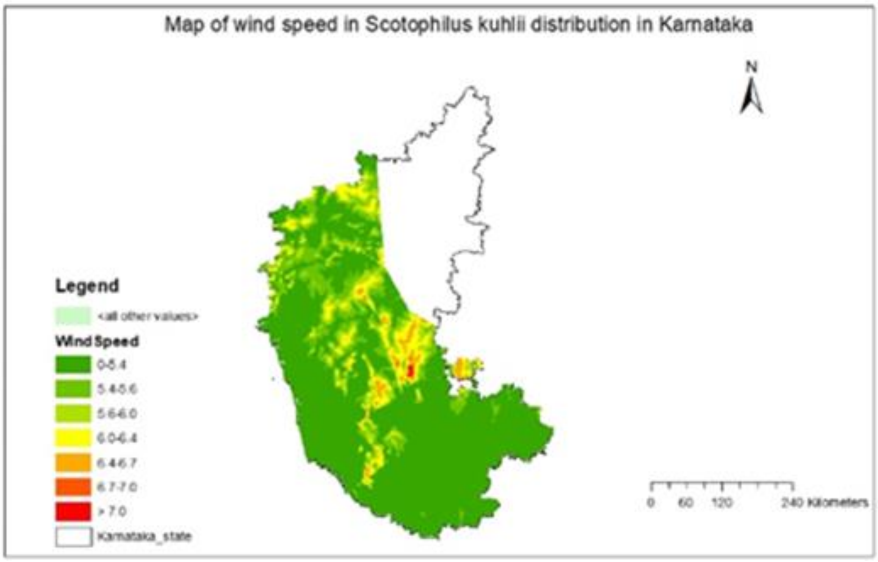
cc. *Hipposideros hypophyllus* : This species is endemic to the Kolar district of Karnataka and listed as endangered by IUCN (Srinivasulu *et al.,* 2014).

The analysis shows that the distribution of certain bat species in Karnataka state such as *Chaerephon plicatus, Eonycteris spelaea, Hesperoptenus tickelli, Hipposideros durgadasi, Hipposideros hypophyllus, Hipposideros Pomona, Kerivoula hardwickii, Miniopterus pusillus, Myotis montivagus, Otomops wroughtoni, Rhinolophus luctus, Rhinolophus pusillus, Taphozous nudiventris,* and *Taphozous theobaldi* are restricted to small patches and which highlights the conservation importance of these habitat patches.

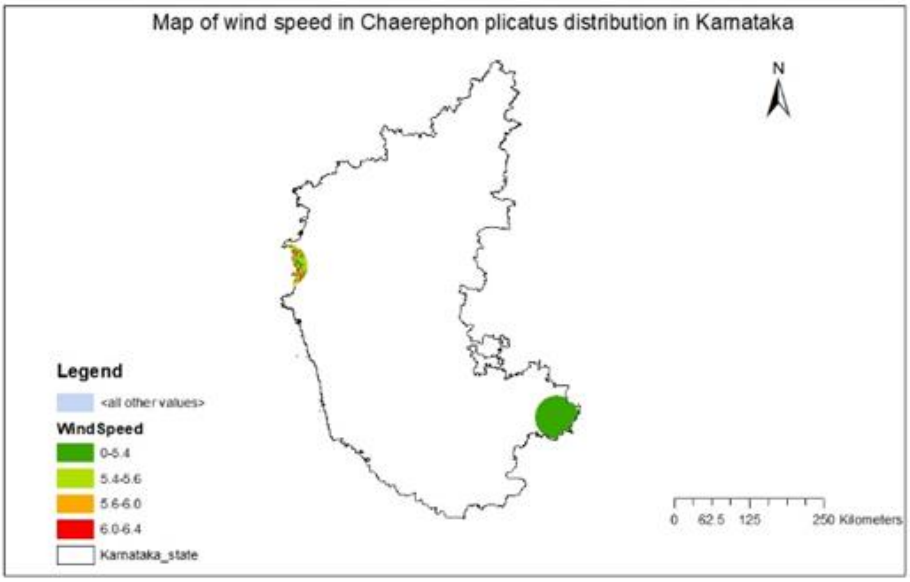
Three species such as *Hipposideros hypophyllus, Hipposideros pomona, Kerivoula picta* are belongs to the IUCN threatened categories (IUCN, 2021). The distribution of

Hipposideros hypophyllus is restricted to a small patch in the southern part of Karnatka, and it is in low wind speed area. Whereas the distribution of *Hipposideros Pomona* is restricted in a small area and overlaps with high wind speed area. *Kerivoula picta* is distributed in both Western Ghats and coastal areas of Karnataka. This area has a high wind speed area along the Western Ghats stretch. Furthermore, few least threatened bat species in Karnataka has very limited area of distribution (Eg: *H. durgadasi, R luctus, T. nudiventris, M. pusillus, C. plictus*).

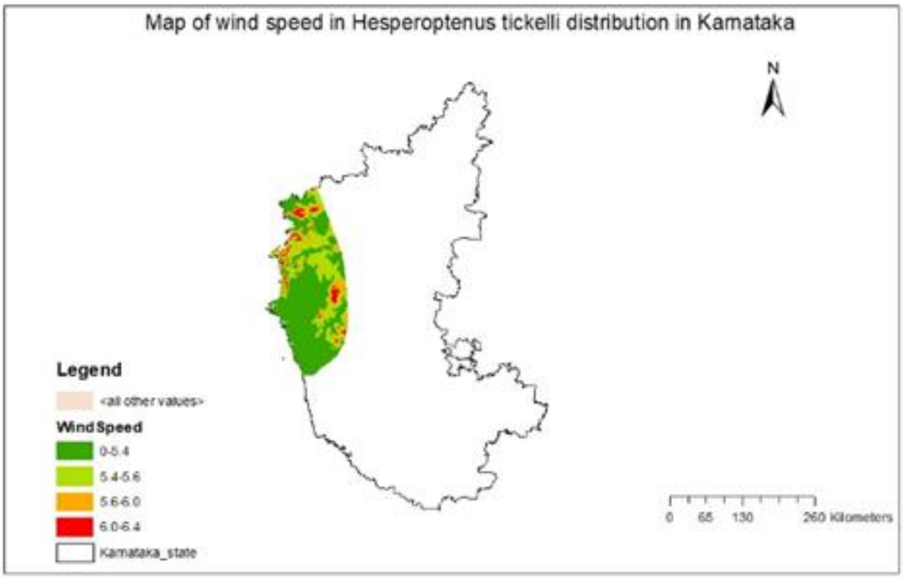
The detailed maps are given below.



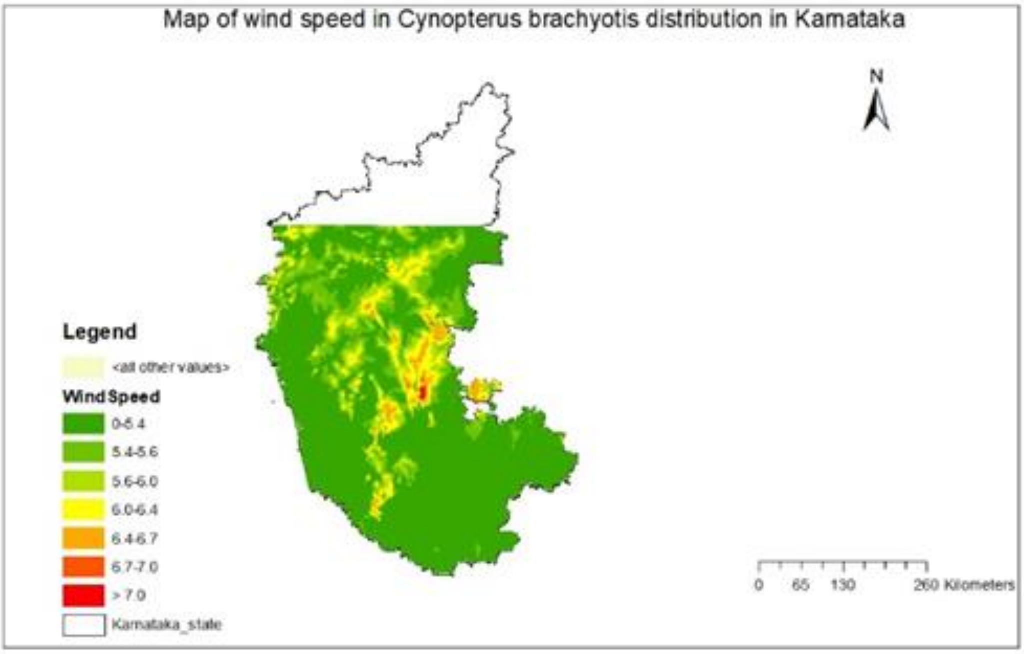
The overlay analysis shows that *Scotophilus kuhli* has wide distribution in Karnataka and overlapping with the potential areas of wind energy in the state. Though, *Scotophilus kuhli* is a widely distributed species, the overlapping of its distribution with high wind potential areas may cause severe impact on this species if there is any wind farm operation now or in the future. Whereas, studies and the data on the distribution of this species and its ecology is very scarce so that the real impact on this species by wind farm operation in its distributional range cannot be predicted.



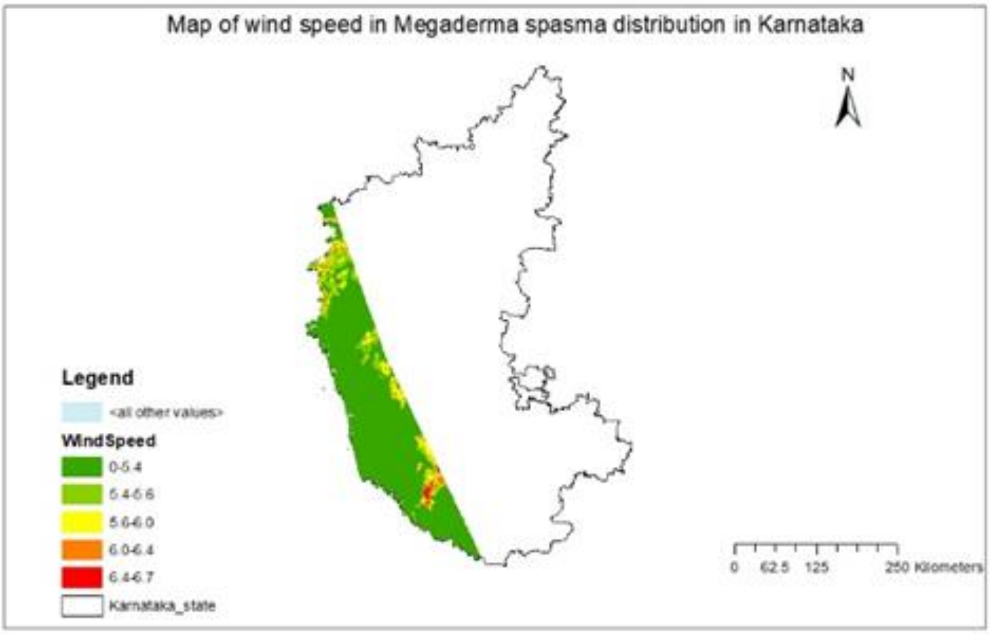
Chaephon plicatus is distributed in a few locations in Karnataka covering the coastal area in the northern part and a small area at south east area and it is overlapping with the high potential areas of wind energy. Development of wind farms in the coastal areas of northern Karnataka will have negative impact on this species *Chaephon plicatus* and as this species has limited ditribution in Karnataka, any additional threats keeps this species more vulnerable.



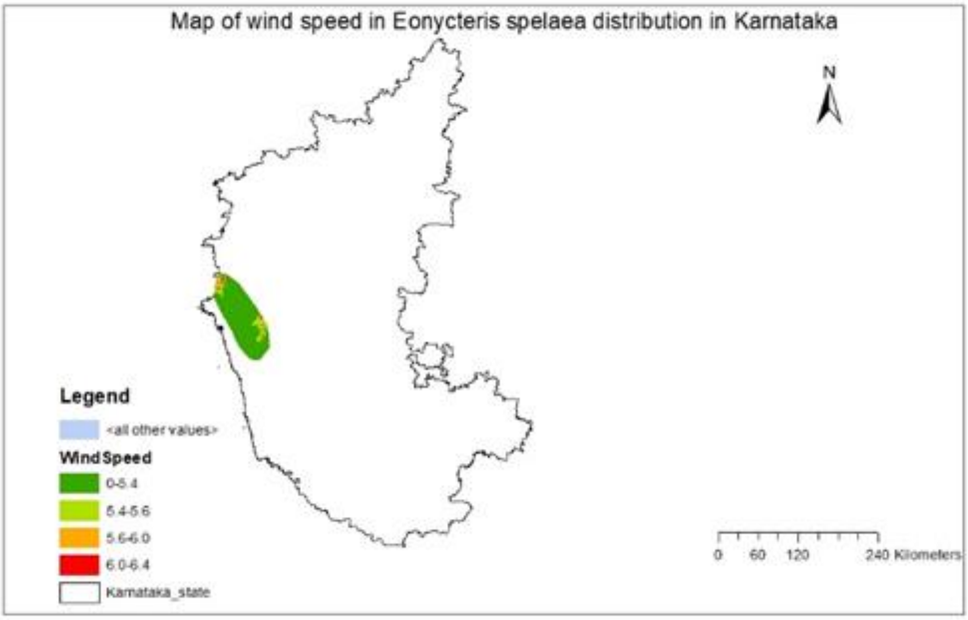
The *Hesperoptenus tickelli* is recorded only from the north west part of Karnataka including the western ghat part of the state. This area has many potential areas for wind farm development scattered from the western Ghats to the coastal areas. Wind farm operations in this areas without considering this species will have negative impact.



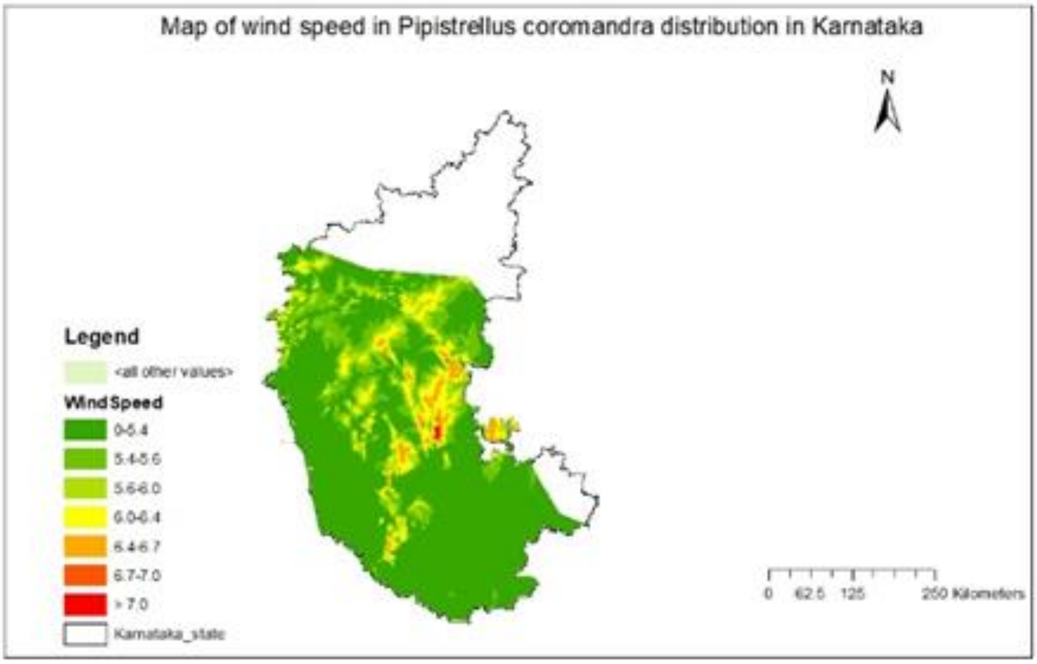
Out of 59 species of bats in Karnataka, many species are exempted from the analysis as many has a wide distribution in India. The species like *Cynopterus brachyotis* are also distributed everywhere in Karnataka except in the northern part of Karnataka.



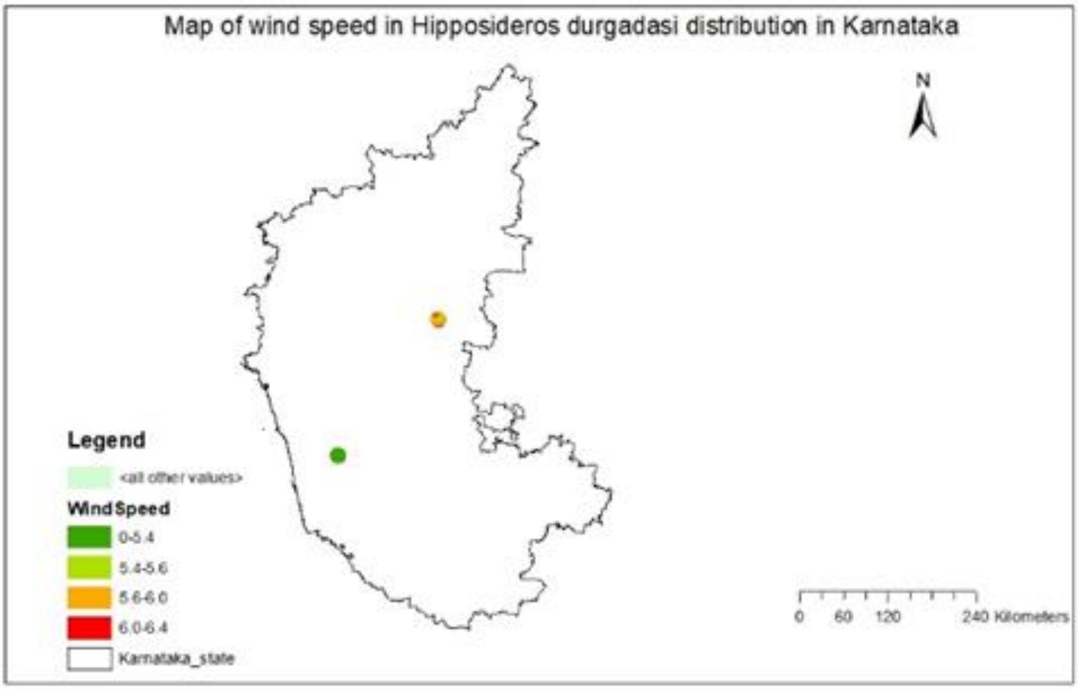
Megaderma spasma is recorded from the western areas of Karnataka and also overlaps with various potential areas of wind energy. This species have a restricted distribution in Karnataka and the high wind potential areas are overlapping with the species range in the southern part. Wind farm operations shall be implemeted or operated only after considering the species conservation importance and other related environmental variables of the area.



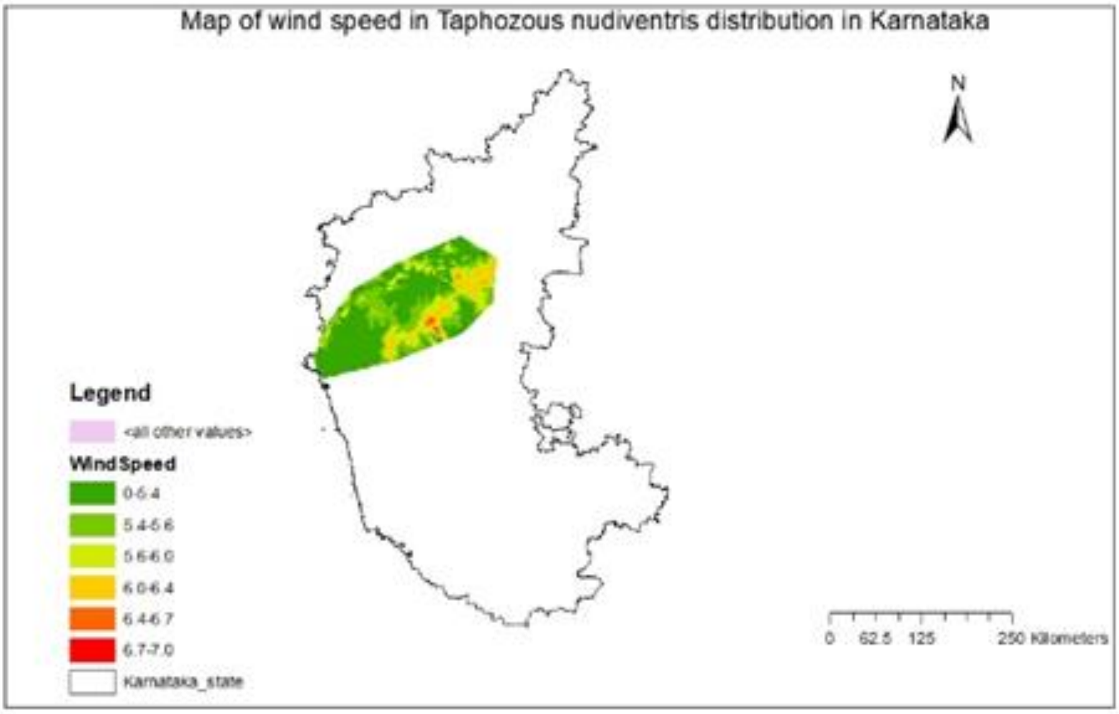
Eonycteris spelaean is recorded from the western part of Karnataka and overlaps with the areas of various categories of wind speed potential.



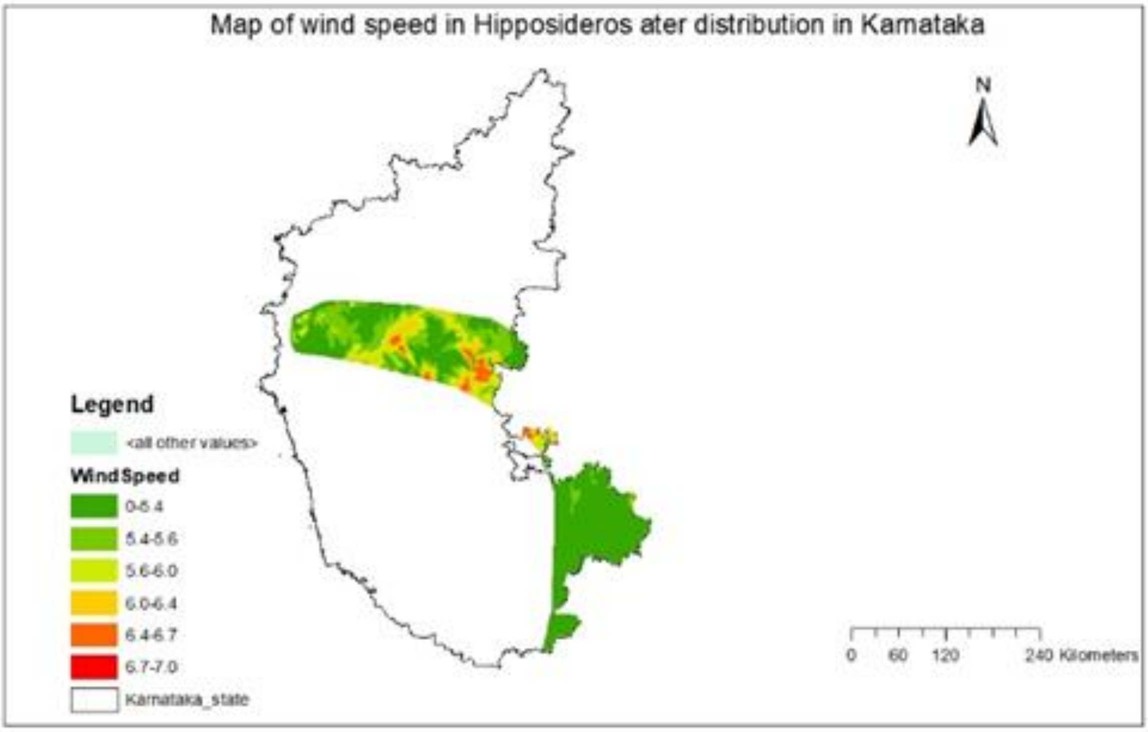
Pipistrellus coromandra has a wide distribution in Karnataka and covers most of the areas with wind energy potential.



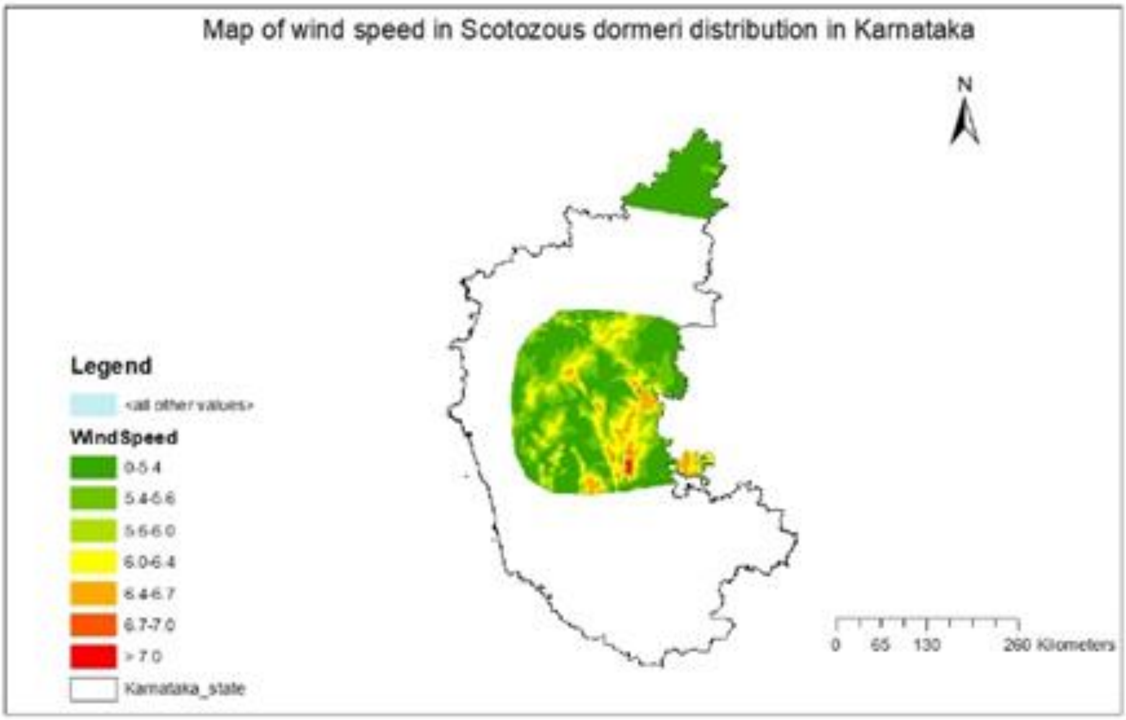
Hipposideros durgasi is reported from a few locations in Karnataka and the analysis shows that the species is locally rare. Distribution of this species in the northern part of Karnataka is being overlapped exactly on the area with high wind potential areas and operating a wind farm here can have serious threat on this species.



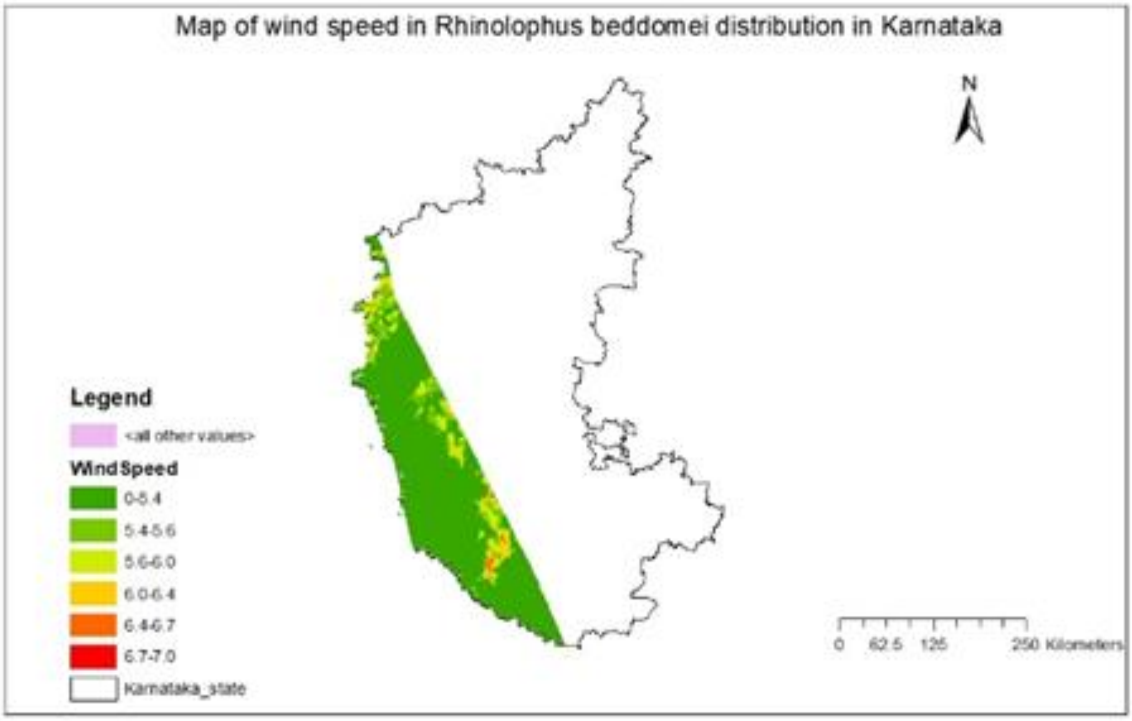
The above map shows the distribution of *Taphozous nudiventris* distribution in Karnataka, it is restricted to the northern side of the state.



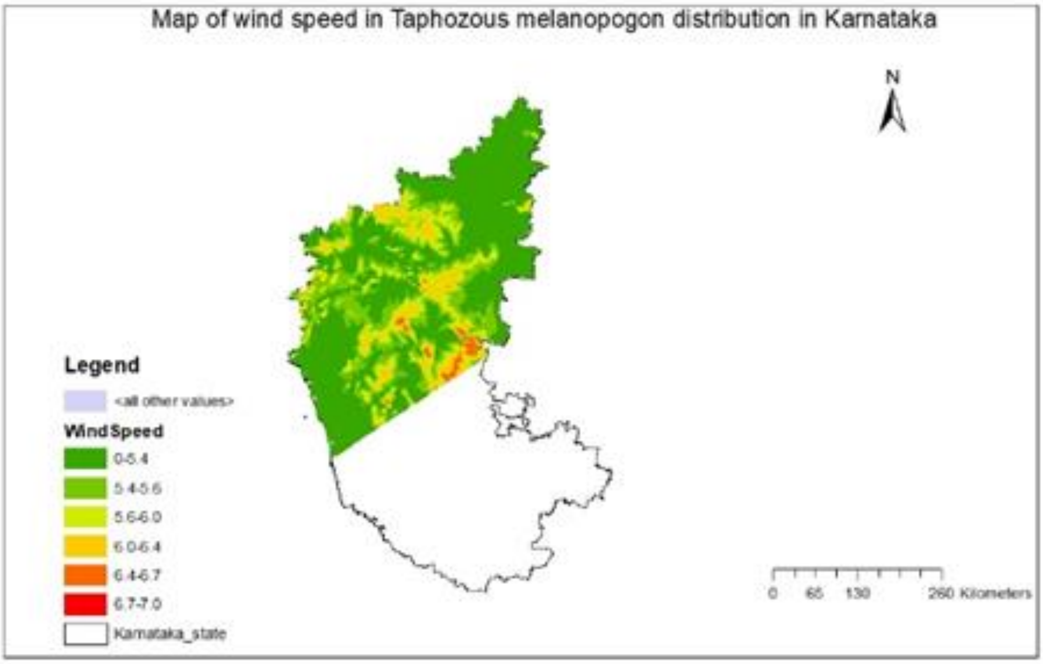
The overlay analysis shows that central area of Karnataka supports the distribution of *Hipposideros ater* distribution. A good percentage of the areas identified from here as with good wind potential and there is a chance of negative impact by wind farm operation like direct collision with the wind turbine blades.



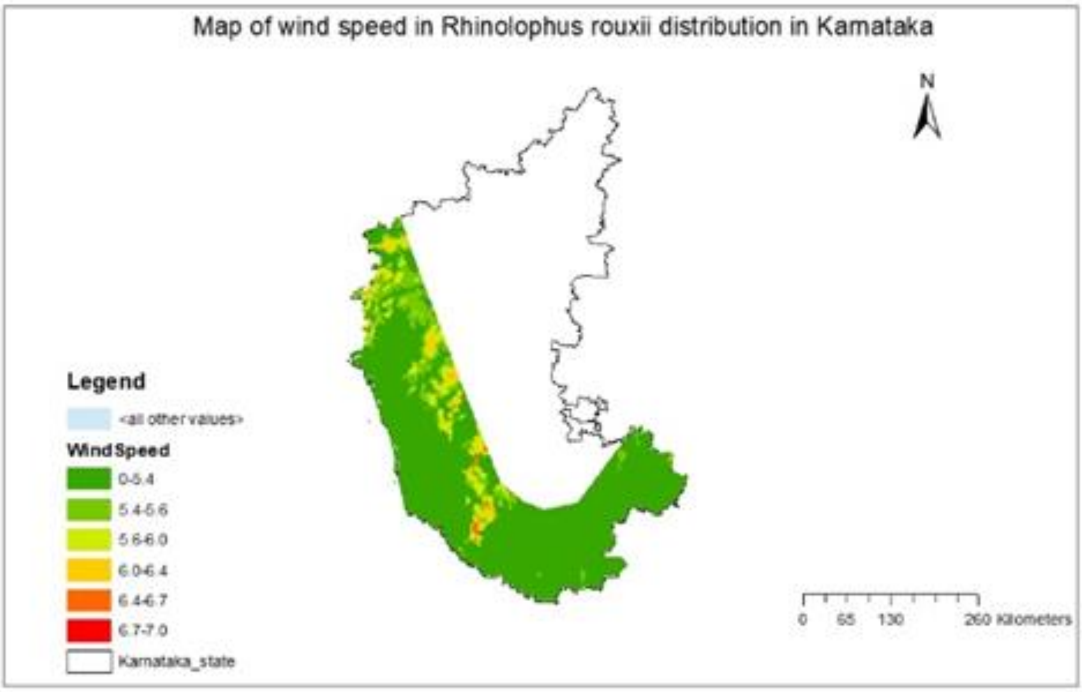
Scotozous dormeri has a wide distribution in the central and eastern part of the state. It overlaps with various categories of potential areas of wind energy.



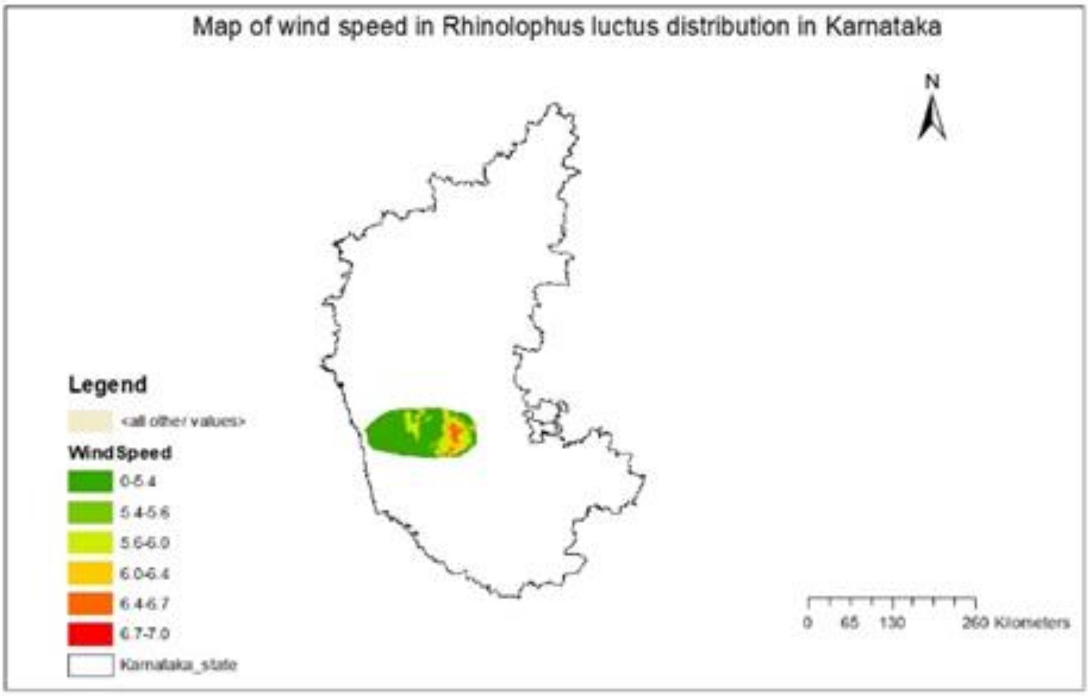
Rhinolophus beddomei is distributed in the western areas of Karnataka which is also an overlapping areas with the many high wind potential areas.



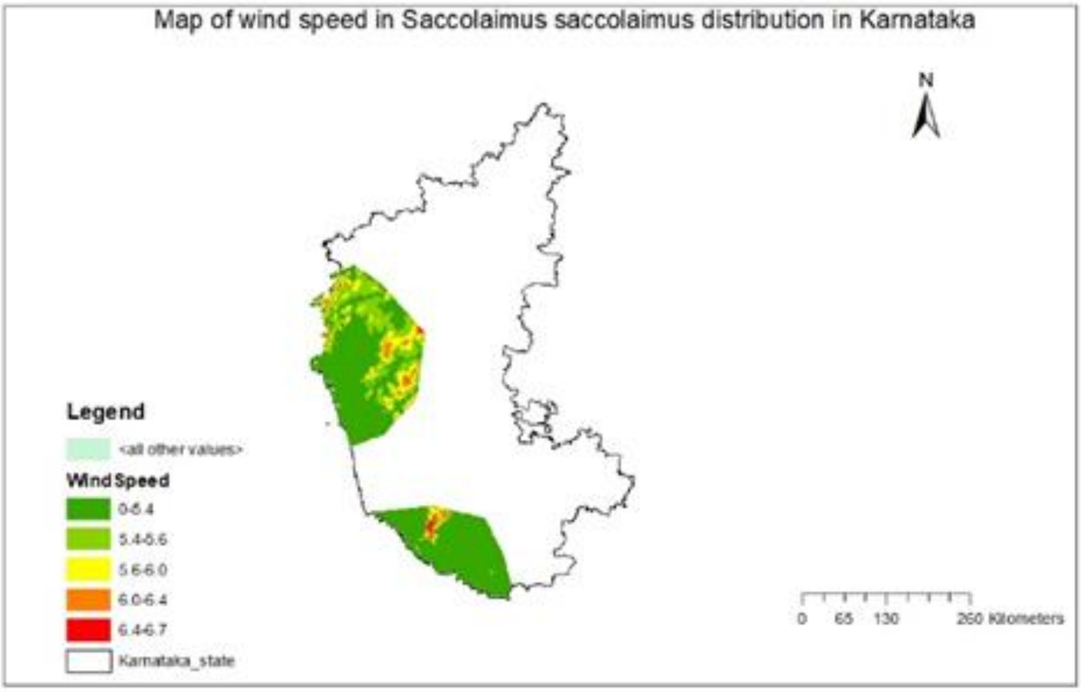
Taphozous melanopogon is distributed in Karnataka in the northern half and overlapping with various categories of potential areas of wind energy



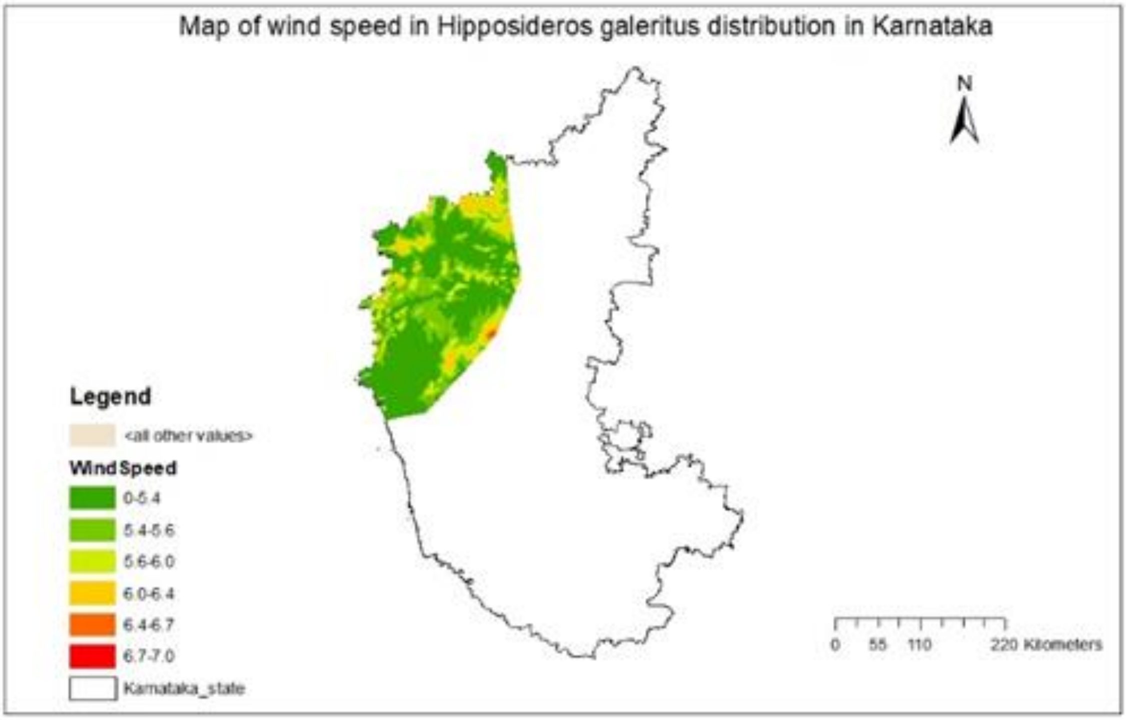
Above map shows the distribution pattern of *Rhinolophus rouxi* in Karnataka and the wind potential areas in its distribution range.



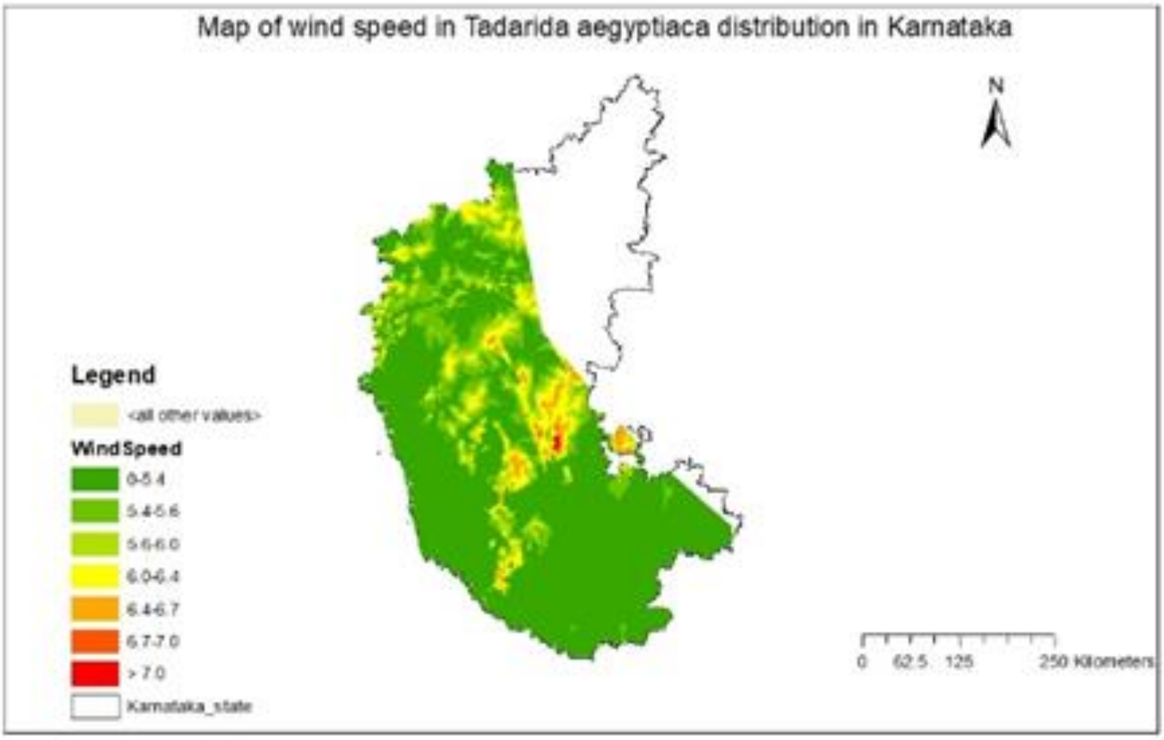
The analysis shows that a small area has the distribution of *Rhinolophus luctus* in Karnataka, and the areas are overlapping with potential areas of wind energy in the state.



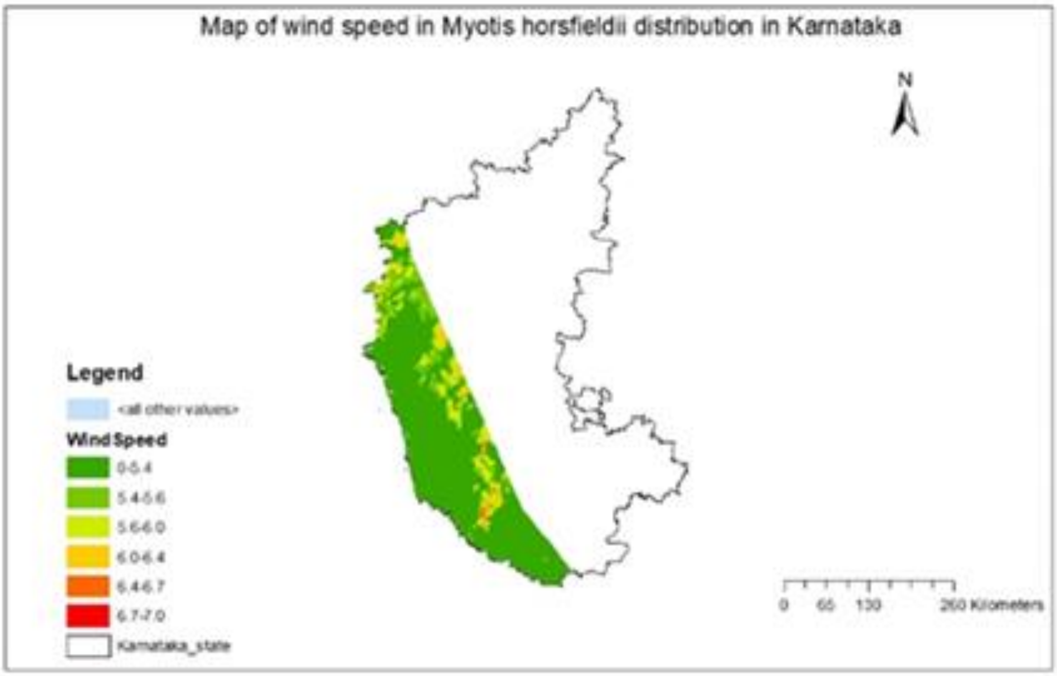
Saccolaimus saccolaimus is documented from the north and south eastern side of Karnataka which covers many high potential areas of wind energy.

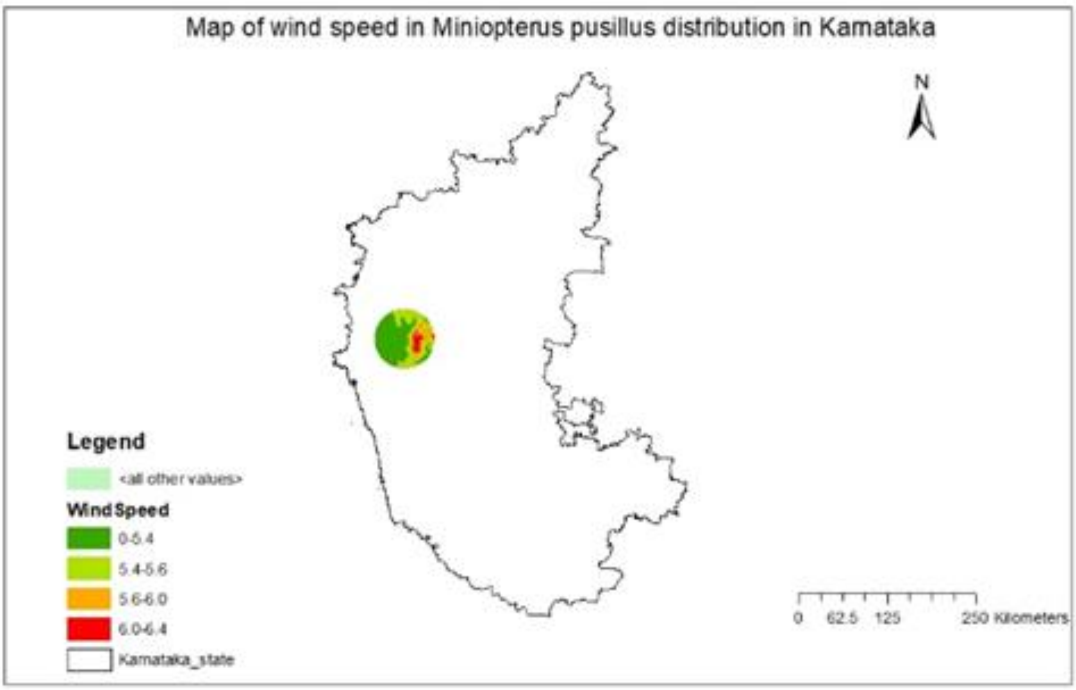


Hipposideros galeritus is distributed in the north west region of Karnataka and the areas has various categories of wind speed.

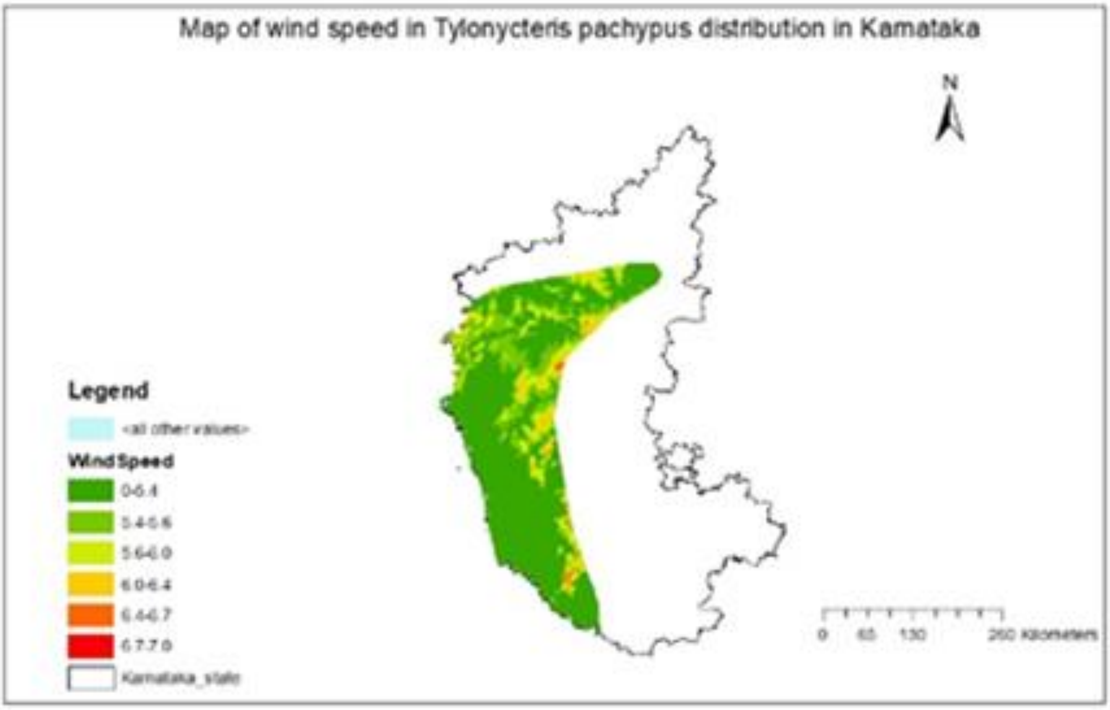


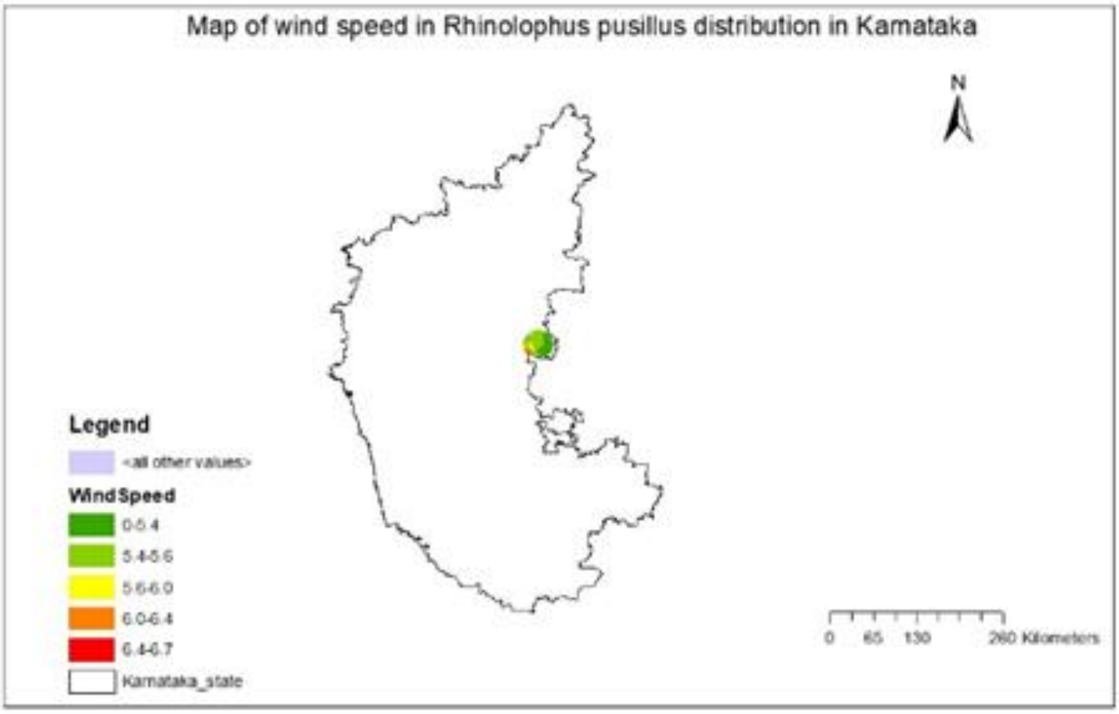
Tadarida aegyptiaca is distributed all over the state except the few regions in the northern part of the state.

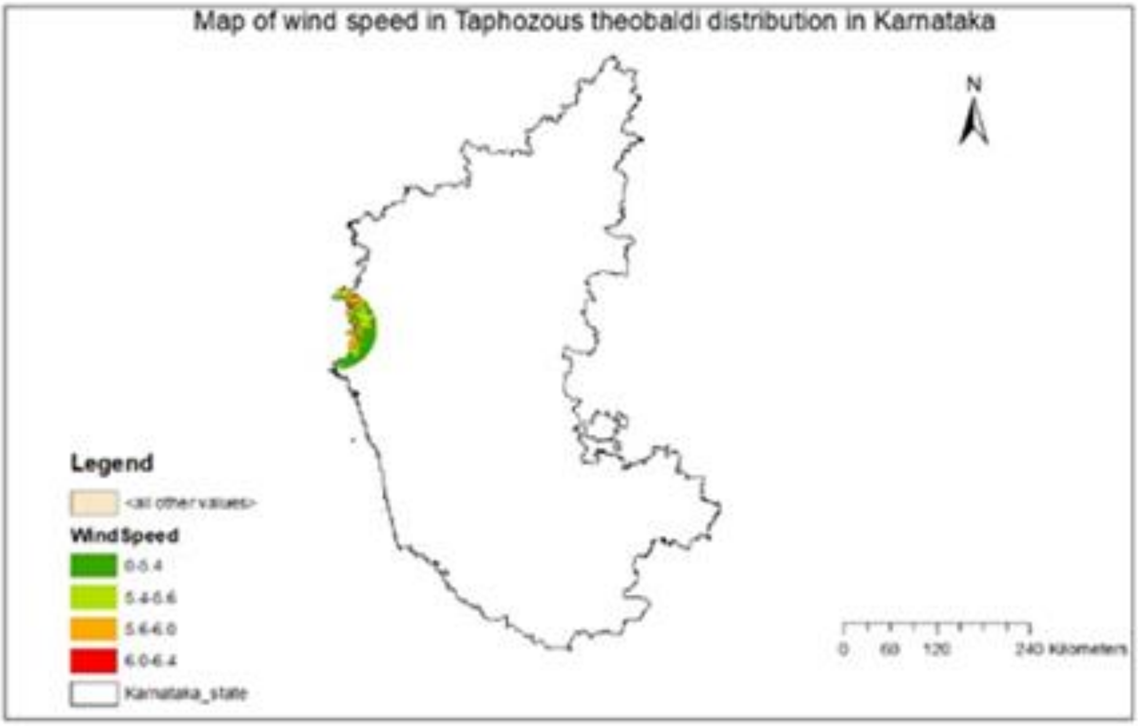


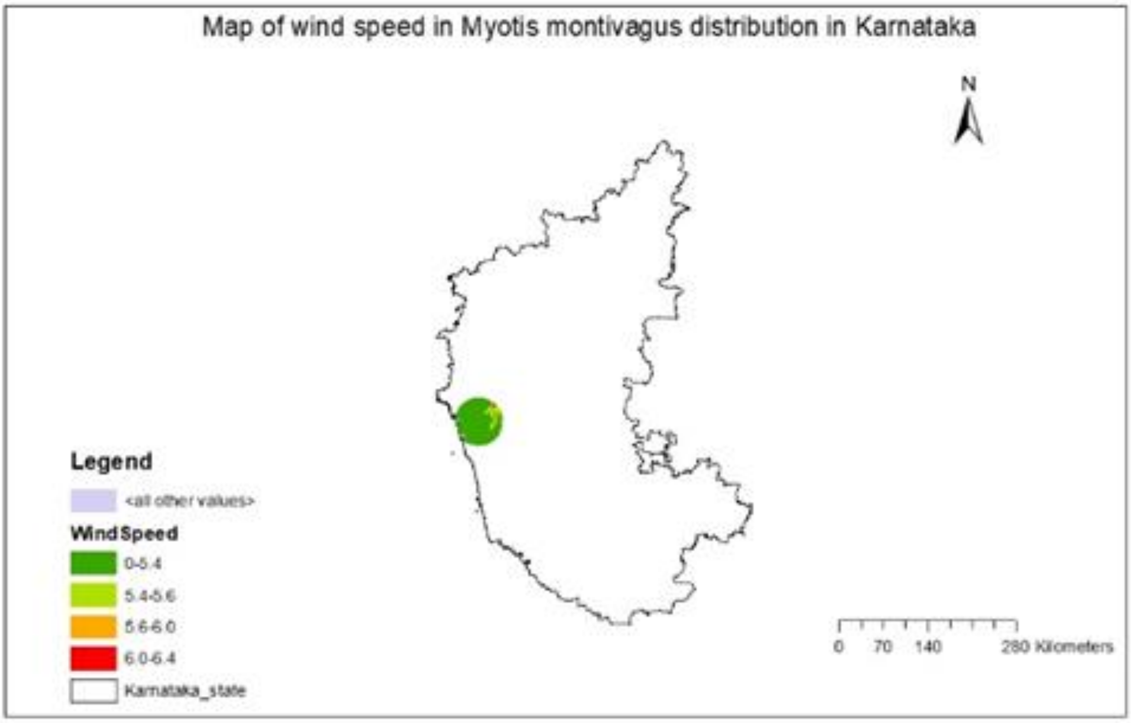


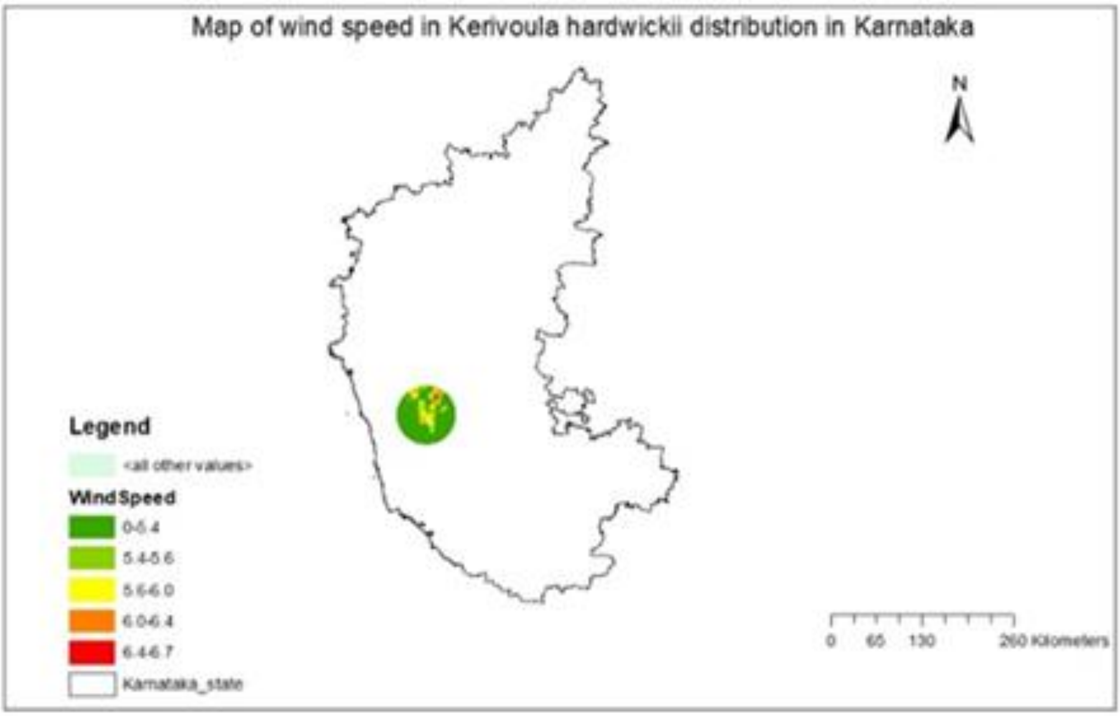
Myotis horsfieldii and *Miniopterus pusillus* are distributed in the areas with high potential of wind energy whereas the distribution of *Miniopterus pusillus* is restricted to a small area comparatively.

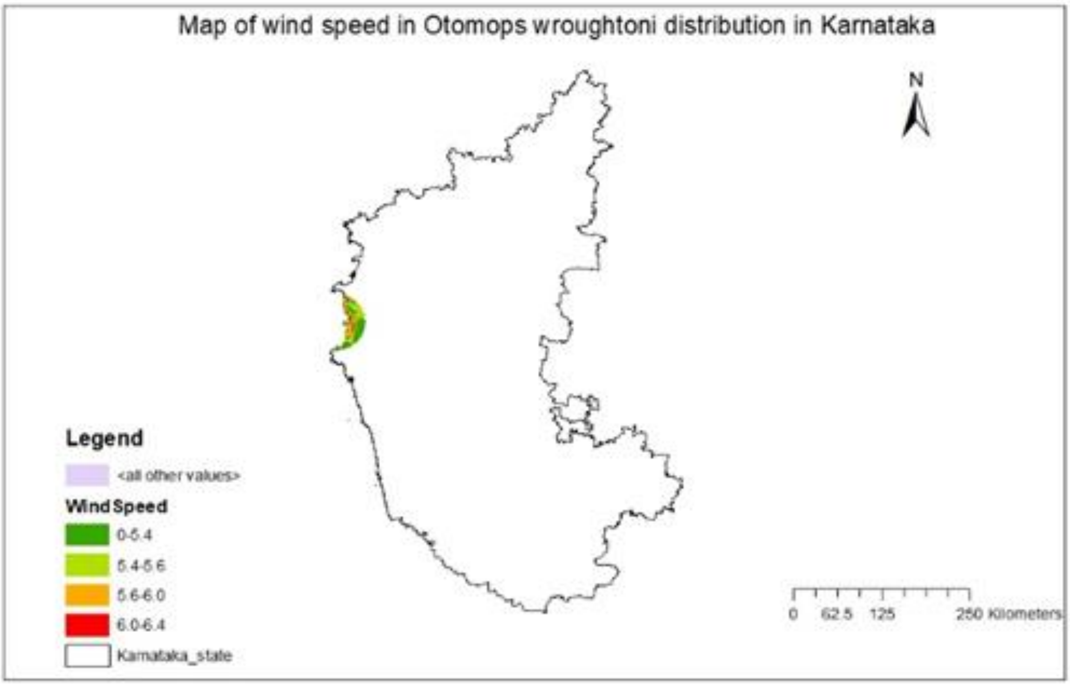





Map of wind speed in Taphozous theobaldi distribution in Karnataka
N
Legend
<all other values>
WindSpeed
0-5.4
5.4-5.6
5.6-6.0
6.0-6.4
Karnataka_state
0 60 120 240 Kilometers

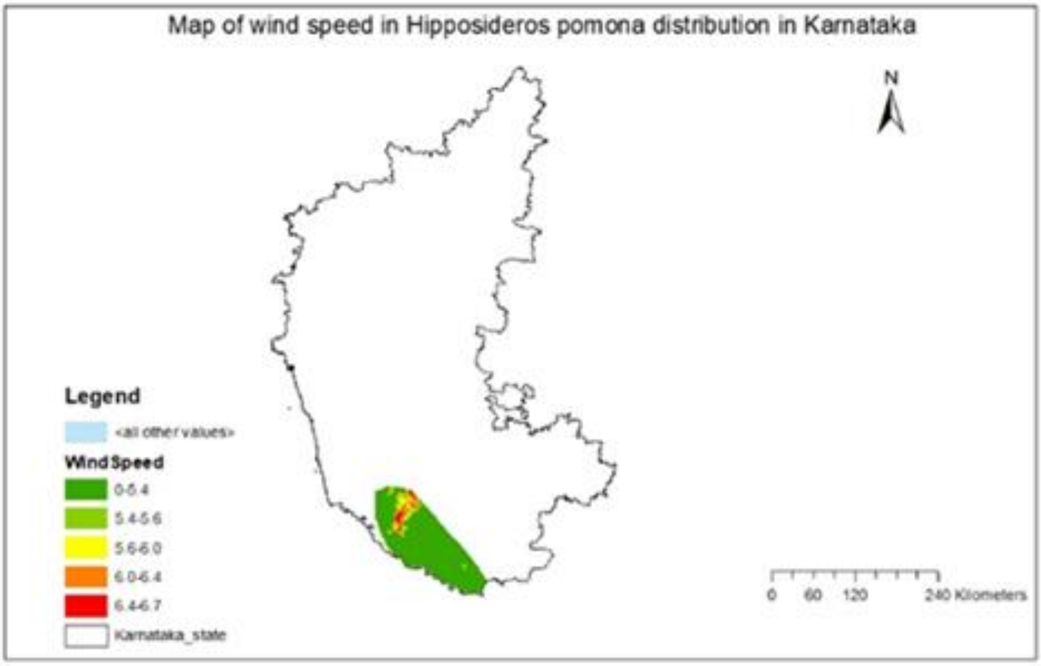

Map of wind speed in Myotis montivagus distribution in Karnataka
N
Legend
<all other values>
WindSpeed
0-5.4
5.4-5.6
5.6-6.0
6.0-6.4
Karnataka_state
0 70 140 280 Kilometers



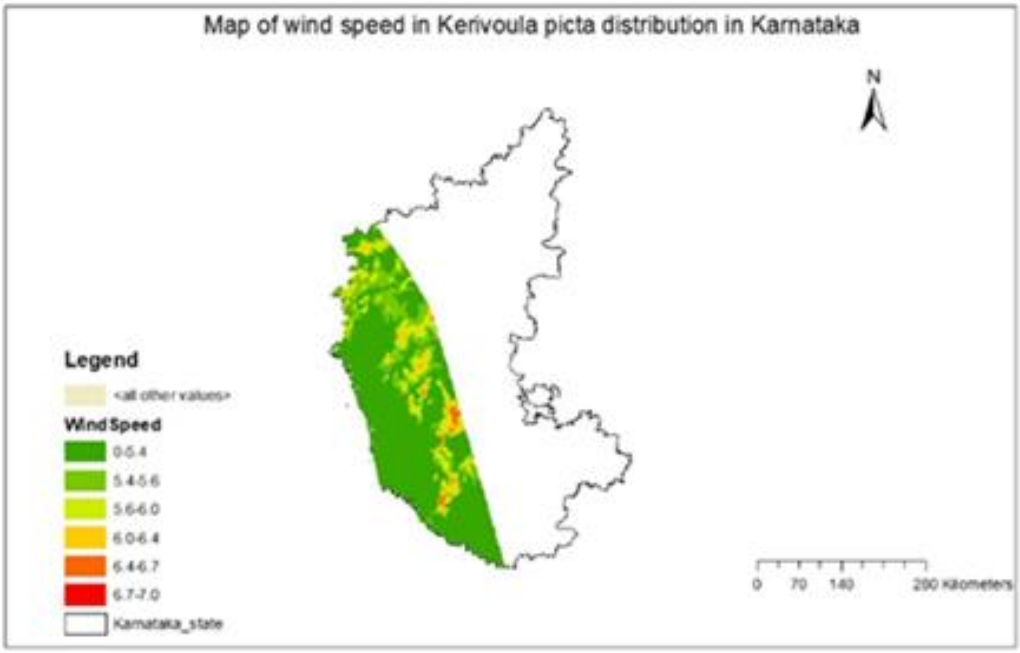


Several species such as *Rhinolophus pusillus, Taphozous theobaldi, Myotis montivagus, Kerivoula hardwickii, and Otomops wroughtoni* are distributed in confined areas in the state of Karnataka whereas they all are come under the areas with high potential of wind energy.

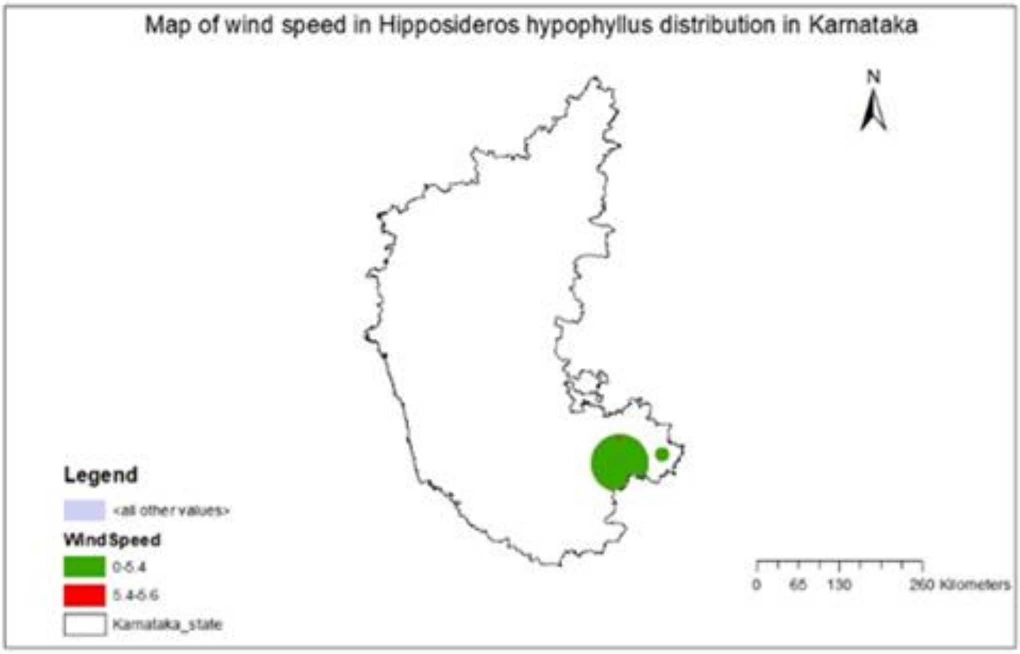
Figure 6.5. Maps with overlapping layers of wind speed with each species of bat in Karnataka



Hipposideros pomona is scheduled as endangered under IUCN category and distributed in the southern side of the state, overlapping with the potential areas of wind energy.



Kerivola picta come under the near threatened category of IUCN and distributed in the western side of the state including the Western Ghats



Hipposideros hypophyllus an endanereged bat in the IUCN list and globally the populatiion is going down. The distribution of the species in Karnataka overlaps with the area with low wind speed

Figure 6.6. Maps with overlapping layers of wind speed with threatened species in Karnataka

6.4 Discussion

Location guidance for wind farm siting is valuable for conservation considering rapid increase of number of wind farms in India. The development of wind farms at a very rapid rate without any study or baseline ecological data collection will be a serious threat to wildlife especially on an aerial group like bats (Madhu *et al.*, 2014). The earlier studies in India discussed only about the impact of wind farms on different animal and plant taxa (Kumar *et al.*, 2013; Pandey *et al.*, 2013; Bright *et al.*, 2008) whereas the present study proposes an approach to minimize the impact of wind farms on bats. The sensitive areas with respect to different anthropogenic threats including wind turbine operations are crucial for the conservation of bats in India. The data generated through the overlapping analysis could be useful for the preparation of broad strategic locational guidance maps for the wind turbines (SNH, 2005).

These output maps will have following uses. Firstly, it indicates at a state level sensitive regions for siting wind farms from the point of view of various bat species, and the cumulative results helps to identify the most sensitive areas with maximum overlap of species distribution (Bright *et al.*, 2008). Bright *et al.*, 2008 and Fielding *et al.*, 2006 have followed a similar approach to develop a strategy to mitigate the impact of wind farms on sensitive birds in United Kingdom. This data will be vitally important to avoid the deleterious impact of wind farm developments on bats in these areas through careful planning in the potential wind energy areas (Santos *et al.*, 2013). A total of 27 species of bats are considered for the overlay analysis. The details of each species are given in the following paragraphs.

Three bat species such as *Hipposideros hypophyllus, Kerivoula picta and Hipposideros Pomona* are belongs to threatened categories in the study area. Among the above-mentioned threatened species *H. hypophyllus* distribution is in low wind speed area so that the chance of wind farm establishment in that location is minimal. Whereas, other two species distribution is overlapping with the areas with high potential areas of wind energy, and the wind farm establishment in that areas in future can affect the species. Though both of this species are distributed in the wind potential areas, some areas are already protected as PAs that will evade development of wind farms in few areas. The wind farm development will affect not only the threatened species but also population of other bat species with limited distribution in the state.

The global distribution and ecology of each bat species is very important while calculating threats of wind farm development on bats. The map was created using the best available information and data whereas it has inevitable caveats for conservation planning. Since the data available on bat distribution is comparatively very low in India, this map will not be a substitute for site specific environmental impact assessment. Furthermore, as the individual data on the effect of wind farms for each species of bat is not available, the impact of wind farms are considered to be the same for all the species distributed in the study area. The infrastructure planning and development can utilize this map to identify the preferred areas based on other factors such as cost, wind speed and technical feasibility. This data will be a useful tool for strategic planning to install wind farms with minimal impact on wildlife.

7 CONCLUSION

Globally, India is one of the biggest energy generators from wind. Even though the wind energy is green and known for its pollution free nature, there are also reported negative impacts on wildlife and environment. This research study examined the bird diversity in the wind farm and adjoining areas, bird and bat mortalities in the wind farm, abundance fluctuation of black- naped hare populations in wind farm and control sites. The study also explored the applicability of GIS and remote sensing based mapping as a tool for developing mitigation strategies to reduce the bat-wind farm conflict.

The study area has patches of dry deciduous forest, villages, wetlands and agriculture lands, the whole area supports good population of birds and mammals. The Ranebennur wildlife sanctuary is located around 80 Km away from the study area. The wind farm and surroundings support 115 species of birds including 44 species of water and water dependent birds. Furthermore, the study area supports many species of bats and other mammals such as black-naped hare.

This study confirms that the wind farm has negative impact on wildlife. The results show a significant change in bird diversity between wind farm and the control site without turbines. Carcass search sampling in the wind farm found bird and bat mortalities and the injuries confirms the reason of mortality is the direct collision on wind turbine. This study reports the highest bat mortality by the direct collision on wind turbine in India, which cues the negative effect of wind farm development in the wildlife areas. The maps generated in the study with the data on wind speed and the extant of distribution of each species of bats in Karnataka will be helpful to mitigate the impact of wind farms on bats by helping in suitably locating the wind farms in areas with least impact potential.

Conservation implication of the Study

There are no major studies on the impact of wind farms on wildlife from South India and the results of this study in this direction will be useful to appropriate planning of wind farm development with minimal impacts. Former studies had suggested for a sensitive map for birds for careful planning of wind farm development (Kumar, 2017). In this study, bat sensitive maps are generated for Karnataka state, which will be useful for the strategy planners and policy makers. This study recommends Pre and post installation impact assessment studies for the wind farm development in Karnataka. So far, in India, there are only two studies (Ramesh, 2017 and Pande *et al.*, 2013) on the impact of wind farms on biodiversity.

Moreover, along with the PAs, the biodiversity value of isolated patches of forests in Karnataka are very important for the conservation of many species. Therefore, a proper documentation of biodiversity in the entire landscape will be helpful to manage the impact of infrastructure developments on environment and the life forms.

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APPENDICES

Appendix 1. Checklist of birds from the study area

S. No.	Common name	Scientific name	IW PA	IU CN	Family	Order
1	Lesser Whistling Duck	*Dendrocygna javanica*	4	LC	Anatidae	Anseriformes
2	Ruddy Shelduck	*Tadorna ferruginea*	4	LC	Anatidae	Anseriformes
3	Gadwall	*Mareca strepera*	4	LC	Anatidae	Anseriformes
4	Eurasian Wigeon	*Mareca penelope*	4	LC	Anatidae	Anseriformes
5	Indian Spot-billed Duck	*Anas poecilorhyncha*	4	LC	Anatidae	Anseriformes
6	Northern Pintail	*Anas acuta*	4	LC	Anatidae	Anseriformes
7	.	*Spatula querquedula*	4	LC	Anatidae	Anseriformes
8	Eurasian Teal	*Anas crecca*	4	LC	Anatidae	Anseriformes
9	Grey Francolin	*Francolinus pondicerianus*	4	LC	Phasianidae	Galliformes
10	Indian Peafowl	*Pavo cristatus*	1	LC	Phasianidae	Galliformes
11	Little Grebe	*Tachybaptus ruficollis*	4	LC	Podicipedidae	Podicipediformes
12	Painted Stork	*Mycteria leucocephala*	4	NT	Ciconiidae	Ciconiiformes
13	Asian Openbill	*Anastomusoscitans*	4	LC	Ciconiidae	Ciconiiformes
14	Woolly-necked Stork	*Ciconia episcopus*	4	VUL	Ciconiidae	Ciconiiformes
15	Red-naped Ibis	*Pseudibis papillosa*	4	LC	Threskiornithidae	Pelecaniformes
16	Indian Pond Heron	*Ardeola grayii*	4	LC	Ardeidae	Pelecaniformes
17	Cattle Egret	*Bubulcus ibis*	4	LC	Ardeidae	Pelecaniformes

18	Grey Heron	*Ardea cinerea*	4	LC	Ardeidae	Pelecaniformes
19	Purple Heron	*Ardea purpurea*	4	LC	Ardeidae	Pelecaniformes
20	Great Egret	*Ardea alba*	4	LC	Ardeidae	Pelecaniformes
21	Intermediate Egret	*Ardea intermedia*	4	LC	Ardeidae	Pelecaniformes
22	Little Egret	*Egretta garzetta*	4	LC	Ardeidae	Pelecaniformes
23	Little Cormorant	*Microcarbo niger*	4	LC	Phalacrocoracidae	Suliformes
24	Black-winged Kite	*Elanus caeruleus*	4	LC	Accipitridae	Accipitriformes
25	Short-toed Snake Eagle	*Circaetus gallicus*	4	LC	Accipitridae	Accipitriformes
26	Booted Eagle	*Hieraaetu spennatus*	4	LC	Accipitridae	Accipitriformes
27	Bonelli's Eagle	*Aquila fasciata*	4	LC	Accipitridae	Accipitriformes
28	Shikra	*Accipiter badius*	4	LC	Accipitridae	Accipitriformes
29	Pallid Harrier	*Circus macrourus*	4	NT	Accipitridae	Accipitriformes
30	Black Kite	*Milvus migrans*	4	LC	Accipitridae	Accipitriformes
31	Brahminy Kite	*Haliasturindus*	4	LC	Accipitridae	Accipitriformes
32	White-eyed Buzzard	*Butasturteesa*	4	LC	Accipitridae	Accipitriformes
33	White-breasted Waterhen	*Amaurornis phoenicurus*	4	LC	Rallidae	Gruiformes
34	Purple Swamphen	*Porphyrioporphyrio*	4	LC	Rallidae	Gruiformes
35	Eurasian Coot	*Fulica atra*	4	LC	Rallidae	Gruiformes
36	Black-winged Stilt	*Himantopus himantopus*	4	LC	Recurvirostridae	Charadriiformes
37	Red-wattled Lapwing	*Vanellus indicus*	4	LC	Charadriidae	Charadriiformes
38	Little Ringed Plover	*Charadrius dubius*	4	LC	Charadriidae	Charadriiformes
39	Bronze-winged Jacana	*Metopidius indicus*	4	LC	Jacanidae	Charadriiformes
40	Common Redshank	*Tringatotanus*	4	LC	Scolopacidae	Charadriiformes

41	Marsh Sandpiper	*Tringastagnatilis*	4	LC	Scolopacidae	Charadriiformes
42	Green Sandpiper	*Tringaochropus*	4	LC	Scolopacidae	Charadriiformes
43	Wood Sandpiper	*Tringaglareola*	4	LC	Scolopacidae	Charadriiformes
44	Common Sandpiper	*Actitishypoleucos*	4	LC	Scolopacidae	Charadriiformes
45	Brown-headed Gull	*Chroicocephalusbrunnicephalus*	4	LC	Laridae	Charadriiformes
46	River Tern	*Sterna aurantia*	4	NT	Laridae	Charadriiformes
47	Whiskered Tern	*Chlidoniashybrida*	4	LC	Laridae	Charadriiformes
48	Rock pigeon	*Columba livia*	4	LC	Columbidae	Columbiformes
49	Eurasian Collared Dove	*Streptopeliadecaocto*	4	LC	Columbidae	Columbiformes
50	Spotted Dove	*Streptopelia chinensis*	4	LC	Columbidae	Columbiformes
51	Laughing Dove	*Streptopelia senegalensis*	4	LC	Columbidae	Columbiformes
52	Yellow-footed Green Pigeon	*Treronphoenicopterus*	4	LC	Columbidae	Columbiformes
53	Greater Coucal	*Centropus sinensis*	4	LC	Cuculidae	Cuculiformes
54	Sirkeer Malkoha	*Taccocualeschenaultii*	4	LC	Cuculidae	Cuculiformes
55	Asian Koel	*Eudynamysscolopaceus*	4	LC	Cuculidae	Cuculiformes
56	Common Hawk-Cuckoo	*Hierococcyxvarius*	4	LC	Cuculidae	Cuculiformes
57	Little Swift	*Apus affinis*	4	LC	Apodidae	Apodiformes
58	White-throated Kingfisher	*Halcyon smyrnensis*	4	LC	Alcedinidae	Coraciiformes
59	Green Bee-eater	*Meropsorientalis*	4	LC	Meropidae	Coraciiformes
60	Blue-tailed Bee-eater	*Meropsphilippinus*	4	LC	Meropidae	Coraciiformes
61	Eurasian Hoopoe	*Upupa epops*	4	LC	Upupidae	Bucerotiformes
62	Coppersmith Barbet	*Psilopogonhaemacephalus*	4	LC	Megalaimidae	Piciformes

63	Black-rumpedFlameback	*Dinopiumbenghalense*	4	LC	Picidae	Piciformes
64	Common Kestrel	*Falco tinnunculus*	4	LC	Falconidae	Falconiformes
65	Laggar Falcon	*Falco jugger*	4	NT	Falconidae	Falconiformes
66	Rose-ringed Parakeet	*Psittaculakrameri*	4	LC	Psittacidae	Psittaciformes
67	Common Woodshrike	*Tephrodornispondicerianus*	4	LC	Vangidae	Passeriformes
68	Common Iora	*Aegithina tiphia*	4	LC	Aegithinidae	Passeriformes
69	Small Minivet	*Pericrocotuscinnamomeus*	4	LC	Campephagidae	Passeriformes
70	Brown Shrike	*Laniuscristatus*	4	LC	Laniidae	Passeriformes
71	Bay-backed Shrike	*Laniusvittatus*	4	LC	Laniidae	Passeriformes
72	Long-tailed Shrike	*Laniusschach*	4	LC	Laniidae	Passeriformes
73	Black Drongo	*Dicrurusmacrocercus*	4	LC	Dicruridae	Passeriformes
74	Rufous Treepie	*Dendrocittavagabunda*	4	LC	Corvidae	Passeriformes
75	House Crow	*Corvus splendens*	4	LC	Corvidae	Passeriformes
76	Cinereous Tit	*Parus cinereus*	4	LC	Paridae	Passeriformes
77	Rufous-tailed Lark	*Ammomanesphoenicura*	4	LC	Alaudidae	Passeriformes
78	Oriental Skylark	*Alauda gulgula*	4	LC	Alaudidae	Passeriformes
79	Ashy-crowned Sparrow-Lark	*Eremopterix griseus*	4	LC	Alaudidae	Passeriformes
80	Red-whiskered Bulbul	*Pycnonotusjocosus*	4	LC	Pycnonotidae	Passeriformes
81	Red-vented Bulbul	*Pycnonotuscafer*	4	LC	Pycnonotidae	Passeriformes
82	Barn Swallow	*Hirundorustica*	4	LC	Hirundinidae	Passeriformes
83	Red-rumped Swallow	*Cecropisdaurica*	4	LC	Hirundinidae	Passeriformes
84	Streak-throated Swallow	*Petrochelidonfluvicola*	4	LC	Hirundinidae	Passeriformes

85	Blyth's Reed Warbler	*Acrocephalusdumetorum*	4	LC	Acrocephalidae	Passeriformes
86	Jungle Prinia	*Prinia sylvatica*	4	LC	Cisticolidae	Passeriformes
87	Ashy Prinia	*Priniasocialis*	4	LC	Cisticolidae	Passeriformes
88	Plain Prinia	*Priniainornata*	4	LC	Cisticolidae	Passeriformes
89	Large Grey Babbler	*Argyamalcolmi*	4	LC	Leiothrichidae	Passeriformes
90	Jungle Babbler	*Turdoides striata*	4	LC	Leiothrichidae	Passeriformes
91	Lesser Whitethroat	*Currucacurruca*	4	LC	Sylviidae	Passeriformes
92	Yellow-eyed Babbler	*Chrysommasinense*	4	LC	Sylviidae	Passeriformes
93	Jungle Myna	*Acridotheresfuscus*	4	LC	Sturnidae	Passeriformes
94	Bank Myna	*Acridotheresginginianus*	4	LC	Sturnidae	Passeriformes
95	Common Myna	*Acridotheres tristis*	4	LC	Sturnidae	Passeriformes
96	Brahminy Starling	*Sturniapagodarum*	4	LC	Sturnidae	Passeriformes
97	Indian Robin	*Saxicoloidesfulicatus*	4	LC	Muscicapidae	Passeriformes
98	Oriental Magpie-Robin	*Copsychussaularis*	4	LC	Muscicapidae	Passeriformes
99	Blue Rock Thrush	*Monticola solitarius*	4	LC	Muscicapidae	Passeriformes
100	Pied Bush Chat	*Saxicola caprata*	4	LC	Muscicapidae	Passeriformes
101	Pale-billed Flowerpecker	*Dicaeumerythrorhynchos*	4	LC	Dicaeidae	Passeriformes
102	Purple Sunbird	*Cinnyris asiaticus*	4	LC	Nectariniidae	Passeriformes
103	House Sparrow	*Passer domesticus*	4	LC	Passeridae	Passeriformes
104	Yellow-throated Sparrow	*Gymnorisxanthocollis*	4	LC	Passeridae	Passeriformes
105	Western Yellow Wagtail	*Motacilla flava*	4	LC	Motacillidae	Passeriformes
106	Citrine Wagtail	*Motacillacitreola*	4	LC	Motacillidae	Passeriformes

107	Grey Wagtail	*Motacilla cinerea*	4	LC	Motacillidae	Passeriform es
108	White Wagtail	*Motacilla alba*	4	LC	Motacillidae	Passeriform es
109	White-browed Wagtail	*Motacillamaderaspat ensis*	4	LC	Motacillidae	Passeriform es
110	Paddyfield Pipit	*Anthusrufulus*	4	LC	Motacillidae	Passeriform es
111	Tawny Pipit	*Anthus campestris*	4	LC	Motacillidae	Passeriform es
112	Long-billed Pipit	*Anthussimilis*	4	LC	Motacillidae	Passeriform es
113	Black-headed Bunting	*Granativoramelanoce phala*	4	LC	Emberizidae	Passeriform es
114	Indian Pitta	*Pitta brachyura*	4	LC	Pittidae	Passeriform es