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Open Access

10.11609/jott.2025.17.6.27035-27170
www.threatenedtaxa.org

26 June 2025 (Online & Print)
17(6): 27035-27170
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

40 Years zoo reach Zoo Outreach Organisation

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

Srivari Illam, No. 61, Karthik Nagar, 10th Street, Saravanampatti, Coimbatore, Tamil Nadu 641035, India
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continued on the back inside cover

Cover: A mesmerising Indian Luna moth *Actias selene* is dancing through the starry night (by Vincent van Gogh) moonlit sky, displaying its ballistic display of feather tail. Digital artwork by Vyshnavee Sneha Jaijar.

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 June 2025 | 17(6): 27098–27109

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9523.17.6.27098-27109

#9523 | Received 27 November 2024 | Final received 31 May 2025 | Finally accepted 20 June 2025

OPEN ACCESS

ARTICLE

Range expansion of Indian Grey Hornbill population: a case study based on land use, land cover, and vegetation changes in Vadodara, Gujarat, India

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Abstract: The Indian Grey Hornbill *Ocyceros birostris*, commonly known to occur in dry deciduous forests and open woodlands, has seen a notable population rise in urban areas of Gujarat, including Vadodara, over the past 14 years. Prior to 2010, no Grey Hornbills were observed amidst the green canopy of the city, but the species has since established a thriving breeding population within city limits. This study attempts to link this shift to land use and land cover change (LULCC), where urban expansion and altered vegetation seem to have created suitable habitats. Traditionally, urbanization is known to lead to biodiversity loss, and habitat degradation, but as far as Vadodara City is concerned, it has offered a unique case of species adaptation. The presence of the Grey Hornbill in urban areas highlights the complex interactions between species distribution and environmental changes, particularly as altered vegetation structures, and food availability could have driven its appearance in city environs. This study explores how the LULCC, normalised difference vegetation index, and climate change are influencing Grey Hornbill's dependency on urban spaces, offering insight into the resilience of species amidst anthropogenic pressures, and changing landscapes.

Keywords: Anthropogenic pressure, Bucerotidae, environmental changes, green canopy, LULCC, NDVI, *Ocyceros*, urbanization.

Editor: S. Balachandran, Migratory Bird Monitoring Trust, Kanyakumari, India. **Date of publication:** 26 June 2025 (online & print)

Citation: Dhaduk, P. & G. Padate (2025). Range expansion of Indian Grey Hornbill population: a case study based on land use, land cover, and vegetation changes in Vadodara, Gujarat, India. *Journal of Threatened Taxa* 17(6): 27098–27109. https://doi.org/10.11609/jott.9523.17.6.27098-27109

Funding: This work was funded by SHODH Fellowship (ScHeme of Developing High quality research) by Government of Gujarat (June 2021 to May 2023).

Competing interests: The authors declare no competing interests.

Author details: Parikshit Dhaduk has been doing his research on Indian Grey Hornbills with aspects of range expansion in Gujarat from the Department of Zoology, The Maharaja Sayajirao University of Baroda, since January 2021. He got the SHODH Fellowship provided by the Government of Gujarat from June 2021 to May 2023. Dr. Geeta Padate served in the Department of Zoology at The Maharaja Sayajirao University of Baroda as a lecturer since 1992 and retired as professor in 2022. She has expertise in various fields like avian biology, wildlife biology, biodiversity, freshwater and marine ecology, etc. Recently she is engaged in giving guidance to the aspiring young field workers with her expertise in field studies.

Author contributions: PD was primarily responsible for the conceptualisation of the research problem, designing the experimental methodology, performing data collection through field surveys, and conducting the statistical analysis. He also prepared the first draft of the manuscript and created all tables and figures. GP provided expert guidance on the study design and methodology, supervised all stages of the research, and offered critical insights during the interpretation of results. She extensively reviewed and edited multiple drafts of the manuscript to enhance clarity.

Acknowledgements: We thank Department of Zoology, The Maharaja Sayajirao University of Baroda to providing facilities for research. We also thank to Government of Gujarat for providing necessary SHODH fellowship for research work. We thank all the bird watchers, who have directly or indirectly contributed to data including eBird site for providing secondary data.

INTRODUCTION

There are 63 species of hornbills in the world (IUCN 2024). The Indian subcontinent is known to be inhabited by 10 hornbill species, with nine species—Great Hornbill *Buceros bicornis*, Malabar Pied Hornbill *Anthracoceros coronatus*, Indian Grey Hornbill *Ocyceros birostris*, Malabar Grey Hornbill *Ocyceros griseus*, Oriental Pied Hornbill *Anthracoceros albirostris*, Wreathed Hornbill *Rhyticeros undulatus*, Rufous-necked Hornbill *Aceros nipalensis*, Austen's Brown Hornbill *Anorrhinus austeni*, & Narcondam Hornbill *Rhyticeros narcondami*—found in India and one species, the Sri Lanka Grey Hornbill *Ocyceros gingalensis*, found in Sri Lanka.

The Grey Hornbill, a common hornbill found on the Indian sub-continent often appears in pairs. This mostly arboreal species with a length of around 60 cm, is a medium-sized hornbill. The greyish-brown upper parts of the body with pale supercilium, darker ear coverts, and a prominent short pointed casque make it easily identifiable.

Grey Hornbills are known to occur in the forested tracts of lowland plains up to 600 m elevation in the Indian subcontinent. They are found from northeastern Pakistan and southern Nepal eastward to northwestern Bangladesh, and southward throughout most of India except in Assam (Hornbill Specialist Group 2024). The species is mostly found in dry deciduous forests, open woodlands and thorn forests (Rasmussen & Anderton 2012), has now become a common species in gardens and parks in many urban areas of central Gujarat (Ganpule et al. 2022), especially areas with many fig trees. Here, concurrent occurrence of Grey Hornbill has been reported from urban to semi urban areas of Vallabh Vidhyanagar (Nena 2020), Mehsana (Patel et al. 2021), Navsari (Bhusara et al. 2022), and also to a lesser extent in Surat, Anand, and Ahmedabad districts of Gujarat.

The division of Avian Biology, Department of Zoology, The M.S. University of Baroda has been conducting regular birdwatching trips/surveys for students for several decades. The first report regarding the presence of the Grey Hornbill in the city limits came in 2010 (Verma 2010). Since this report was filed, over the last 14 years, the population has risen remarkably from a single sighting on the outskirts of Vadodara City to an established breeding population by 2024. This led us to investigate the reasons for the increase from none to the established breeding population of Grey Hornbills in the city.

Altered vegetation structure, fluctuations in food availability, conducive reproductive sites, and elevated population densities are the primary motivators driving species relocation between habitats. Historical evidence indicates that rapid land use change and climatic transformations are the drivers to instigate shifts in the species distributions (Telwala et al. 2013). Furthermore, given the criticality of species' capacity to adapt to changing climatic conditions for survival (Serra-Diaz et al. 2014), the major threats to biodiversity are the rapid pace of climate change and the direct human activity-induced degradation of natural habitats. Satellite-derived Normalised Difference Vegetation Index (NDVI) maps are becoming important tools in ecological studies to show response of environmental changes and linking vegetation to animal performances (Pettorelli 2005). Further, LULCC is a critical factor known to affect biodiversity significantly (Sodango et al. 2017). Land cover delineates the spatial distribution of various surface features such as forests, agricultural lands, urban expansions, water bodies, and others. On the other hand, land use refers to the manner in which humans use and change land for various purposes, such as industry, housing, and agriculture (DeFries et al. 2004). These days, the conversion of forests into agricultural land, residential area, industrial locations, mainly due to urbanization has brought with it a number of negative effects, such as the loss of biodiversity, degraded soil, and polluted environmental geographic areas (Lemarkoko 2011).

Two approaches were used to find out changes in the environment of Vadodara which have attracted Grey Hornbills to the city. In this paper, attempts have been made to find out the probable influence of LULCC in attracting Grey Hornbill to the city and establish a breeding population. This is the first comprehensive attempt to look at Grey Hornbill's adaptation in urban areas like Vadodara in accordance with the LULC changes. Further, as climate is also considered an important factor influencing range extension of species (Ancillotto et al. 2016) attempts were made to look into possible change in the same over the last 23 years. Here the annual rainfall, annual maximum temperatures (T_{max}) as well as annual minimum temperatures (T_{min}) have been considered over the past 23 years.

MATERIAL AND METHODS

Study area

Vadodara (Image 1) is located in western India at 22.293° N & 73.193° E, at an elevation of 35.5 m between the fertile land of the river Narmada and Mahi.

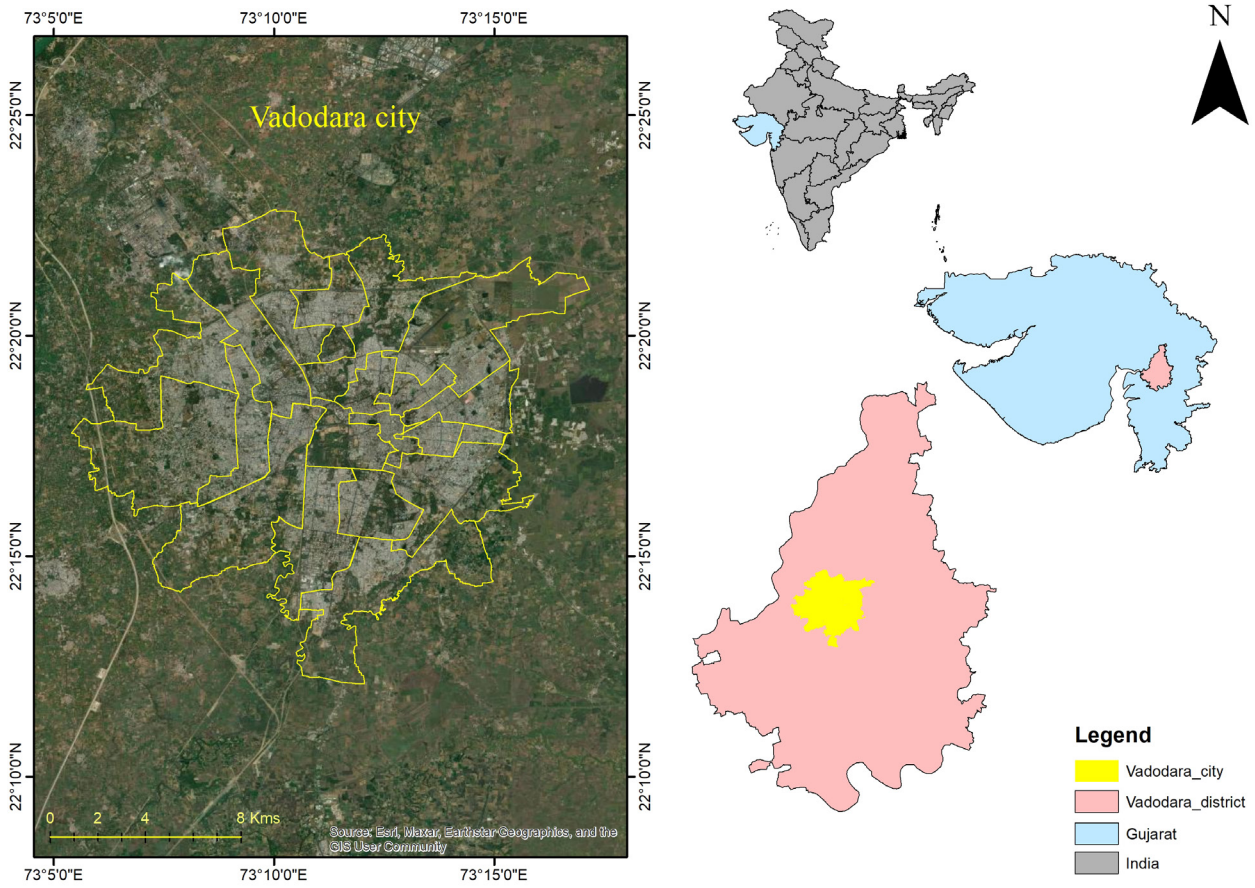

Image 1. Study area location of Vadodara in Gujarat, India.

A small river, Vishwamitri, cuts the city in two parts. Vadodara is the third most populated city in the Indian state of Gujarat after Ahmedabad and Surat. Vadodara is known as Banyan City owing to the presence of a large number of Banyan Trees *Ficus benghalensis*. The city is growing at a fast rate with the development of industrial areas and business centres, as well as residential areas, producing a strong gradient of suburbs. It has palaces, parks, ponds, residential areas with patches of vegetation in, and around them. The city receives an average rainfall of 931 mm. The mean temperatures in Vadodara ranges between maximum 40.4°C in summer to minimum 20.4°C in winter; occasionally rising to 44°C and dropping to minimum 9.8°C (Vadodara Municipal Corporation accessed on 08.ix.2024).

Methodology

The study was conducted in Vadodara City from January 2021–July 2024. Primary data were collected through field surveys and secondary data were obtained from the eBird website and enthusiastic bird watchers. To understand the distribution of Grey Hornbills in the city, the city area was divided into 180 grids (1 x 1 km). Throughout the study, rapid, and broad field surveys were conducted almost monthly (except during the lockdown) through the point count method (Bibby et al. 2000). The presence of Grey Hornbills was mainly explored in the residential area, roadside area, gardens, and near water bodies. All the observations are tagged on Google Earth. Secondary data from eBird is also used to understand the status of Grey Hornbills in the city. The majority of the primary observations were performed on foot or by riding a motorcycle.

For the collection of NDVI and LULCC data, shape file for Vadodara was outlined for 208.84 km^2 and the data for years 2010, 2015, and 2020 were collected. This helped in finding out temporal and spatial changes at specific time intervals. As cloud cover is at its lowest and vegetation cover is good in January, satellite images of Landsat 7 and Landsat 8 for Vadodara City were downloaded from the USGS Earth Explorer site (https://earthexplorer.usgs.gov assessed on 01.i.2023) for respective years to find out changes over the last 15 years. In order to create LULCC and NDVI maps ArcGIS

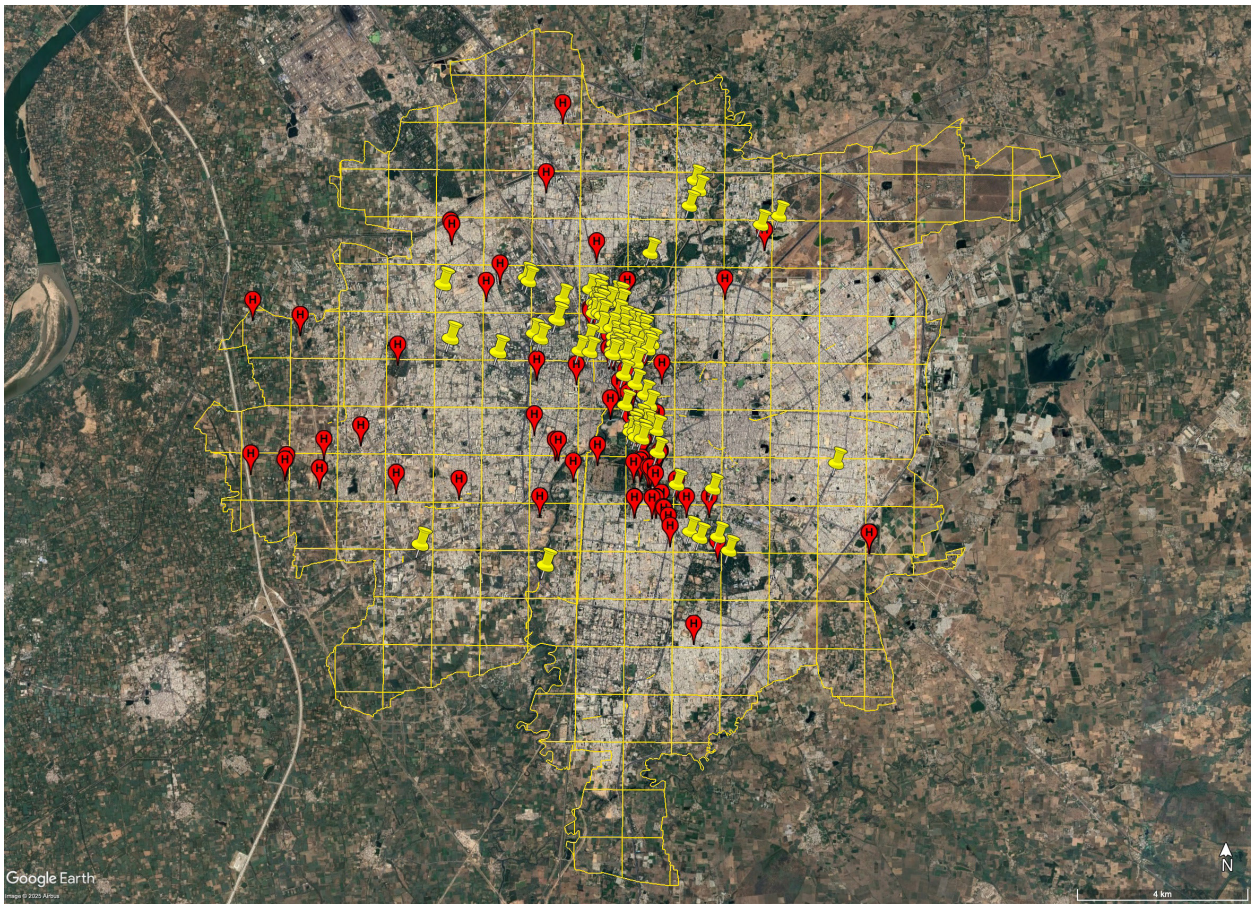

Image 2. Primary (yellow indicators) and secondary (red indicators) records of Indian Grey Hornbill in Vadodara City 2021–2024.

10.8 software is used. NDVI utilizes data from satellite sensors that detect near-infrared (NIR) and red (R) light. NDVI values range from -1 to +1, with higher values indicating healthier, dense vegetation, and lower or negative values indicating sparse vegetation or non-vegetated surfaces such as open areas. LULCC data from different years delineate the temporal and spatial distribution of various land surfaces, and how the human influence changes the same.

Further, climate data were collected in GRD file format from the Indian Meteorological Department's (IMD) website for the years 2000 to 2023 (Pai et al. 2014). These include annual rainfall, minimum, and maximum temperature data. That GRD data was converted into CSV format, using code, and run in Python software. The generated CSV file was loaded into ArcGIS to extract spatially accurate climatic data for Vadodara City.

RESULTS

Out of 180 grids, Grey Hornbills were reported from 41 grids, including three in the centre of the city, which had the maximum sightings. Although Grey Hornbills showed local movements, most of these were noted in restricted areas only. Grey Hornbills were observed in all months, but their movement was low during breeding months. Fourteen nests were noted between 2022 and 2024, indicating the presence of a breeding population (Image 2). No data on nesting could be recorded in 2021 due to the COVID-19 lockdown.

In the checklist of birds of Vadodara District (Padate et al. 2001), the Grey Hornbill was not reported from the district. By 2010, there was only a single sighting of the Grey Hornbill, reported from the outskirts of the city. Between 2010 to 2015, six sightings were recorded within the city limits by birdwatchers and uploaded on the eBird website, while between 2015 to 2020, it increased remarkably to 65 (Table 1). Simultaneously, the second author also began observing them and receiving information about their presence in the

university campus, its surrounding areas, as well as other vegetated patches from the students of avian biology. By the time popularity of eBird also started increasing, leading to more records being added.

Image 2 shows locations of both primary and secondary data of sightings of Grey Hornbill during the study period from 2021–2024. This image shows that over the years, Grey Hornbills have established themselves in the central vegetated patches of Vadodara. When the changes in NDVI values over the last 15 years are compared (Figure 2), it can be noted that in 2010 the values ranged -0.44 to 0.82, whereas in 2015 and 2020 they ranged -0.39 to 0.89 and -0.21 to 0.79, respectively. The increase in NDVI values indicates that the vegetation of the area is changing. It is important to note that the green patches in the northern, western, and southern parts of the city are mainly agricultural lands where Grey Hornbills were not recorded during the survey.

As per LULCC in the year 2010 (Figure 3a, Table 2), the built-up area encompassed 90.58 km^2, constituting approximately 43% of the total area, while vegetation cover was spread over 28.66 km^2, representing around 14%. Other land patterns, including agricultural land, barren land, and water bodies, occupied 44.45 km^2 (21%), 42.29 km^2 (20%), and 2.86 km^2 (1%) respectively (Table 2). By 2015 (Figure 3b, Table 2), the built-up area had expanded to 96.68 km^2, accounting for 46% of the total area while vegetation cover decreased just by 1% to 27.85 km^2 (13%), and agricultural land, barren land as well as water bodies occupied 40.05 km^2 (19%), 42.69 km^2 (20%), and 1.56 km^2 (1%), respectively (Table 2). By 2020 (Figure 3c, Table 2) the built-up area further increased to 107.42 km^2, now constituting 51% of the total area but vegetation cover also expanded to 44.54 km^2 (21%). Conversely, agricultural land decreased to 26.89 km^2 (13%), while barren land, and water bodies occupied 28.80 km^2 (14%) and 1.16 km^2 (1%), respectively (Table 2).

Table 1. eBird website records of hornbill sightings in Vadodara.

Year	No. of hornbills	Year	No. of hornbills
2010	Nil	2017	5
2011	Nil	2018	18
2012	1	2019	13
2013	Nil	2020	26
2014	1	2021	42
2015	4	2022	82
2016	3	2023	83

Changes in annual rainfall

The rainfall fluctuated from year to year (Figure 3), showing significant oscillations with an equation of y = -7.4609x + 15950 and R^2 = 0.0225. A linear trend line suggests a slight downward trend in rainfall over the years.

Changes in T_{max} and T_{min}

T_{max}: The average maximum temperature stayed mostly around 33–35°C throughout the period. The trend line shows a slight downward trend, with an equation of y = −0.0293x + 34, and R^2 = 0.2232 (Figure 4), indicating a minor decrease in the average maximum temperatures over time.

T_{min}: The average minimum temperature remained between 19–22 °C over the years. The trend line shows a slight upward trend, with an equation of y = 0.056x + 20.353 and R^2 = 0.5935 (Figure 4). This suggests a more pronounced increase in the minimum temperatures over time.

DISCUSSION

The Grey Hornbill, generally adapted to live in the dry deciduous forest, open woodlands, thorn forests,

Table 2. Total area and percentage of LULCC of Vadodara City for 2010, 2015, 2020.

	Year	2010		2015		2020	
	Land type	Total area (in km^2)	%	Total area (in km^2)	%	Total area (in km^2)	%
1	Agriculture land	44.45	21	40.05	19	26.90	13
2	Barren land	42.29	20	42.69	20	28.80	14
3	Built-up area	90.58	43	96.68	46	107.43	51
4	Vegetation	28.66	14	27.85	13	44.54	21
5	Waterbodies	2.86	1	1.57	1	1.16	1
6	Grand Total	208.84	100	208.84	100	208.84	100

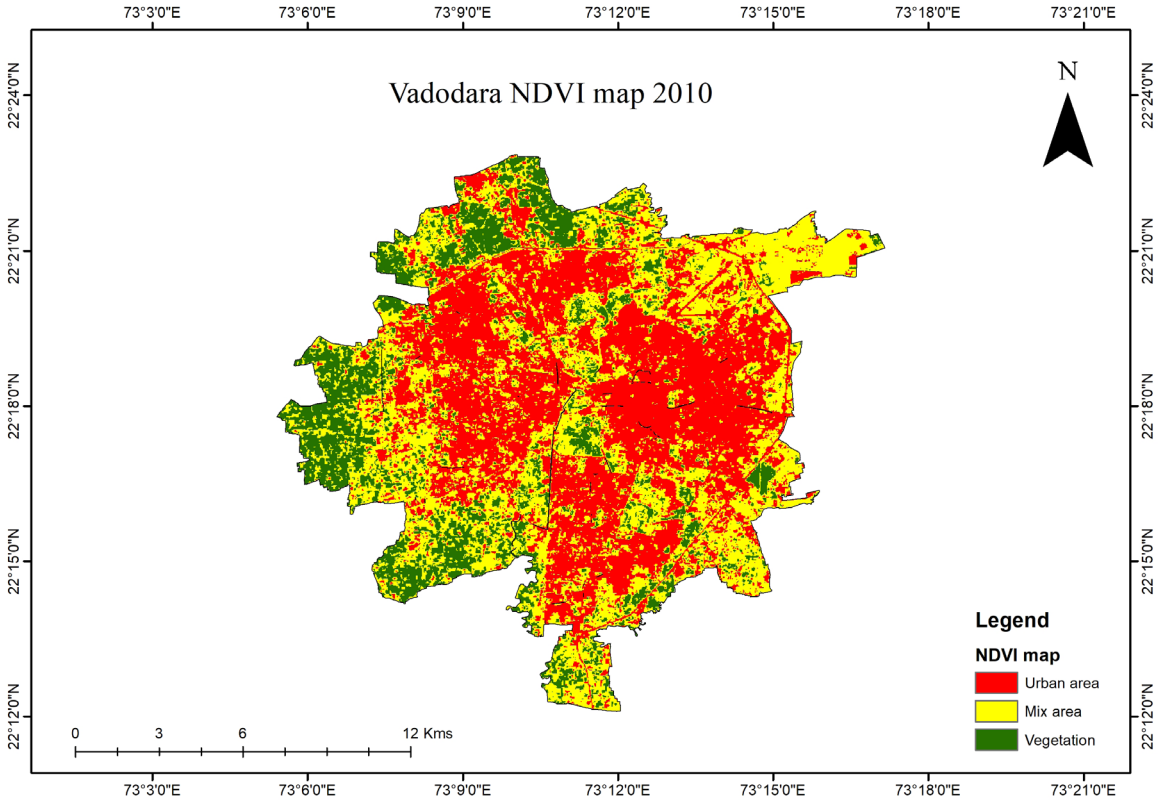

Figure 1(a). Vadodara City NDVI map 2010.

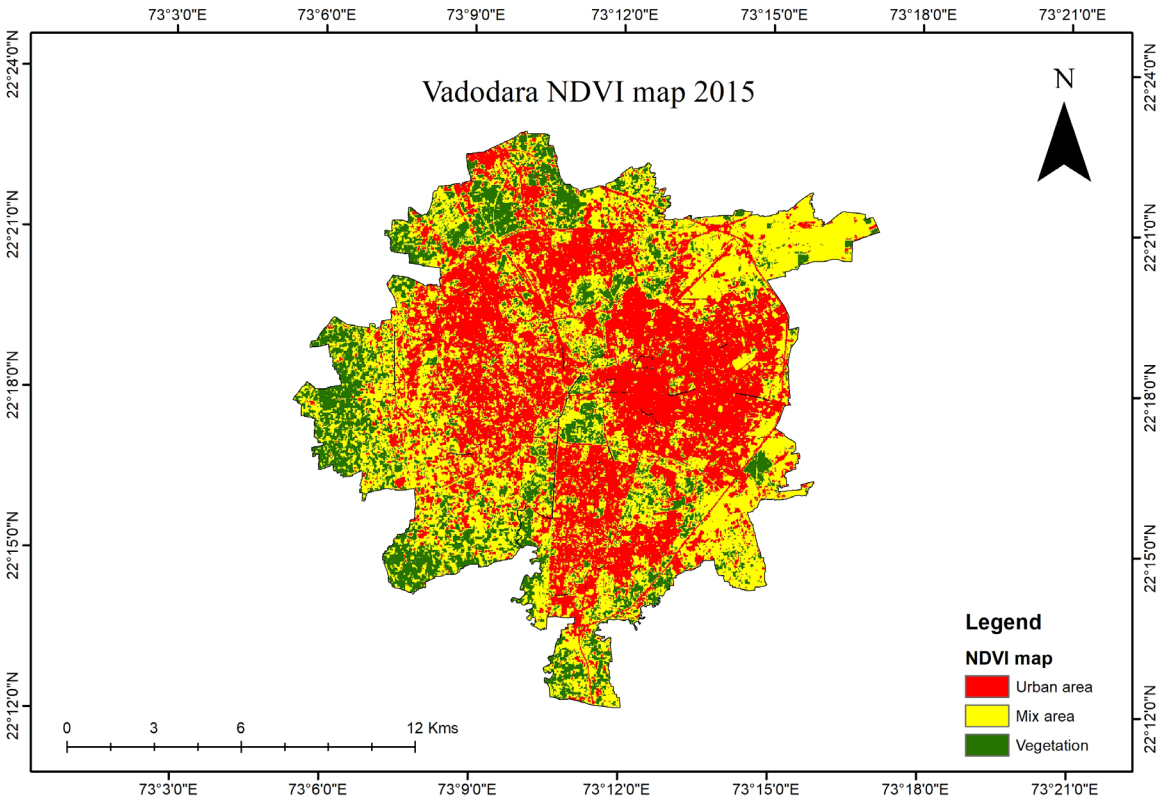

Figure 1(b). Vadodara City NDVI map 2015.

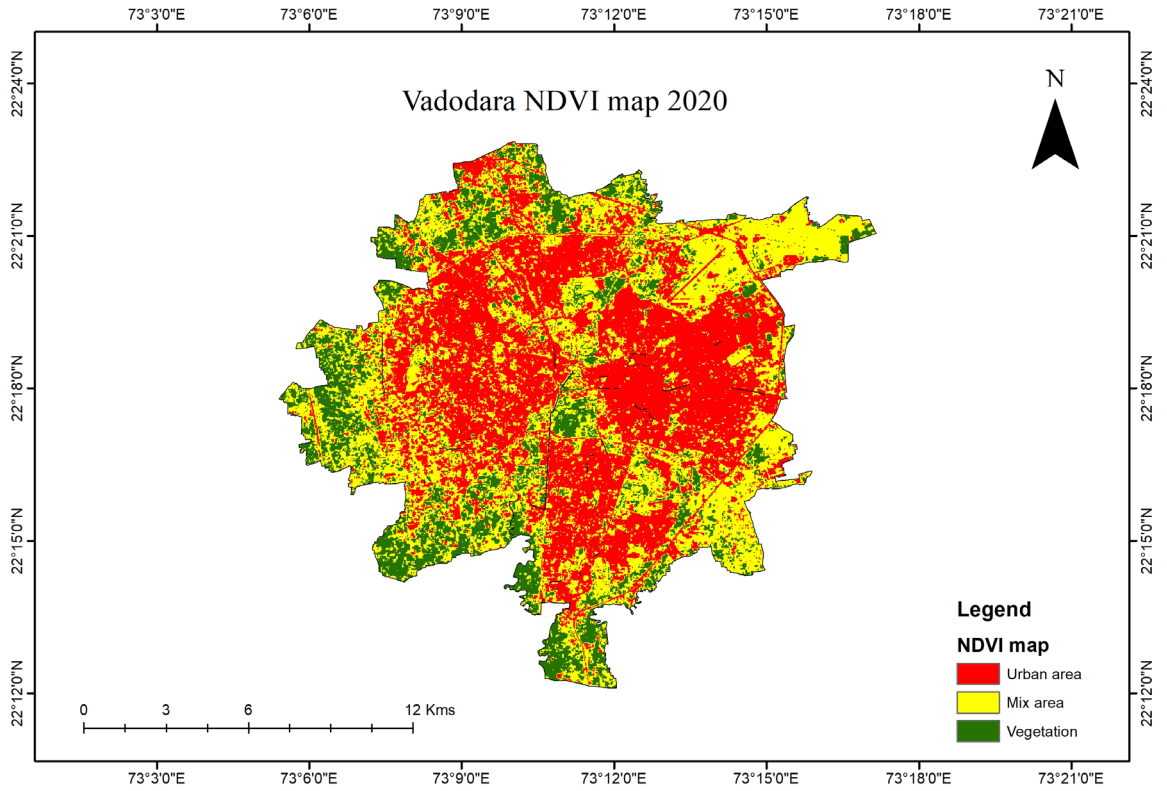

Figure 1(c). Vadodara City NDVI map 2020.

and shrublands (Rasmussen & Anderton 2012), has recently started appearing in urban gardens and parks (Ganpule et al. 2022; Hornbill Specialist Group 2024) of Gujarat. Here, Grey Hornbill regularly occurs in the eastern forested tribal belt. State of India's Birds 2023 (SOIB) shows that the long-term trend for Grey Hornbill is not conclusive due to insufficient data for the Gujarat State (https://stateofindiasbirds.in/species/inghor2/). But this kind of long-term trend documented from the Vadodara region of Gujarat provides some inputs to conclude the rapidly increasing long-term trend for Grey Hornbill at national level.

In Vadodara City, a slow and steady increase in appearance in the Grey Hornbill population in the vegetated patches has been noted after 2010. By 2024, they have established themselves as a viable breeding population. Recent reports indicate that they are also adaptable to nesting in urban concreted forests (Kasambe 2020).

Veech (2011) reported that the process of range expansion is influenced by habitat ecology. Croplands, urban land, and shrubland are examples of habitats that are physically open, and probably offer year-round food supplies. Possible factors that influence range extension include habitat loss in their traditional range, population change, poor prior documentation, and habitat change in the new area (Rappole et al. 2011). As far as the previous area for Grey Hornbill in Gujarat is concerned, it is the tribal belt where the flesh of Hornbills is traditionally used for pregnant women to relieve labour pain. This kind of poaching practice might have forced the Grey Hornbills to move away from their habitat. In many other areas of India, the flesh of different species of Hornbills is also used for various medicinal purposes (Chakravorty et al. 2011; Samal et al. 2020). Thus, one of the most probable reasons for shifting beyond its known ranges is the threat due to poaching. Further, changes in the seasonal food availability, influenced by climatic change-related factors, such as mean annual precipitation, or monthly means for night-time-low temperatures during the breeding season, cannot be ruled out. Fluctuations in temperatures and rainfall in a particular area are likely to affect biodiversity. High temperatures and lower rainfall can cause biodiversity loss, and fragmentation (Mantyka-Pringle et al. 2012). The changes in the temperature and rainfall pattern in Vadodara City were examined. T_{max} and annual rainfall in Vadodara City are somewhat decreasing while T_{min} is slightly increasing. Thus, we observe that temperature and rainfall could have negligible influence on Grey Hornbill in our study

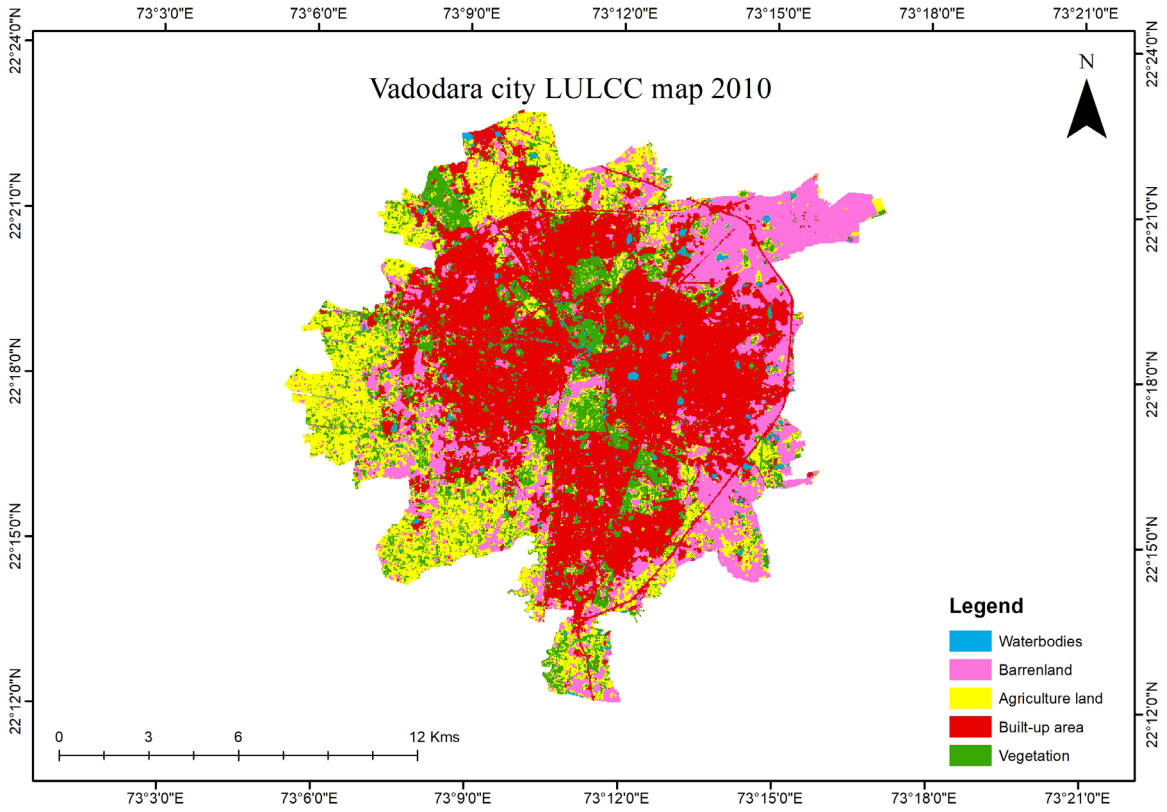

Figure 2(a). Vadodara City LULCC map 2010.

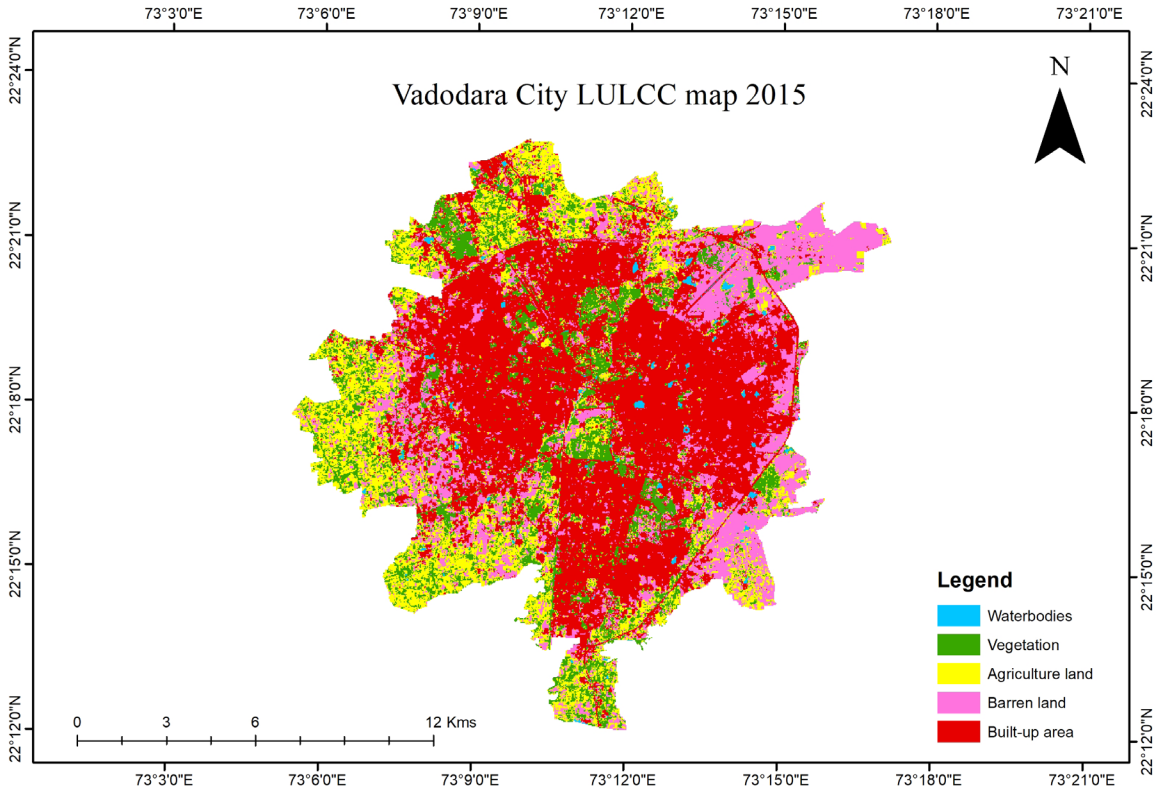

Figure 2(b). Vadodara City LULCC map 2015.

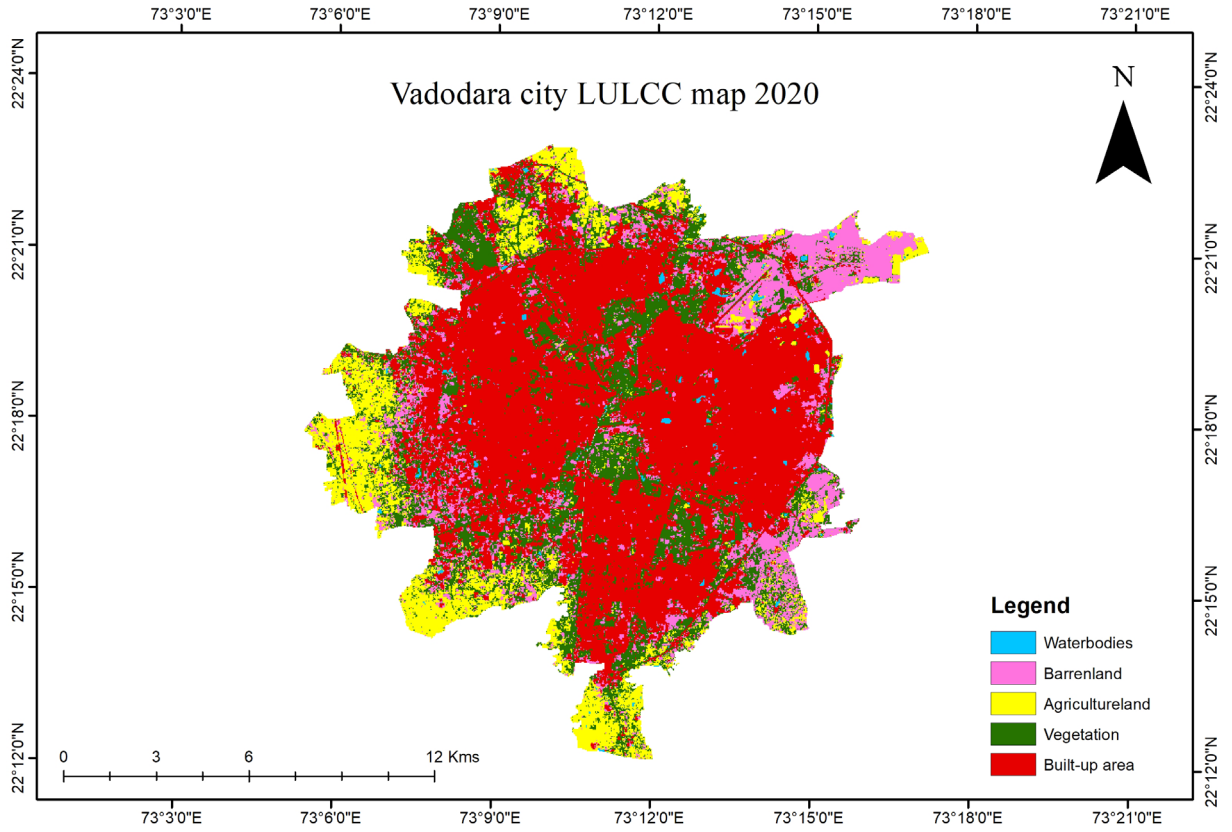

Figure 2(c). Vadodara City LULCC map 2020.

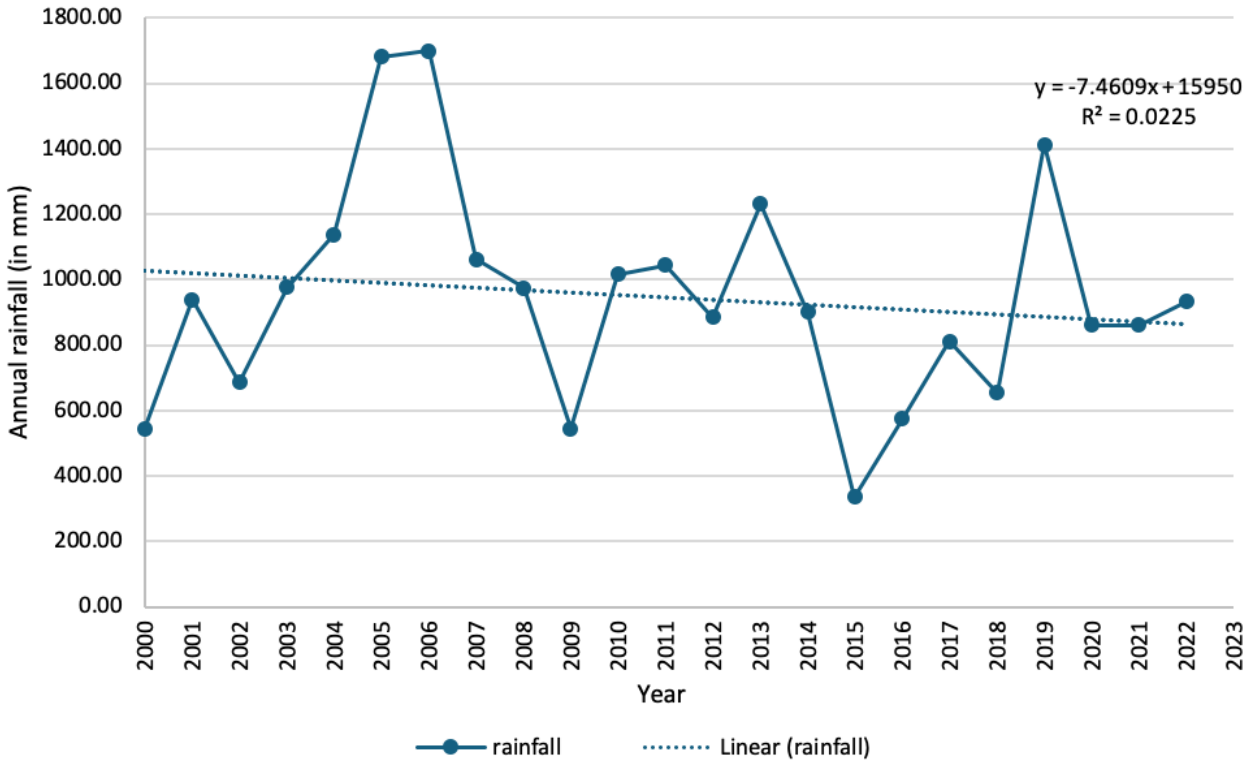

Figure 3. Annual rainfall since 2000 to 2023 in Vadodara City.

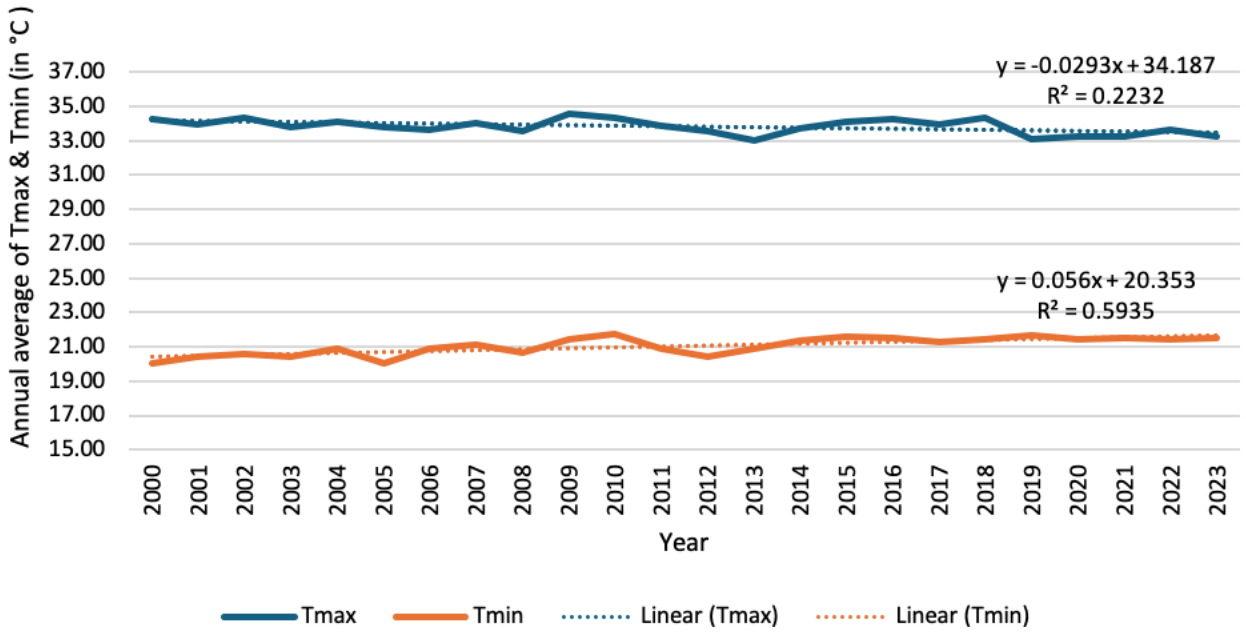

Figure 4. Annual average of T_{max} & T_{min} since 2000 in Vadodara City.

location. Although, climate has been identified as the primary driver of several species' range expansions, even if habitat availability is likely to have an impact. Pigot et al. (2010) discusses the progress of range expansion (pace of spread and saturation) as unevenly over vast regional and geographical scales, indicating that the process is very uncertain, and dynamic. Based on the distribution pattern of common and uncommon species, modern processes have influenced the distribution patterns of species richness at large geographical scales. This implies that when studying ecological trends at vast geographical scales, anthropogenic activity cannot be excluded as a potential driving component (La Sorte 2006). Temperature and rainfall could have negligible influence on Grey Hornbills in our study area but in 2010, the landscape was characterized by extensive vegetative areas and minimal urban spread. As mentioned by Grimm et al. (2008) and Yao et al. (2019), the urban built-up areas surged while vegetation cover declined in 2015 — a clear sign of rapid urbanization. The trend shifted by 2020; The change in the trend witnessed during 2020 had shown a remarkable increase in both vegetation and built-up areas, also a reduction in mixed (areas having a composition of barren land, agricultural land, and water bodies) areas. This indicates that during this period, despite urban development encroaching into mixed areas, proactive efforts contributed to a simultaneous increase in vegetation cover, showcasing a potential path forward for sustainable urban growth. The increased influence of urbanization with improved vegetation cover has been reported in several areas globally (Zhao et al. 2016; Wang et al. 2022). The increase in the vegetation cover in Vadodara City may be attributed to either new town planning laws, where planting vegetation near new construction is mandatory.

Further, with the help of LULCC%, we can also say that in Vadodara, built-up area has increased at a greater rate by converting agriculture and mixed lands, which shows a decrease in the spread over the years, as is also observed in Delhi (Naikoo et al. 2020). Hence, it can be assumed that the vegetational changes in the city area helped the Grey Hornbills to establish a breeding population. This species seems to have expanded its range over the green patches along the riverine and drainage system around Vadodara.

Vadodara, known as the city of 'Vad' (Banyan) and other old natural vegetation, provided food as well as shelter to this species. Though LULC changes are reported to impact biodiversity negatively, in Vadodara, these changes appear to have helped the entry of Grey Hornbills in the city limits to establish a breeding population during the last decade.

CONCLUSION

According to the study, it reveals a significant rise in the presence and distribution of Grey Hornbills in Vadodara City over the past decade, with recorded breeding activity between 2022 to 2024. Initially

unreported in the region, their numbers have grown steadily, particularly in the central vegetated patches of the city, as supported by both direct observations, and citizen science data (eBird). Although sightings remain mostly restricted to specific green patches 14 nests in different areas strongly indicate the establishment of a breeding population. Vegetation dynamics, as shown by rising NDVI values, and land use data, suggest that urban greenery has increased in some areas despite overall urban expansion. This likely contributes to the Grey Hornbill's ability to persist and breed within the city. Their absence from agricultural lands suggests a preference for urban green spaces over rural or open landscapes. Climatic variables, including slight decreases in maximum temperatures and minor increases in minimum temperatures, along with fluctuating rainfall patterns, do not appear to significantly limit the species' distribution at present, but needs continued monitoring. Overall, the findings underscore the Grey Hornbill's adaptability to urban environments and highlight the importance of conserving, and enhancing urban green spaces to support biodiversity within rapidly growing cities like Vadodara.

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Journal of Threatened Taxa is indexed/abstracted in Bibliography of Systematic Mycology, Biological Abstracts, BIOSIS Previews, CAB Abstracts, EBSCO, Google Scholar, Index Copernicus, Index Fungorum, JournalSeek, National Academy of Agricultural Sciences, NewJour, OCLC WorldCat, SCOPUS, Stanford University Libraries, Virtual Library of Biology, Zoological Records.

NAAS rating (India) 5.64

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www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

June 2025 | Vol. 17 | No. 6 | Pages: 27035–27170
Date of Publication: 26 June 2025 (Online & Print)
DOI: 10.11609/jott.2025.17.6.27035-27170

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