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Comparative Assessment and Monitoring Changes in NDVI of Achanakmar Tiger Reserve (ATR) and its Buffer Zone, India

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ABSTRACT

Achanakmar Tiger Reserve (ATR), endowed with rich biological diversity and lush green vegetation in and around, makes it more unique. It is also an integral part of the Achanakmar Amarkantak Biosphere Reserve (AABR) and has been identified as one of the important tiger reserves of the Central Indian landscape due to its connectivity with other protected areas and tiger reserves in neighboring landscapes. Vegetation mapping and monitoring are important to understand changes in ecosystem processes and associated temporal and spatial impacts. Pre- and post-monsoon IRS, LISS III, and AWiFS satellite data from 2000, 2004, 2008, 2010, and 2013 were used for the present study. This paper is an attempt to examine the variation in the normalized difference vegetation index (NDVI) of ATR and its buffer zone on a seasonal and temporal basis. Climate conditions such as temperature, precipitation, relative humidity, etc. play an important role in the growth and development of healthy vegetation. The NDVI value of ATR has shown fluctuation and recorded positive growth over the past 14 years with few exceptions. The post-monsoon season recorded a higher NDVI value as compared to the pre-monsoon months. The maximum NDVI value was recorded in 2004 (+0.539) for the entire ATR and its buffer zone.

INTRODUCTION

Since the early 1970s, the Normalized Difference Vegetation Index (NDVI) has been the most widely used vegetation index for studying vegetation and phenology. This term was first used by Rouse et al. (1973) and is directly related to the photosynthetic capacity and thus the energy absorption of plant canopies (Sellers 1985, Myneni et al. 1995).

NDVI is a sensitive parameter of surface vegetation and vegetation growth that reflects the difference between the radiation absorption in the red spectral region caused by chlorophyll and the reflectivity of canopy structure caused by the near-infrared spectral region, which can effectively characterize the vegetation environment, its changes, and effects (Leon-Tavares et al. 2021, Morawitz 2006, Pu et al. 2022). NDVI is associated with biomass, carbon sequestration, plant water stress, and biodiversity (Nagendra et al. 2013, Gillespie et al. 2019).

Multispectral satellite data collected at regular intervals with a Geographical Information System (GIS) provides a suitable platform for vegetation data analysis (Muhati et al. 2018). This technique and data are more appropriate than traditional ground surveys because it takes less time to detect the changes that have preceded the area, is less expensive, and provides a nearly real picture of larger and physically inaccessible areas (Nad et al. 2022).

Achanakmar was officially established as a wildlife sanctuary in the year 1975 under the Wildlife (Protection) Act, 1972. Later, it was declared a tiger reserve in 2009 due to the presence of endangered tiger species. Tigers and leopards are the biggest predators in this area. It is a habitat for more than 50 species of mammals, including bison, spotted deer, sambhar, nilgai, mouse deer, striped hyena, etc. The Maniyari River, which originates in the core zone of ATR, is its lifeline. Many seasonal and perennial tributaries feed into the Maniyari River. This area is home to a few indigenous tribal groups such as the Baiga, Kol, Munda, and others. The ATR connects many different tiger reserves and protected areas of the Central Indian landscape through corridors.

Champion & Seth (1968) categorized ATR's forest vegetation into northern tropical moist deciduous and southern dry mixed deciduous forests (Roychoudhury 2013). Sal (*Shorea robusta*) is the dominant tree species, followed by Sal mixed forest, which includes tree species such as *Terminalia tomentosa, Diospyros melanoxylum, Adina cordifolia*, *Pterocarpus marsupium*, *Madhuca indica*, *Anogeissus latifolia*, and *Tectona grandis* (plantation). Bamboo (*Dendrocalamus strictus*) is also found on higher and lower slopes with various tree species (Mandal et al. 2017). More than 50 tree species and over 600 medicinal plant species were found here. Twenty-five threatened floral species under various threat levels as enlisted by the IUCN Red List are found in ATR. It includes one critically endangered species (*Rauwolfia serpentina*), five endangered species (*Adiantum capillus veneris* L., *Lygodium flexuosum* (L.) *Sw, Clerodendrum serratum* (Linn.) Moon, *Acorus calamus* L., *Eulophia herbacea* Linds.), and 19 vulnerable species (Roychoudhury et al. 2012).

Numerous studies have been carried out in the ATR to assess floral diversity (Sahu 2011, Singh & Sharma 2017, Sandey & Sharma 2016, Singh et al. 2005, Shukla & Singh 2009) and faunal biodiversity (Roychoudhury et al. 2019, Mandal et al. 2017). However, little is known about the use of geospatial technology in monitoring the vegetation of the Achanakmar Tiger Reserve.

Today, remote sensing and GIS have emerged as useful tools to monitor ecological impacts and changes in green corridors, offering capabilities to detect and interpret floral and faunal habitat quality (Nad et al. 2022). There have been an increasing number of studies that have used NDVI to study ecosystem dynamics and disturbances in protected areas (Prasai 2022, Gillipsie et al. 2019, Nemani et al. 2009).

The present study aims to assess and monitor the seasonal and annual NDVI trends of ATR between 2000 and 2013. Emphasis has also been placed on examining the same NDVI trends for its buffer zone (excluding the core zone), as more than 30% of the ATR consists of the buffer zone, which is more vulnerable to anthropogenic influence, and therefore fluctuations in the NDVI value of this area may impact the overall NDVI trend of the entire reserve area.

MATERIALS AND METHODS

Study Area

The geographical extent of the Achanakmar Tiger Reserve (ATR) is between 22°17' and 22°38' North latitudes and 81°31' and 81°57' East longitude. It covers an area of 914.017 km^2, of which 626.195 km^2 belongs to the core

Table 1: Area details of the core and buffer zone of ATR.

Area	Area (km^2)	Status	Legal Status	Total Forest Area (km^2)
Core Area (Critical tiger Habitat)	551.552	Achanakmar Wildlife Sanctuary	Reserve Forest	626.195
	74.643	Non Protected area of Bilaspur and Marwahi Forest Division	Reserve Forest	
Buffer Area	248.902	-	Reserve Forest	287.822
	38.920	-		
Total Tiger Reserve Area = 914.017 km^2				

(Source: Forest Dept., Govt. of Chhattisgarh)

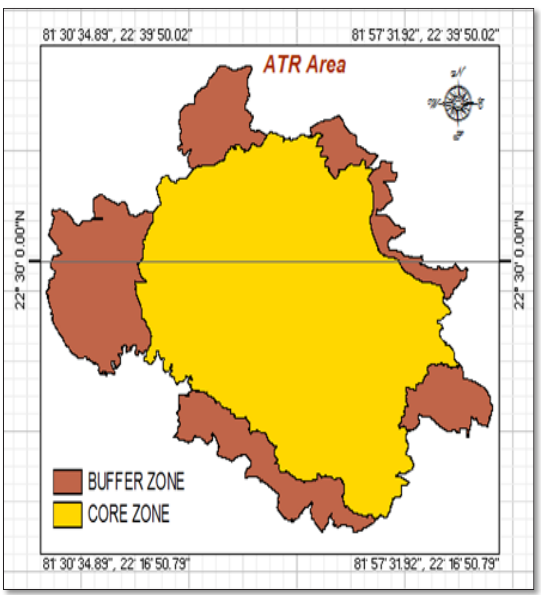


Fig. 1: Map of Achanakmar Tiger Reserve (ATR) illustrating its core and buffer zones.

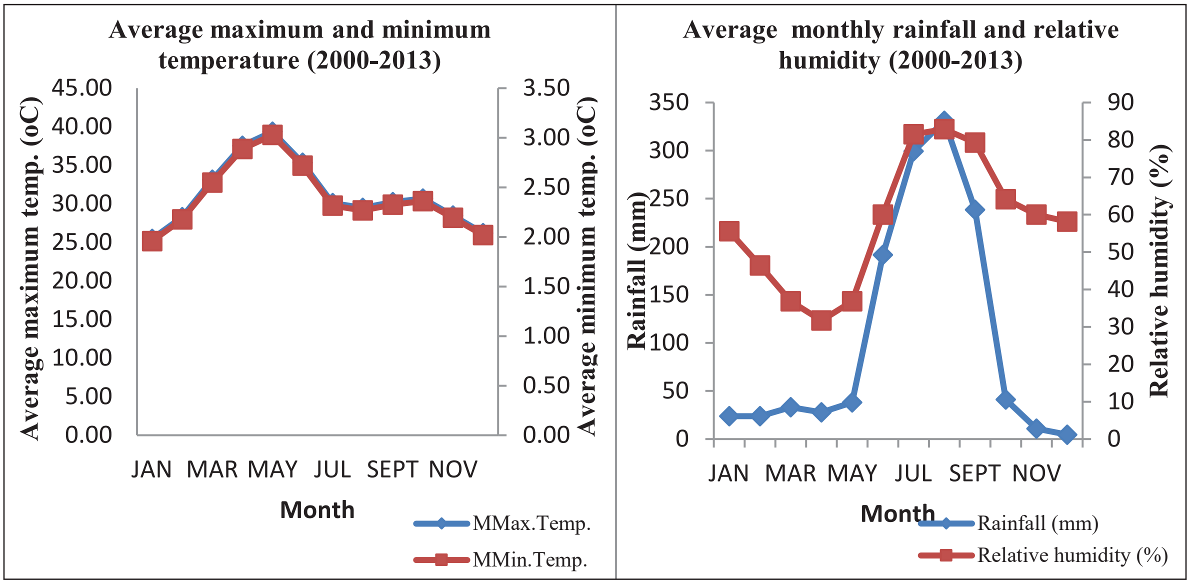
zone (critical tiger habitat) and 287.822 km^2 to the buffer zone (Fig. 1, Table 1). It is located in the Mungeli district of Chhattisgarh state.

Climate

The study area is characterized by a tropical climate. The average annual precipitation of the study area is more than 1200 mm (Fig. 3), and most of the precipitation falls from July to October. The average annual temperature of the region ranges from 2°C to 46.7°C (Fig. 2). The meteorological data has been obtained from the Indian Meteorological Division (IMD, Pune) of ATR's nearest meteorological station, Pendra Road station.

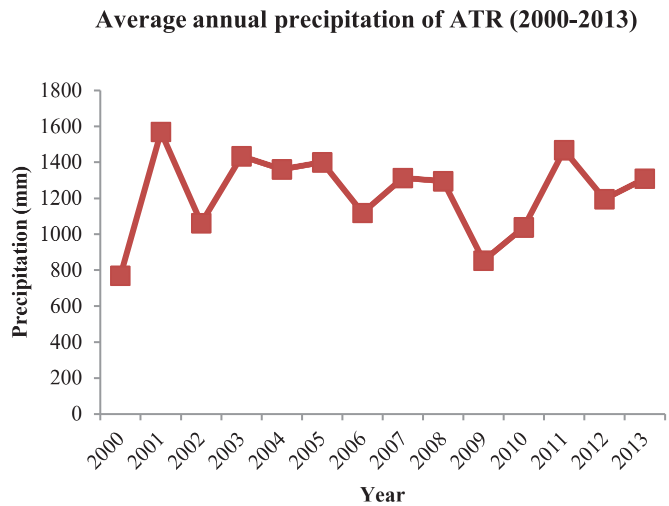
Data Used

Multitemporal and multispectral satellite data from Indian Remote Sensing (IRS) satellites was used to assess and monitor NDVI for the entire ATR and its buffer zone. For the current study, cloud-free data from pre-monsoon and post-monsoon have been used (Table 2). IRS-1 D LISS-



(Source: IMD, Pune)

Fig. 2: Average maximum and minimum temperature (a) and average monthly rainfall and relative humidity (b) of ATR during 2000-2013.



(Source: IMD, Pune)

Fig. 3: Average annual precipitation of ATR during the time frame (2000-2013).

Table 2: Detailed description of satellite data.

Satellite and Sensor	Path/row	Date and year of image acquisition
IRS 1D, LISS 3	102/56	28th Feb 2000
		10th Oct 2000
IRS P6, LISS 3	102/56	29th Feb 2004
		19th Nov 2004
IRS P6, LISS 3	102/56	3rd March 2008
		29th Oct 2008
IRS P6, AWiFS	99/58	6th Feb 2010
		28th Oct 2010
IRS P6, LISS 3	102/56	5th Feb 2013
		14th Dec 2013

LISS - Linear Imaging and Self Scanning, AWiFS - Advanced Wide Field Sensor

III satellite data from 2000 and IRS-P6 LISS-III satellite data from 2004, 2008, and 2013 covering the Achanakmar Tiger Reserve area have been procured from the National Data Centre, National Remote Sensing Centre (NRSC), Hyderabad. IRS P6 and AWiFS satellite imagery for 2010 was downloaded from the website (http://bhuvan.nrsc.gov.in/). The satellite data for the year 2000 was geo-corrected using the ground control points from the 2004 geo-referenced satellite imagery. The entire tiger reserve area and its buffer zones are delineated based on the map provided by the state forest department.

Methodology

The obtained images were registered in the Universal Transverse Mercator (UTM) map projection with the datum WGS-84. The study area is located in zone 43 (N) of UTM. IGIS software version 1.0 has been used for image processing. Image pre-processing includes layer stacking, mosaicking, and image enhancement. The geo-referenced satellite images were clipped (an image subset) using the Achanakmar Tiger Reserve (ATR) area boundary. The ATR shape file was obtained from the Forest Department, Government of Chhattisgarh. The image transformation tool of IGIS software has been used to extract NDVI information. The pre and post-monsoon satellite images of the years 2000, 2004, 2008, 2010, and 2013 were used for the present study. NDVI analysis and monitoring were performed separately for the entire ATR area and its buffer zone.

RESULTS

The analysis of spatiotemporal NDVI of ATR was performed during pre- and post-monsoon months for ATR and its buffer zone (excluding the core zone), as illustrated in Fig. 4.

NDVI Dynamics of ATR During Pre-Monsoon Months

The data reveals that during 2000, the NDVI value ranged between -0.129 and +0.405 for the entire ATR. NDVI values in the buffer zone decreased slightly (-0.122 and +0.344) during the same time period. The maximum NDVI value for both ATR and its buffer zone was recorded in 2004 at +0.414. In 2008, the recorded NDVI value ranged from -0.022 to +0.281. During 2010, the NDVI value ranged between -0.118 and +0.360 for ATR, whereas its buffer zone recorded a lesser NDVI value of +0.318. In 2013, the maximum

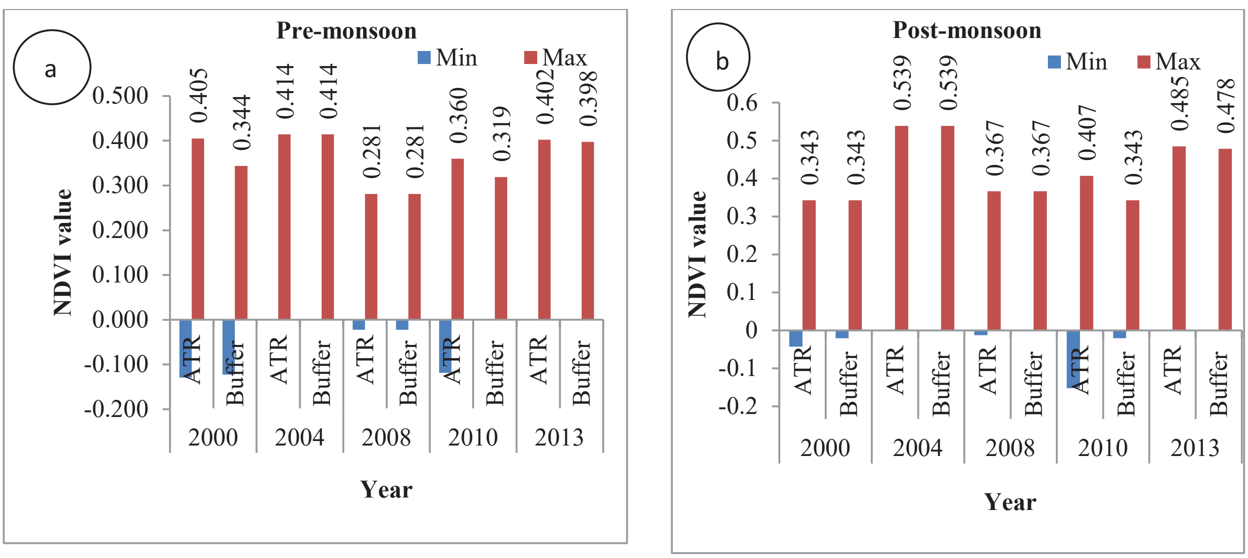


Fig. 4: Spatial patterns and seasonal differentiation of NDVI change for ATR and its buffer zone a) Minimum and maximum NDVI values during pre-monsoon and b) post-monsoon season.

NDVI value recorded was +0.402 for the entire ATR, while the buffer zone recorded a decline in NDVI value of +0.397.

NDVI Dynamics of ATR For the Post-Monsoon Months

The variation of NDVI values of ATR and its buffer zone during post-monsoon months is depicted in Fig. 4. The positive values represent different types of vegetation classes, while near zero and negative values indicate non-vegetation classes, such as water and barren land. The data reveals that in 2000, the NDVI value ranged between -0.042 and +0.343 for the entire ATR. In 2004, the maximum NDVI value for ATR and its buffer zone was +0.539. In 2008, the minimum and maximum values ranged from -0.012 to +0.367. During the same year, the buffer zone recorded a maximum NDVI value of +0.367. For 2010, the NDVI value ranged from -0.152 to +0.407 and -0.020 to +0.343 for ATR and its buffer zone, respectively. The year 2013 recorded a maximum NDVI value of +0.485 for the entire ATR and its buffer zone of +0.478. The higher NDVI values may be due to the development of ground flora, crops in agricultural fields, and a healthier tree canopy (Fig. 5).

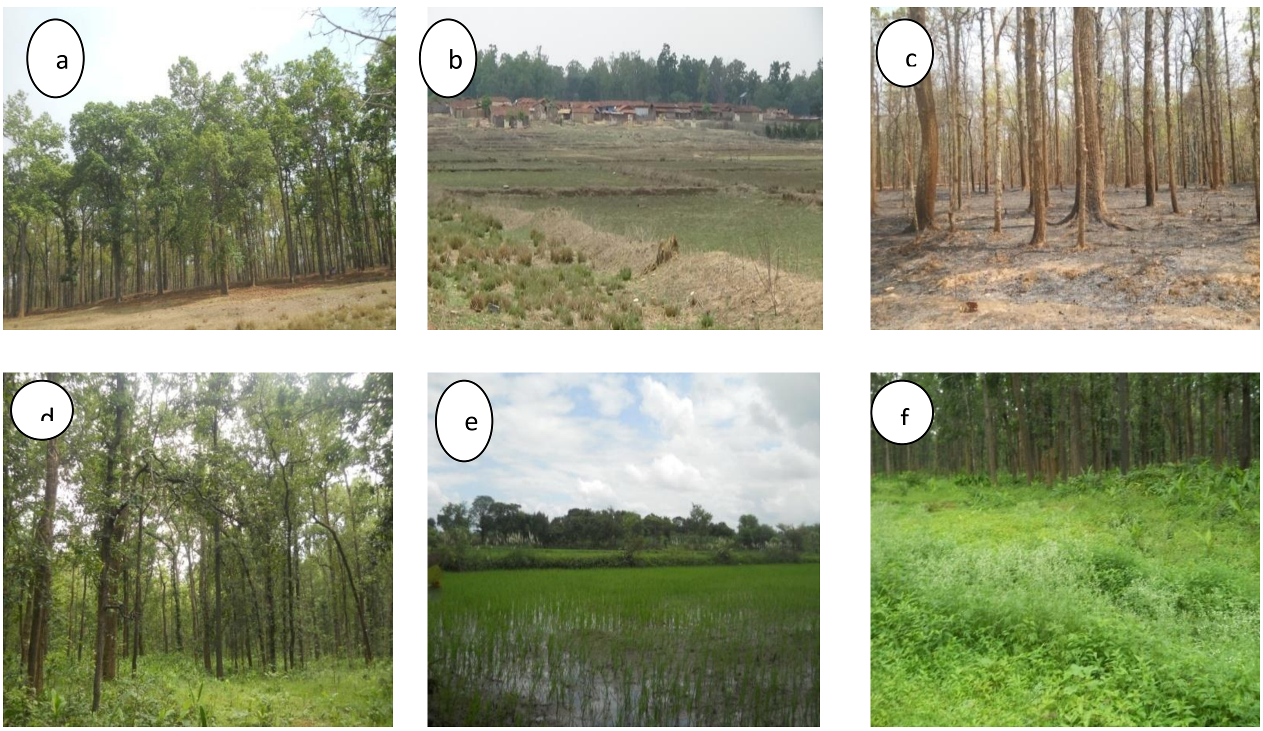
Table 3: Mean NDVI values of ATR and its buffer zone (2000, 2004, 2008, 2010 and 2013).

Year	Pre-monsoon		Post-monsoon	
	ATR	Buffer	ATR	Buffer
2000	0.0883	0.0268	0.1205	0.0393
2004	0.1431	0.0451	0.1956	0.0633
2008	0.0656	0.0203	0.1292	0.0419
2010	0.0644	0.0282	0.1233	0.0393
2013	0.1527	0.0484	0.1763	0.0563

Analysis of NDVI Trends

The ATR area recorded the highest mean NDVI value of 0.1956 (standard deviation of 0.2022) in 2004, followed by 2013 (mean NDVI of 0.1763 and standard deviation of 0.1825 during the post-monsoon month for the entire ATR area) (Table 3). The temporal and seasonal variation in NDVI values is due to fluctuations in greenness in the entire tiger reserve area and its buffer zone.

The variation in maximum NDVI values for the entire ATR and its buffer zone was recorded at its highest for the years 2000 (0.0612), 2010 (0.0412), and 2013 (0.0043)



(Photo courtesy: Author)

Fig. 5: Field photographs showing forest and ground flora of ATR, during pre-monsoon (a- Sal forest, b- fallow agricultural land, c-post fire occurrence) and post-monsoon season (d-mix forest with ground regeneration, e- cultivated agricultural fields, f- parthenium weed growth beside the roadside of the core zone).

during the pre-monsoon months. Both the ATR area and its buffer area recorded similar NDVI values. In contrast, variation in NDVI values for ATR and its buffer zone was observed in the post-monsoon months of 2010 (0.0647) and 2013 (0.0065). As a result, the variation in NDVI values of ATR and its core zone was greater during pre-monsoon months than during post-monsoon months.

DISCUSSION

The Achanakmar Tiger Reserve recorded the highest NDVI value during the post-monsoon month of 2004 (+0.539) and the lowest NDVI value (+0.281) in 2008 during pre-monsoon. The higher NDVI coincides with the good rainfall during this period, which is responsible for the formation of a healthy canopy. The maximum variation in NDVI value for the entire ATR and its buffer zone was observed during the post-monsoon season in 2010. This may be due to the growth of ground vegetation and the natural regeneration of forest tree species. Agricultural fields and weed growth, in addition to the fragmented landscape such as roads, etc., also lead to an increasing greening of the area.

Pu et al. (2022) used MODIS NDVI data from 2000 to 2020 for spatiotemporal vegetation monitoring of China Panda National Park. The study stipulated that there is a strong correlation between precipitation and NDVI and that this is the most important controlling factor in vegetation structure, composition, and distribution (Bolstad 1998). The annual temperature and variability of a region also regulate photosynthesis (Liu et al. 2010), influencing the NDVI value.

On the other hand, the pre-monsoon season experiences dry summer months and occasional forest fires, leading to a reduction in vegetation canopy, reducing reflectance, and therefore NDVI values. Thus, water availability and other climatic factors such as temperature and solar radiation affect the NDVI values of the ATR area. NDVI decreased significantly in protected areas of southern California during the summer, according to Gillespie et al. (2018). Weil & Xinfeng (2015) have shown a positive correlation of NDVI with precipitation and average air temperature in the Yarlung Zangbo river basin, Tibet. Similar results were recorded for ATR; the years with relatively good rainfall had higher NDVI values compared to years with prolonged dry summer months and less rain.

Studying the mechanism of climate change response to NDVI changes is of great importance for predicting vegetation dynamics (He et al. 2021). A similar study was carried out by Prasai et al. (2022) to analyze the annual and seasonal variation of the NDVI of Chitwan National Park in Nepal, and a positive trend of the NDVI was observed between 1988 and 2000. Much advance study has been done by Matas et al. (2022), in which long-term monitoring of NDVI was used to assess the vulnerability of threatened plants in the protected areas of southern Europe.

A similar study has been done by Mallegowda et al. (2015), who analyzed the NDVI of the Biligiri Rangaswamy Temple Tiger Reserve, South India. The studies illustrate the drastic changes in the protected areas' LULC and NDVI between 1973 and 2014, and higher NDVI values were recorded in 1973 compared to 2014. Reddy & Reddy (2013) used the NDVI to measure the vigor of vegetation and assess LULC in the Kaddam watershed of the Godavari river basin, India. The study illustrates the seasonal relationship between NDVI values for all LULC classes in the same year, observing the dynamic behavior of vegetation vigor with respect to the season.

Similar studies were carried out by Biswal et al. (2013), and the study reported that the NDVI class >0.4 of the buffer zone excluding the core zone of Simlipal Biosphere Reserve increased by 20,000 hectares. The result of this study showed that less dense vegetation has undergone deforestation compared to very dense vegetation. The protected areas, which are less affected by human activities, can be used to track the effect of climate change on vegetation and the functioning of natural ecosystems.

CONCLUSION

The current study focuses on the spatiotemporal NDVI trends of ATR and its buffer zone between 2000 and 2013. The year 2004 recorded higher NDVI values during the pre-monsoon season (+0.414) and the post-monsoon season (+0.538) for ATR as well as for its buffer zone. The variation in maximum NDVI values occurs during the post-monsoon months. The declines in NDVI values during pre-monsoon months have also been recorded.

Therefore, water availability and other climatic factors such as temperature and solar radiation affect the NDVI values. While the lowest NDVI peak was recorded during March 2008 for both the ATR area and its buffer zone, the current year and previous years recorded longer periods of higher temperatures and less precipitation.

Long-term monitoring and analysis of ATR's NDVI can help study the impact of climate change and other climatic factors on floral and faunal diversity. There is a need to develop and provide scientifically credible information on the current status and long-term changes in the composition and vegetation of protected areas. The study can also help shape policies and other conservation measures and in addressing issues such as climate change, habitat degradation, and biodiversity loss.

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