सत्यमेव जयते

Key Biodiversity Areas

Conservation-Based on Threats and Ecosystem Services Using GIS-Based Modelling in Central India

nidm
Resilient India - Disaster free India
National Institute of Disaster Management
Ministry of Home Affairs, Government of India

सत्यमेव जयते

KEY BIODIVERSITY AREAS

Conservation-Based on Threats and Ecosystem Services Using GIS-Based Modelling in Central India

2025

nidm

Resilient India - Disaster free India

National Institute of Disaster Management

(Ministry of Home Affairs, Government of India)

Plot No. 15, Pocket 3, Block B, Sector 29, Rohini, Delhi-110042

Key Biodiversity Areas: Conservation-Based on Threats and Ecosystem Services Using GIS-Based Modelling in Central India

ISBN: 978-81-986279-2-6

Edition: 2025

Authors:
Prof Manish K Goyal
Prof Anil K Gupta
Shri Rajendra Ratnoo, IAS
Ms Pritha Acharya

Published By:
National Institute of Disaster Management (NIDM), Ministry of Home Affairs, Government of India, Delhi 110042

Citation:
Goyal, M., Gupta, A.K., Ratnoo, R. and Acharya, P. (2025). Key Biodiversity Areas: Conservation-Based on Threats and Ecosystem Services Using GIS-Based Modelling in Central India. National Institute of Disaster Management, New Delhi, Pages 42.

सत्यमेव जयते

DR AKHILESH GUPTA

SECRETARY, SERB & SENIOR ADVISOR

Department of Science & Technology (DST)
Government of India
Technology Bhawan, New Mehrauli Road
New Delhi 110016

MESSAGE

The Department of Science and Technology (DST) is the nodal agency of the Government of India for the implementation of two important missions under the National Action Plan for Climate Change (NAPCC) including a. National Mission for Sustaining Himalayan Ecosystem (NMSHE) and b. National Mission on Strategic Knowledge for Climate Change (NMSKCC).

Under the 2nd mission, it has been extending support to NIDM for the Climate Adaptive Planning for Resilience and Sustainability in Multi-Hazard Environment (CAP-RES) project. The project tries to improve the knowledge gap and tries to establish a network or networks which contribute to the increased understanding of key issues related to climate change and disaster. Under the CAP-RES project, NIDM and DST have released many unique and extremely relevant documents as part of the various case studies and research done under the project. This report on "Key Biodiversity Areas: Conservation-based on threats and ecosystem services using GIS-based modelling in Central India" is one such case study.

I congratulate all the authors for taking up this study on such an important topic and publishing such an interesting report.

(Akhilesh Gupta)

nidm
Resilient India - Disaster Free India

राजेन्द्र रत्नू, भा. प्र. से.
कार्यकारी निदेशक
Rajendra Ratnoo, IAS
Executive Director

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

राष्ट्रीय आपदा प्रबंधन संस्थान
National Institute of Disaster Management
(गृह मंत्रालय, भारत सरकार)
Ministry of Home Affairs, Govt. of India
प्लॉट नं. 15, ब्लॉक बी, पॉकेट 3,
सेक्टर 29, रोहिणी, दिल्ली - 110042
Plot No. 15, Block B, Pocket 3,
Sector 29, Rohini, Delhi-110042

FOREWORD

The National Institute of Disaster Management (NIDM) was constituted under an Act of Parliament with a vision to play the role of a premier institute for capacity development in India and the region. NIDM holds the nodal responsibilities for human resource development, capacity building, training, research, documentation and policy advocacy in the field of disaster management.

Under our strategic partnership with the Department of Science and Technology (DST)- Govt. of India, we have been implementing the CAP-RES project. The project has taken up various case studies involving a number of institutions across the country. The study 'Key Biodiversity Areas: Conservation-Based on Threats and Ecosystem Services Using GIS-Based Modelling in Central India' tries to bring out the importance of KBAs and the need to recognise them as strategic areas.

This study has come out to be an interesting and relevant document. I hope that it will serve as an excellent reference read for students, policymakers, researchers, trainers and capacity-building professionals.

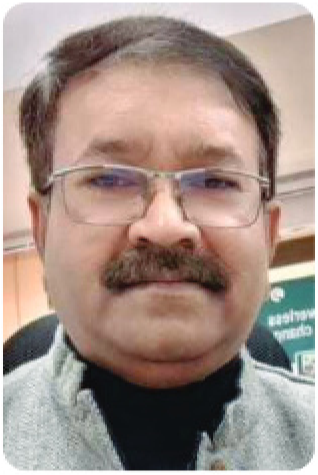
(Rajendra Ratnoo)

फोन / Ph: +91-11-20873401, • ई मेल / E-mail: ed.nidm@nic.in, ratnoor@ias.nic.in, • वेब साईट / Website: www.nidm.gov.in

Resilient India - Disaster free India

राष्ट्रीय आपदा प्रबंधन संस्थान
(गृह मंत्रालय, भारत सरकार)
National Institute of Disaster Management
(Ministry of Home Affairs, Govt. of India)
Plot No. 15, Pocket-3, Block-B, Sector-29,
Rohini, Delhi-110042

PREFACE



PROF ANIL K GUPTA

PROFESSOR AND HEAD ENVIRONMENT, CLIMATE AND DISASTER RISK MANAGEMENT DIVISION

Key Biodiversity Areas (KBAs) are extremely important and valuable for their ecological integrity and they contribute significantly to the Earth's biodiversity. However, as we pass through the Anthropocene- the era of humans, environmental degradation and species loss are one of the most persistent and critical issues we face.

The importance of conserving biodiversity on land and in water has been sketched out by the Sustainable Development Goals (SDGs) and other important global conventions like the Ramsar Convention, Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD) etc. In fact, the present decade has been declared as the United Nations Decade on Ecosystem Restoration (2021 to 2030).

This case study by NIDM jointly with IIT Indore tries to enhance the understanding of Biodiversity and its vulnerabilities in central India which critically focus to analyse various threats faced by KBA and identify parameters. The result will be a critical and useful tool for policymakers for (i) land-use policy development and (ii) implementation of five prevention measures and also to monitor and enforce policies.

(Anil K Gupta)

ACKNOWLEDGEMENT

The thematic paper on "Key Biodiversity Areas: Conservation-based on Threats and Ecosystem Services using GIS-based Modelling in Central India" is carried out under the Project Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES) supported by Department of Science & Technology (DST), Government of India. A special note of thanks to Dr Akhilesh Gupta, Senior Advisor and Secretary, Science and Engineering Research Board (SERB) for entrusting NIDM with the opportunity to take up and work on the CAP-RES project. The project team is thankful to Shri Rajendra Ratnoo, Executive Director, NIDM, Dr (Mrs) Anita Gupta, Head of Climate change and clean energy Division, Dr Nisha Mendiratta, Advisor and Head of WISE-KIRAN Division at the Department of Science and Technology, Dr Susheela Negi, Scientist E, and Dr Rabindra Panigrahi, Senior Scientist of Department of Science and Technology, Government of India for their support to this study.

Contributions of the authors including Prof. Manish Goyal (Dean Infrastructure, IIT Indore) and Ms Pritha Acharya (Research Associate, CAP-RES, NIDM) are acknowledged for joining hands with us in undertaking this study.

A special thanks to Ms Pritha Acharya for designing the report and coordinating the study. The project team also extend thanks to Shri Surendra Thakur Ji (Joint Director, NIDM), Dr. Kundan for review and useful inputs, Shri S.K. Tiwari (Librarian, NIDM) and the entire publication cell of NIDM including Ms Karanpreet Kaur Sodhi, Jr Consultant (Publication) for helping in printing and publication of this report.

PROF ANIL K GUPTA
(PROJECT DIRECTOR, CAP-RES)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CBD	Convention on Biological Diversity
GEE	Google Earth Engine
GEF	Global Environment Facility
FDSI	Forest Drought Stress Index
HCVA	High Conservation Value Areas
IBAs	Important Bird Areas
KBAs	Key Biodiversity Areas
LPI	Living Planet Index
MODIS	Moderate Resolution Spectroradiometer
METT	Management Effectiveness Tracking Tool
NDVI	Normalized difference vegetation index
SNPP	Suomi National Polar-orbiting Partnership
SWIR	Short Wave Infrared
VIIRS	Visible Infrared Imaging Radiometer Suite
WOCAT	World Overview of Conservation Approaches and Technologies
WTPs	Wastewater Treatment Plants
WUE	Water Use Efficiency

1. INTRODUCTION

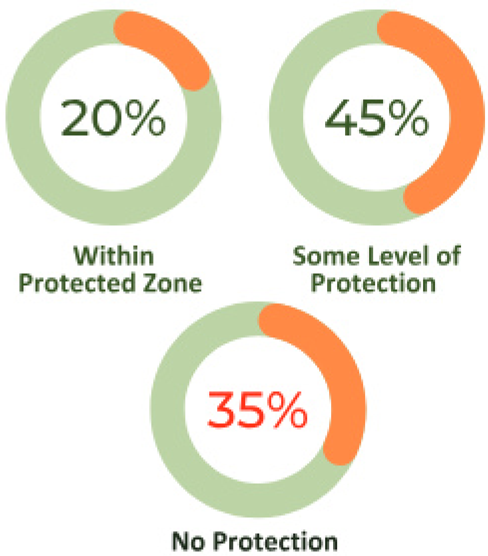
BACKGROUND

Key Biodiversity Areas, also known as KBAs, are locations that have an extraordinary amount of significance for the maintenance of biodiversity (IUCN, 2016). They are categorized according to predetermined criteria and fall into one of five primary groups viz. (i) endemism (geographically restricted biodiversity); (ii) biological processes; (iii) ecological integrity; (iv) endangered (threatened) biodiversity; and (v) irreplaceability (Dudley, et.al., 2014). There are around 16,000 KBAs spread across over 200 countries, most of which are in poor nations (The KBA Partnership, 2018). These locations encompass around 8.85 per cent of the earth's terrestrial surface.

The process of locating and defining the boundaries of these sites is continuous. Monitoring KBAs may involve conducting local and field-based surveys and evaluating for change (Brink et al., 2018). Such kinds of data are gathered using tried-and-true methods so that comparisons may be made not only across time but also between locations. There are a lot of monitoring strategies that are field-based available to accomplish this objective (IUCN, 2016). A well-known method for keeping track of protected areas is called the Management Effectiveness Tracking Tool (METT) (Stolton and Dudley, 2016).

Monitoring Important Bird Areas (IBAs), which are the sites of international significance for bird conservation and consist of the most distinguished KBAs, is under conceivable recognition to an up-front process that has been consistent on an international level and created by BirdLife International (IBAs; BirdLife International, 2006). Despite an adequate rise in the IBA monitoring process, with more than 25 % of IBAs all over the world having been examined at least once by the year 2012, a substantial number of IBAs remain unmonitored in the context of this framework.

How Well are our KBAs protected...



Source: Sun et al., 2022

Forest and biodiversity policies play an essential role in ecosystem restoration and biodiversity conservation practices.

The preliminary estimate of the number of sites that are monitored in some manner is available, but the extent to which these sites are observed is unknown, as the procedure is yet to be completed. This is because the basic estimate of the number of sites that are monitored in some ways exists.

However, the capability to conduct such on-ground monitoring is restricted, specifically in under-developed nations, which usually contain the most biodiversity but are often most susceptible (Buchanan et al., 2013). Besides, field-based monitoring, remote sensing is a critical tool that may be utilized to monitor environmental changes in locations that are particularly important to conservation efforts (Turner et al., 2003; Rose et al., 2015). The preceding decade was momentous in terms of the availability of massive amounts of satellite data, as well as developments in processing capability, such as cloud computing, which have considerably boosted the usefulness of remote sensing as a technique for conducting long-term and large-scale analysis (Leidner and Buchanan, 2018).

Concurrently, developments in satellite technology have enabled image production with a high spatial resolution, which may be used for applications related to biodiversity conservation (Brink et al., 2018). In relevance to the KBA the studies related to Indian forests, extreme weather events, climate change, and remote sensing provide better representation and identification of threat and conservation approaches.

India has prominent forest policies like the Indian Forest Act 1927, the Wildlife Protection Act 1972, the Forest Conservation Act 1980, the National Forest Policy 1988 and the Biological Diversity Act 2002.

Kotwal et al. (2008) studied sustainable forest management to minimize the impact of climate change on Indian flora and fauna. It was carried out based on the Bhopal India process, which mentioned eight criteria and forty-three indicators for assessment. This method was proposed by the Indian Institute of Forest Management and the International Tropical Timber Organization jointly for managing the Indian forests. The National Working Plan Code 2014 employs this method to conserve Indian forests and biodiversity by adopting these criteria and indicators (Kotwal et al., 2008; Kumar et al., 2021).

As the Indian forest region, occupies 21.71% of the country's region (ISFR, 2021) it comprises several endemic species. Indian biodiversity has high endemism in fish, reptiles, amphibians, birds, mammals, and plant species (IUCN, 2021).

Studies by Nandy et al., (2022) used the Water Use Efficiency (WUE) indicator as a linkage between carbon and hydrological cycles of terrestrial ecosystems. The value of WUE indicates the quantity of carbon assimilated as biomass per quantity of water used by the vegetation. The WUE parameter was computed from 2003 to 2018 for some forest formations by taking the ratio of MODIS (Moderate Resolution Spectroradiometer) Gross Primary Productivity (GPP) to Evapotranspiration.

Tropical thorn forests have maximum WUE, while alpine forests indicate lower WUE among the forest groups. The studies show an increasing WUE trend with latitude and a decreasing WUE trend with elevation, indicative of the fact that temperature plays a key role in changing the WUE of forests.

Koulgi et al. (2019) studied tiger reserves using satellite data, which revealed that more than fifty per cent of India's tiger reserves face vegetation drying or browning phenomena. Since the beginning of Project Tiger in 1973, no scientific studies presented the effectiveness of conserving tiger habitats (Koulgi et al., 2019).

A study carried out by Duveiller et al., 2021 over 67 sampling sites using remote sensing by assessing the cloud cover at different pressure levels over afforested regions shows that afforestation can decrease global warming by increasing both low-level cloud cover and carbon sequestration. It represented the effectiveness of vegetation in generating cloud cover to be more in needle leaf forests than in the broader leaf forests (Duveiller et al., 2021).

Population increase, urbanization, industrial development, global warming conditions, and climate change impact several ecosystems across the globe. The concept of restoration identifies actions for reducing stresses on the surrounding environment of ecosystems so that they can restore themselves.

The United Nations estimates restoring terrestrial and aquatic degraded ecosystems will generate 3 trillion US dollars in economic value and reduce thirteen to twenty-six gigatons of greenhouse gas emissions (United Nations, 2021b).

Studies carried out by Thakur et al., (2021) developed a Forest Vulnerability Index using elevation, slope, population density, NDVI (Normalized difference vegetation index), rainfall, and temperature datasets. The index developed in this study was validated through ground-based observation obtained from the forest department and reports of the state and Forest Survey of India (FSI). The Forest Vulnerability Index provides indications of threats from changing climatic conditions, forest fires, drought, floods, etc.

The increasing threats to different ecosystems led to declaring the years '2021-2030' as the "Decade of Ecosystem Restoration" with the specific objectives of efficiently restoring freshwater and marine ecosystems across different regions globally.

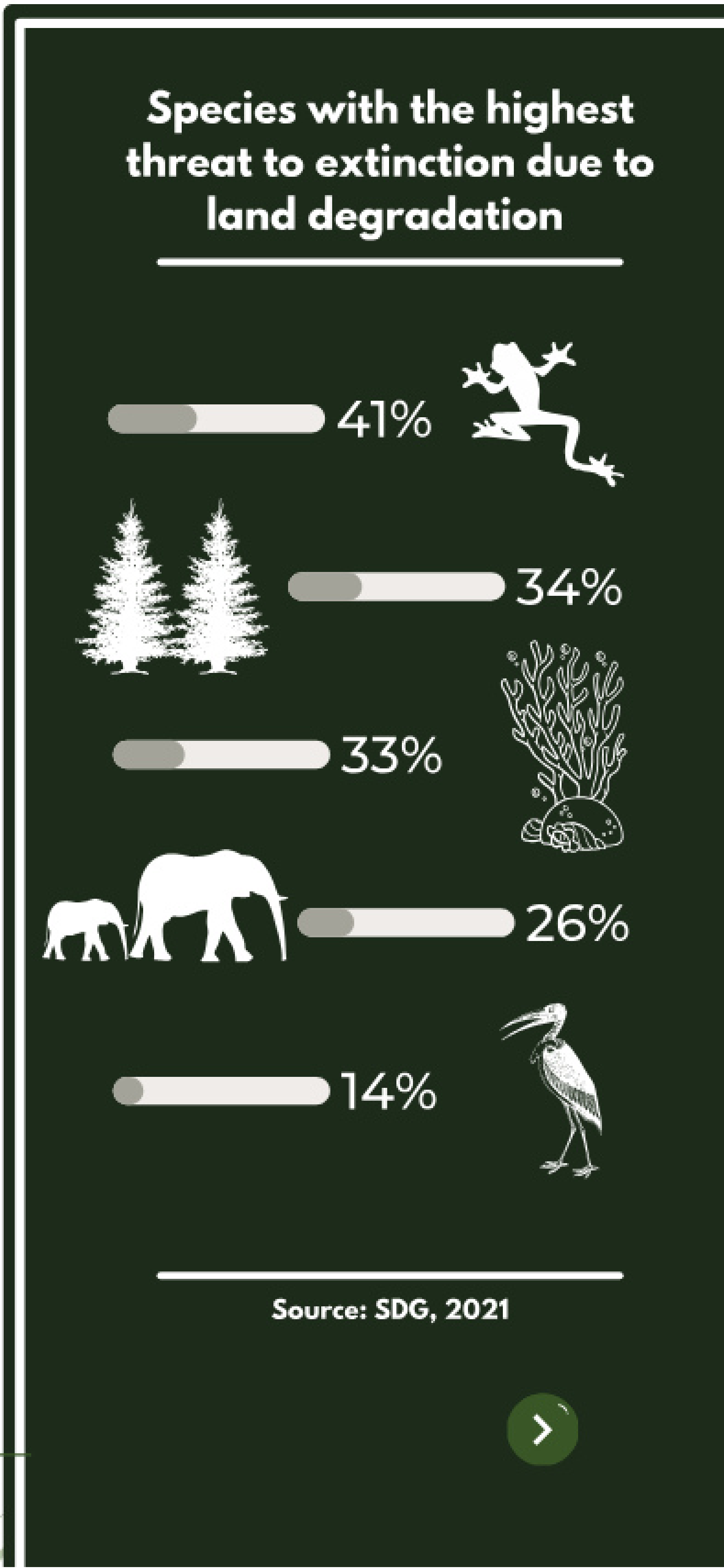
United Nations, 2021

Forest land degradation is increasing at an alarming rate as 100 Mha Forest land loss occurred in two decades from 2000 to 2020. According to the International Union for Conservation of Nature (IUCN) red list, a total number greater than 37,400 species are threatened with the risk of extinction (Sustainable Development Goals, 2021).

The World Overview of Conservation Approaches and Technologies (WOCAT) defined sustainable land management as "the supervised monitoring and use of land resources, including animals, soils, plants, and water to fulfil changing human requirements, whereas concurrently meet the long-term productive potential of these resources and the maintenance of their environmental functions" (Olsson et al., 2019).

Deforestation, converting forest land to non-forest land, is one of the principal causes of forest land degradation. The term Sustainable Forest Management (SFM) is defined as "the supervised monitoring and use of forests land as well as forests in a way and at a rate such that it maintains their regeneration capacity biodiversity, vitality, productivity, and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" (Europe, 1993; Mackey et al., 2015; Olsson et al., 2019). SFM being a subset of Sustainable Land Management (SLM), the terminology of SLM also applies to forest lands.

Forests are an essential natural resource as they contain about 80% of the earth's terrestrial biodiversity, major sinks for carbon dioxide-absorbing 2.4 billion tonnes of carbon dioxide annually through terrestrial carbon sequestration and provide sustainable livelihoods to 1.6 billion across the earth (IUCN, 2021).



The protection of forest land from degradation is covered under the 15th objective of the 2030 Sustainable Development Goals i.e "Life on Land" which aims towards "Protection, Restoration and Promotion of sustainable use of Terrestrial Ecosystems, stopping biodiversity loss, combating desertification and halting and reversing land degradation across the earth."

Park Williams et al., (2013) observed that temperature will act as a potential driver for the occurrence of regional forest drought stress and mortality of trees in the forest regions of the southwestern United States. This study developed a Forest Drought-Stress Index (FDSI) using evapotranspiration datasets during the pre-monsoon period, rainfall datasets for the post-monsoon period, and tree ring datasets to represent the tree mortality from 1900 to 2007. The high correlation between forest drought stress and tree mortality was suggestive of drought-related decline of the forest regions. Forest drought studies in India are performed less due to their limited recognition among scientific societies. However, the National Institute of Disaster Management plans to evaluate the impact of forest drought on Indian biodiversity and the hydrological cycle (Down to Earth, 2016).

Climate change impacts have back-and-forth interactions with wastewater management, water quality, and aquatic ecosystems.

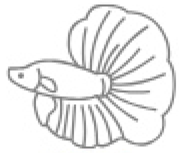
Extreme weather events like floods, cyclones, and droughts (Goyal et al., 2022, 2023a; Rakkasagi et al., 2023) affect regional water supply and demand patterns, which further affect the operational performance and treatment efficiency of wastewater treatment plants (WTPs) (Abdulla and Farahat, 2020). Climate change at a global scale causes variations in weather patterns, extreme weather events and surges in temperature changes the water cycle, impacting water quality and leading to water-scarce-like conditions.

More than 74% of natural disasters reported between 2001 to 2018, were water-associated. Such disasters degrade water quality and create poor sanitation and hygienic conditions for humans and other living beings. Poor water quality, sanitation, and hygiene cause the death of 700 children below five years every day due to diarrhoea. Presently, around 450 million children reside in water-vulnerable regions and by 2040, one in every four children will live in areas of severe water stress conditions (UNICEF, 2021).

The living planet index (LPI) is accepted by Convention on biological diversity (CBD) as a statistical parameter for growth to achieve the goal for 2011-2020 of taking efficient and vital action to discontinue the biodiversity loss (WWF, 2021).

The aquatic ecosystem specific to freshwater biodiversity is a vital component of the biosphere (Reid et al., 2019; Strayer and Dudgeon, 2010; van Rees et al., 2021). There are several anthropogenic and natural threats to freshwater biodiversity including Invasive Alien Species (IAS), overexploitation or utilization of water resources, alteration, deterioration, and fragmentation of natural habitats, climate change, and water pollution.

The biodiversity of freshwater ecosystems is influenced by freshwater quantity, occurrence, and quality (Shumilova et al., 2018; van Rees et al., 2021).
The LPI is determined for marine, terrestrial, and freshwater habitats globally by monitoring the population abundance of 21,000 species that are either threatened or non-threatened (WWF, 2020a). The freshwater ecosystem comprises water bodies like rivers, wetlands and lakes, which include 1% of the earth's surface and are home to half of the fish and one in ten known animal species (WWF, 2020b).
The sharp decline of freshwater ecosystem biodiversity in Latin America and the Caribbean region can be attributed mainly to pollution-driven habitat loss (decline in water quality), flow modification, sand mining, etc. Nearly one in three freshwater species is "threatened with extinction"(WWF, 2020a).



"From 1970 to 2016, nearly 3741 freshwater populations constituting 944 species across the world shows 84% fall in the mean abundance of population size"

Source: LPI,2020

Extensive and multi-level efforts are needed to control water quality degradation to conserve and restore freshwater ecosystems and biodiversity (WWF, 2020b).
Studies on water quality were carried out by Ross et al., (2019) using remote sensing to evaluate the water quality using five indicators, i.e., Total Suspended Solids (TSS), Secchi Disk depth, chlorophyll-a, and dissolved organic carbon through Landsat and MODIS data. These datasets were compared with past observations, and then future water quality projections were provided with higher confidence. Such remote sensing technology will be helpful in regularly assessing wetlands' water quality and remote water locations in forest regions of India.

Chen et al., (2021) conducted studies on monitoring temperate forest degradation using Landsat and Sentinel remote sensing datasets through the Google Earth Engine platform. They present an approach using continuous change detection through spectral mixture analysis, combining time series analysis and spectral mixture analysis to monitor abrupt and gradual temperate forest degradation. Using remote sensing datasets from 1980 to 2019 they predicted forest degradation in Georgia with 91% accuracy. Beresford et al., (2020) also used the Google Earth Engine platform to monitor key biodiversity regions, providing regular monitoring using remote sensing datasets to identify ecological threats to local flora and fauna by forest fire events. They performed study validations through historical datasets from 1992 to 2013.

IMPACT ON KBAs

A recent research examined the dangers faced by protected areas globally and found control fires, forest clearing for agriculture and logging to be the most common hazards in India. In this context, remote sensing has the potential to play an important role in site monitoring. There are accessible tools and techniques for comprehensive observation and site-based utilisation.

This study will evaluate forest fire, tree loss, and nighttime lights to determine the ecological threats to the Key Biodiversity Areas of Central India.

This study will utilize these tools and techniques to understand the changes in multiple important conservation sites across Central India. Although, their potential to provide information with high geographical and temporal precision regarding particular KBAs, using them on a continental scale would need a significant investment of resources, yet they are far less time-consuming than field surveys. The datasets used are simple to work with concerning the management of sites, and they can be utilized to create quick evaluations of the most widespread stresses on KBAs of Central India.

The loss of forest cover, forest fires, and the increase of stable night lights have significant impacts on KBAs and the species and ecosystems they support. The descriptions of each of them are presented in the next page.

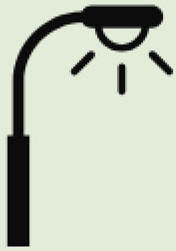
FOREST LOSS

Deforestation and habitat fragmentation have negative impacts on biodiversity, reducing the area available for species to live and reproduce and increasing the likelihood of species extinction. KBAs are often located in areas with high deforestation pressures, and the loss of forest cover can have severe impacts on the species and ecosystems they support.

FOREST FIRES

Forest fires can cause widespread damage to KBAs, leading to the loss of biodiversity, degradation of habitat, and alteration of ecosystem processes. Forest fires also release large amounts of carbon into the atmosphere, contributing to global warming and climate change impacts.

STABLE NIGHT LIGHTS



The increase of stable night lights has negative impacts on biodiversity, particularly on species that rely on darkness for foraging, migration, and reproduction. The increase in stable night lights can also lead to behaviour changes in wild animals, causing disruptions to their migration patterns and foraging habits.

Therefore, it is important to implement measures to mitigate the impacts of forest loss, forest fires, and stable night lights on KBAs and the species they support. Such measures generally include reducing deforestation pressures, promoting sustainable forest management practices, and limiting the spread of stable night lights in areas surrounding KBAs.

This study represents a thorough evaluation of the demand load on sites and describes how remote sensing variables can ease information availability to users or any stakeholders, for informed management choices or priority setting.

The present study on KBAs looks at three different instances of trailing variations in forest loss, fire frequency, and night-time lighting.

For many years, fires have been monitored to determine variations in their natural forms of burning. Detection of destructive fires and tracing the potency of management strategies and specified burning for vegetation management can probably be done using time series datasets on near to real-time fire events. Studies by Buchanan et al., (2013) and Tracewski et al., (2016), on tree loss in IBA serve as an excellent example of utilizing resulting products of remote sensing data can be used to carry out change evaluations which could be swiftly revised (Tracewski et al., 2016). Importantly, their investigation considered the viewpoints of environmentalists to 'confirm' the findings obtained from the datasets obtained by using remote sensing processes. At the national level, these datasets allowed for off-screening of outcomes lacking any conservation concerns.

Various studies have used night-time lights (also known as anthropogenic light pollution), to map urban areas and investigate the effects of light pollution on the environment. These night-time lights often overlap with streetlights, car headlights and other forms of urban and household lighting. It is rather important to differentiate urbanisation subtleties and to examine the natural effects of light pollution. However, up until this point, no significant in-depth studies have examined night lights as an indicator of infrastructural encroachment into areas recognized for biodiversity significance.

The present study utilizes the openly available datasets from the 'Google Earth Engine (GEE)' (a free cloud-processing platform) to evaluate the changes of three threat indicators obtained from remote sensing overtime on KBAs in Central India (Madhya Pradesh and Maharashtra) as an addition to the development of a universal remote observing procedure for conservation importance sites, comprising KBAs. The sites and ecoregions picked up in this study are those which have encountered considerable changes and try to characterize the pattern of occurred changes.

As a result, the study showcases straightforward methods that can be carried out globally or across any network of locations. These methods can also be updated by conservation end-users so that they may be used with different datasets as per the availability.

Fig. 1. Different aspects of KBAs which enables countries for effective conservation.
Source: KBA Partnership (2020) KBA Programme Annual Report 2019

Countries can utilize KBAs as a tool to enhance their planning and achieve the greatest possible conservation of biodiversity while minimizing any detrimental impact on them. Identifying and preserving KBAs can enhance the diversity of species, ecosystems, and genes conserved within a country, and can assist countries in identifying conservation measures as shown in Figure 1."

ROLE OF KBAs

The potential of KBAs has been acknowledged well to aid in decision-making and planning. Some organizations are already utilizing the general concept of KBAs in their work, but few such as the World Bank Group and the Global Environment Facility are willing to do so more formally. Additionally, some institutions are using KBAs as a framework for their efforts. However, it is important to note that the time available to establish a standard for KBA identification and develop a functional database is limited, particularly for countries with limited biodiversity data and high development rates.

KBAs play an important role in identifying and conserving areas of high biodiversity value as mentioned below (Dudley, et.al., 2014).

Determining sites based priority for conservation:

These include designating areas through international conventions, such as identifying suitable Ramsar sites. This helps in identifying and protecting specific sites. Additionally, two important strategies could be beneficial viz. (i) creating protected area networks to represent a diverse range of ecosystems and habitats; and (ii) including these areas as part of High Conservation Value Areas (HCVA) which will consider both ecological and social values of these sites.

Directing investments:

One of the main purposes of identifying priority sites for conservation is to guide conservation-driven investments. This allows donors to ensure that their funds are directed towards the most crucial area of the global preservation of biodiversity. The Global Environment Facility (GEF) and other funding sources can be used to support conservation efforts in these priority areas.

Prioritising biodiversity research:

Identifying KBAs, even in a preliminary capacity, can prioritize biodiversity research in areas where data is limited. This allows scientists to focus on conducting more detailed surveys in such areas.

Providing a centralised data source for end-users:

There is a need for a centralized data source for end-users that incorporates existing approaches and databases to provide comprehensive data for all realms, regions, and ecosystems.

Providing additional political recognition:

By providing additional political recognition, sites that currently lack recognition from governments and other stakeholders can gain greater visibility. This includes indigenous peoples and community-conserved areas, as well as important wetlands that have not yet been added to the Ramsar list.

Identifying core sites for restoration:

Identifying core sites for restoration or maintenance of ecosystem services involves identifying priority areas within a landscape. This can include sites that are considered priorities under initiatives such as the IUCN Bonn Challenge on restoration.

Identifying no-go areas:

Some end-user groups perceived KBAs as areas that should be excluded from development, while others opposed the notion that all KBAs should be treated as "no-go" areas.

Informing, validating, and confirming existing approaches:

The purpose of informing, validating, and confirming existing approaches is to identify significant sites for biodiversity across various taxonomic groups, regions, ecosystems, or realms (such as marine and freshwater). These approaches have already been developed and established and are currently under use to identify important areas for biodiversity conservation.

Identifying internationally significant sites for local action :

Identifying globally significant sites that require local action involves identifying areas where local conservation efforts are needed to address global issues. For example, major flyways may be threatened by degradation at specific sites along the migration route, requiring local action to mitigate this threat.

Identifying ecosystem services:

Collecting information on ecosystem services alongside KBA data can help prioritize site agencies with a dual mandate of conservation and development, by identifying the importance of ecosystem services provided by the KBAs.

Making developmental decisions:

Identifying areas that require specialized forms of management can guide decision-making related to development.

Stabilizing land tenure:

In some cases, the identification of KBAs has helped indigenous peoples and community groups strengthen their collective governance over territories and natural resources by providing additional evidence to support their claims (although there may be situations where the opposite effect may also occur).

BUSINESS AND KBAs

The KBA Standard provides the means of engagement with various influential parties, including the business sector, which are powerful entities to either promote or harm biodiversity conservation efforts. Certain business practices can result in significant harm to biodiversity, such as (i) altering land use, (ii) polluting the environment and, (iii) introducing invasive alien species. It is thus crucial to integrate effective strategies for managing biodiversity risks and impacts into all aspects of business activities to address the ongoing biodiversity crisis.

Importantly, businesses need to take action and influence the effective management of commercially productive areas within KBAs, such as cultivated areas, managed forests, fisheries, and mineral sites which can be directly or indirectly impacted by business operations or their supply chains.

The conservation of biodiversity for which KBAs are significant can benefit from the positive impact of businesses and other relevant actors in various ways, including (The KBA Partnership, 2018):

1. PROJECT DASHBOARD

Providing the information collected during their project and biodiversity management operations, including the data from risk and impact assessments and monitoring operations, to civil society and the scientific community can be very valuable, especially if the business assessments indicate that the biodiversity values have already been damaged.

2. CORPORATE SOCIAL RESPONSIBILITY

Focusing on KBAs as recipients of philanthropic and corporate social responsibility initiatives can enhance the visibility of donors since it provides a narrative based on the globally acknowledged identification.

3. DISCUSSION MAKING GUIDANCE

Giving priority to KBAs as a recipient of compensation for residual impacts in comparison to non-KBA sites can be beneficial, only if it does not impact the compensation for significant losses of other important biodiversity or ecosystems. This strategy may result in investing in an area that has greater potential for conservation impact than the one impacted by the project for which the offset is intended. Consequently, businesses can invest in offsets that would lead to better conservation results, ultimately enhancing the net outcomes.

OVERVIEW OF KBAs SELECTION CRITERIA

A. The vulnerability-based criterion is as follows:

Criterion 1: Globally threatened species. This criterion identifies sites that are regularly occupied by significant numbers of globally threatened species.

B. The irreplaceability-based criteria are as follows:

Criterion 2: Restricted-range species: This criterion identifies sites that hold a significant proportion of the global population of one or more restricted-range species on a regular basis.

Criterion 3: Congregatory species: This criterion identifies sites that hold a significant proportion of the global population of congregatory species on a regular basis.

Criterion 4: Biome - restricted assemblages: This criterion identifies sites that hold a significant proportion of a group of species whose distributions are restricted to a specific biome or subdivision of a biome.

The four key criteria for identifying key biodiversity areas are based on two primary considerations when planning networks of conservation sites: vulnerability and irreplaceability, as noted by Margules and Pressey (2000).

WETLANDS AND KBAs

Wetlands can be important components of KBAs, as they often provide critical habitat for a wide range of plant and animal species. In fact, many wetlands themselves are designated as KBAs due to the high levels of biodiversity they support. Protecting and conserving wetlands is therefore an important part of global efforts to safeguard biodiversity and can contribute to the preservation of KBAs and the species they support. However, not all wetlands are KBAs, and not all KBAs are wetlands. While wetlands are important for biodiversity conservation, they are just one type of ecosystem which supports high biodiversity levels.

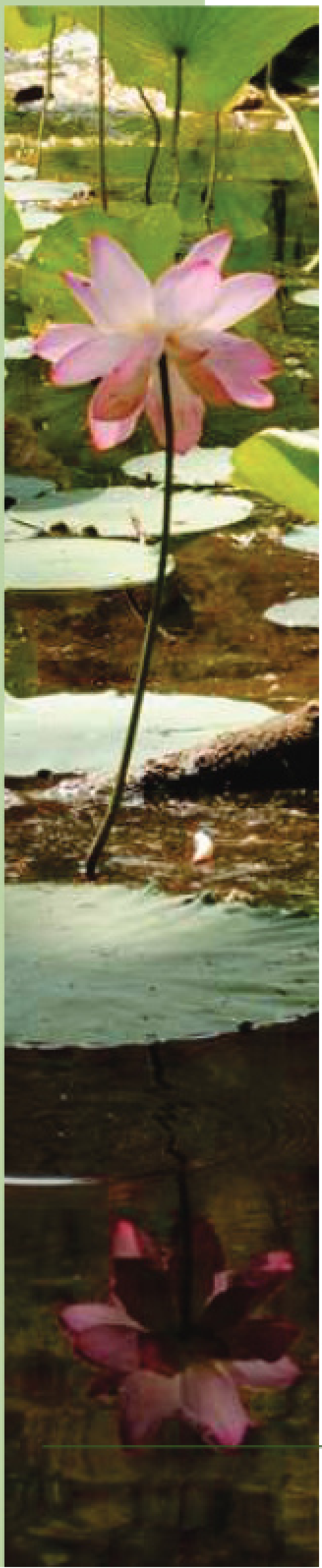
Protecting KBAs requires a comprehensive approach that considers a range of factors, such as habitat loss and fragmentation, invasive species, and climate change. By protecting both wetlands and KBAs, we can ensure that our planet's biodiversity is preserved for future generations. As of November 2022, there are 4 wetlands (i.e., Bhoj Wetlands, Sakhya Sagar, Sirpur Wetland, and Yashwant Sagar) in Madhya Pradesh and 3 wetlands (i.e., Lonar Lake, Nandur Madhameshwar, and Thane Creek) in Maharashtra (MoEF&CC, 2022).

The present study on KBAs has utilized Landsat datasets to create an extensive time series of inundation maps for the study sites (delta) to date, with a medium spatial resolution of 30 m. The study also created an automated version of a previously described method that relies on SWIR band thresholding in GEE, a cloud-based geospatial analysis tool.

A 30-year time series of peak inundation was generated and provided evidence for the accuracy of the SWIR thresholding approach. The inundation maps and GEE code are accessible to stakeholders, land managers, and scholars for use and modification.

The creation of inundation maps can provide an analysis of wetlands' past and present conditions, predict future changes, and help understand the effects of climate change, natural events, and human activities on them (Dottori et al., 2018; Inman and Lyons, 2020). These maps can also be beneficial for wetland management plans and biodiversity research (Shirzaei and Bürgmann, 2018). In addition, if the area of interest is vast or inaccessible or if the workforce is limited, satellite images can be utilized to produce inundation maps easily (Schumann et al., 2009).

2. OBJECTIVES



This study will help in identifying and assisting the regional population, policymakers and enable different users to identify and understand existing threats to the KBAs and approaches to protect them. There are certain KBAs like the Pench Tiger Reserve present which share their boundaries with different states (Madhya Pradesh and Maharashtra), their conservation requires collaborative efforts from the representative states. It provides a better approach for the protection of key species present in these KBAs and their ecosystem. Based on this, the present study will focus on the following objectives

- To analyze various threats faced by KBAs and further find the threat trends at the local level and ecoregion level.
- To identify the threat parameters such as forest loss, forest fire, and nighttime lights.
- To assess parameters for different time periods depending upon the dataset available and site monitoring.
- To map the inundation patterns of wetlands which are KBAs using the automated SWIR thresholding technique in Google Earth Engine.

3. STUDY REGION

India is home to high levels of biodiversity owing to its varied topography, diverse ecosystems, and climatic conditions. There are over 650 KBAs identified in India, covering an area of over 1.1 million sq. km. (Figure 2).

Some of the most notable KBAs in India include the Western Ghats, Eastern Himalayas, Sundarbans, Great Nicobar Biosphere Reserve, Gulf of Mannar, Kaziranga National Park, and Nanda Devi Biosphere Reserve. By focusing conservation efforts on these critical areas, India can maximize the benefits of biodiversity conservation while minimizing the negative impacts of development and other human activities.

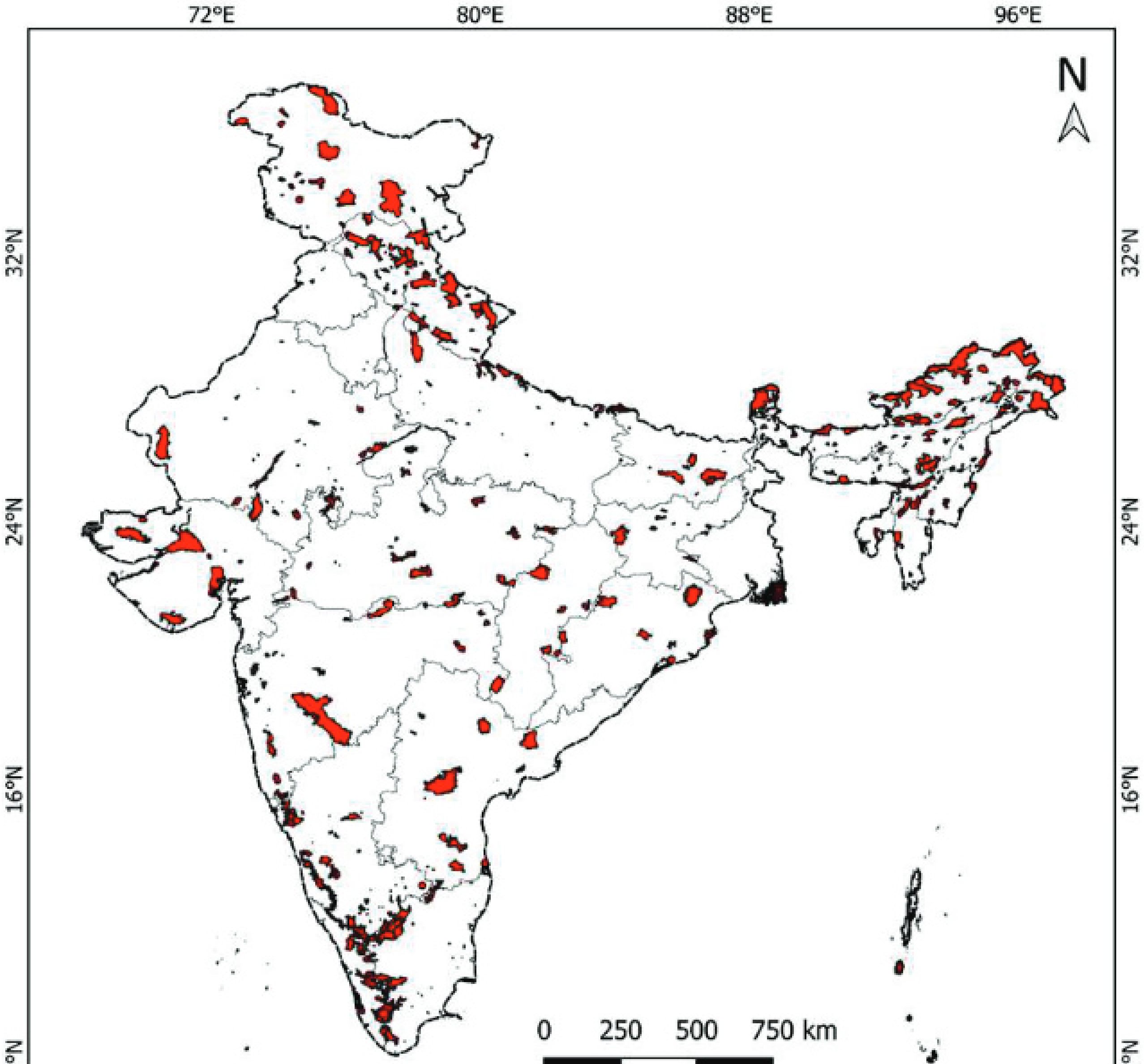
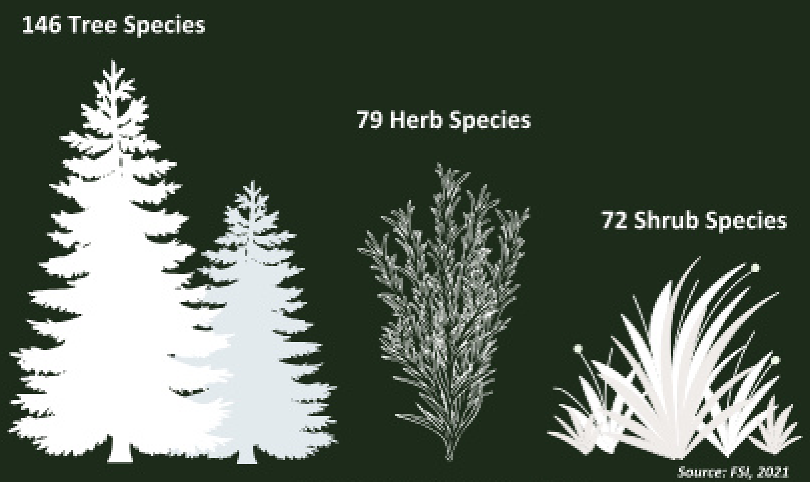


Fig. 2. The location of KBAs across India

Key Biodiversity Areas (KBAs) of Madhya Pradesh



Regional Biodiversity of MP

Madhya Pradesh the Central Indian state has the largest forest cover in the country with an area of almost 80,000 sq. km which helps to sustain the large floral and faunal diversity of the region. The state is present in the Deccan plateau physiographic zone of India (FSI, 2021). The state has observed an increase in forest cover by 11% exhibiting a total geographical area of 25.14% of the state.

The state's forest cover area significantly maintains the utility of the perennial flow of all the major rivers flowing from the state. These rivers provide an enormous supply of water while they flow to other states like Gujarat, Telangana, Uttar Pradesh, Maharashtra, and Jharkhand which is useful for their regional population and biodiversity. Thus, this water resources management due to increasing forest cover makes Madhya Pradesh the "Water Capital of India".

The mean rainfall in the region is between 800 mm to 1,800 mm and the mean temperature changes from 22°C to 25°C. In and around these forest covers, the state sustains twenty-six key biodiversity areas (KBAs) which include wetlands, national parks, biosphere reserves and wildlife sanctuaries with a total area of 10,30,522 sq. km (FSI, 2021). Some of these KBAs have huge areas which they share with the neighbouring states of Maharashtra, Rajasthan, Uttar Pradesh etc. The location map is shown in Figure 3 and the list of all the KBAs present in the state is shown in Table 1.

The state has observed increasing threats of forest fire, in fact, it is ranked 2nd in the country in terms of numbers of forest fire incidents. Between the years 2019-20 and 2020-21, around 9,537 and 47,795 numbers of fire incidents were captured in the state using the Suomi-NPP (SNPP) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite. Maximum fire incidents are observed in the East Nimar, Raisen, and Chhindwara districts of the state. The forest fire-prone classes and their classification with their geographical area are presented in Table 2.

The state of Madhya Pradesh has a significantly higher open forest area of 36,619 sq. km while the area of very dense and moderately dense forest is 6,665 and 34,209 sq. km respectively. The open forest in the state often observes a large number of fire incidents and lacks good health. This leads to the loss of various ecosystem services and habitats for the regional biodiversity and increases many threats to them. Therefore, several steps for the restoration of open forests need to be implemented to achieve the protection of KBAs and their associated targets.

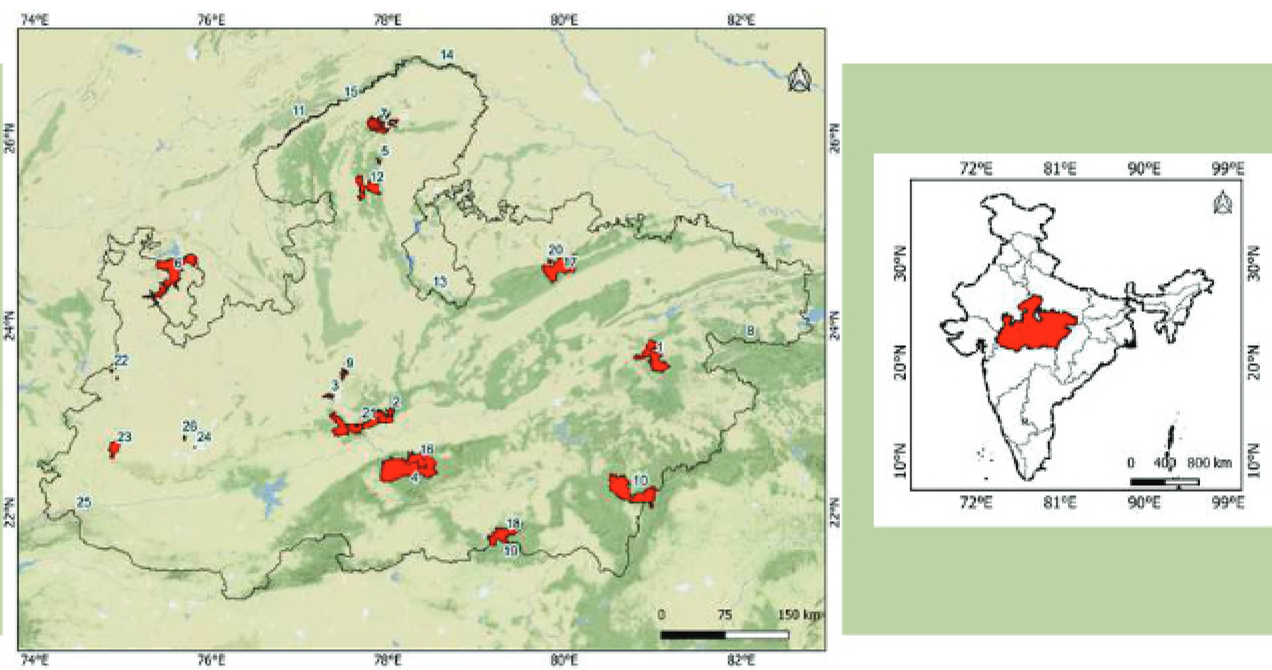
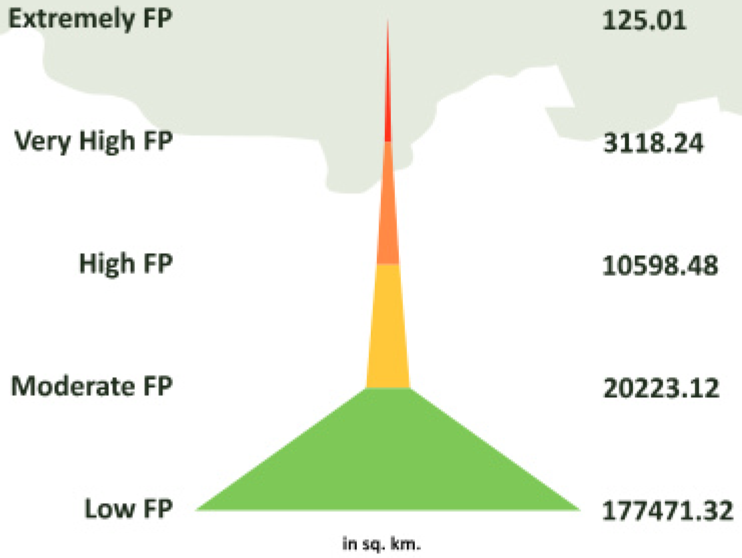


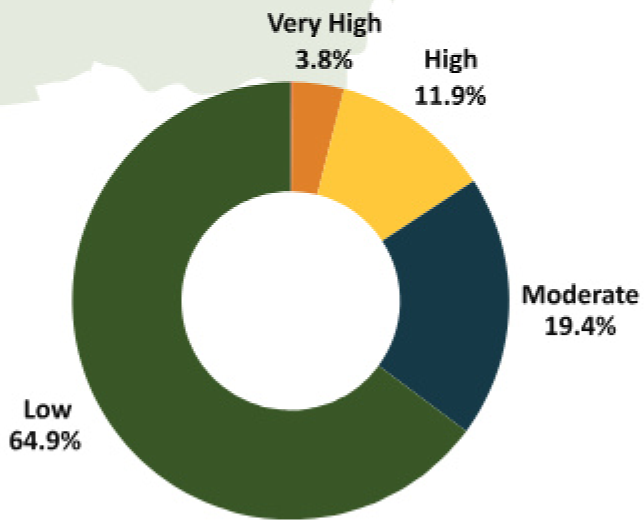
Fig. 3. Location map of KBAs of Madhya Pradesh

Table 1: KBAs of Madhya Pradesh

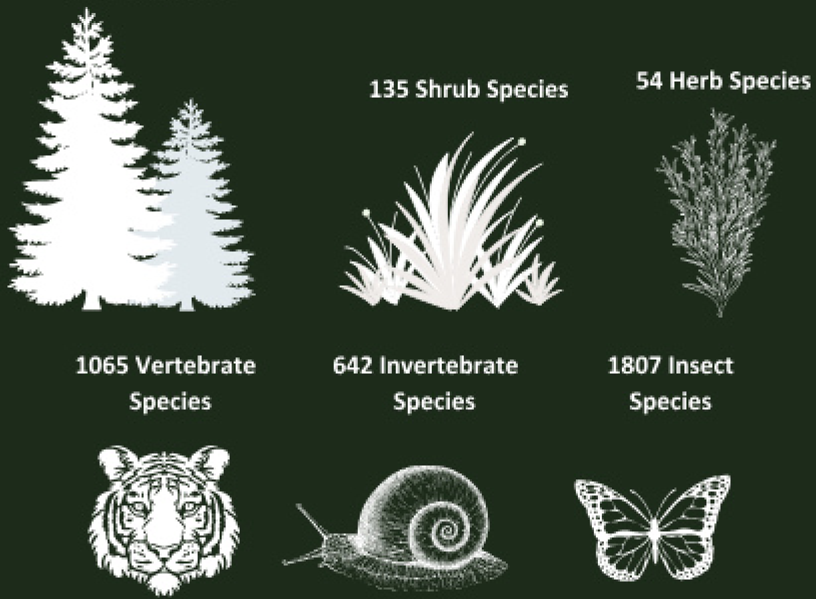
Sl. No.	KBAs in Madhya Pradesh
1	Bandhavgarh National Park
2	Barna Reservoir
3	Bhoj wetland
4	Bori Wildlife Sanctuary
5	Dihaila Jheel and other wetlands
6	Gandhi Sagar Wildlife Sanctuary and reservoir
7	Ghatigaon Bustard Sanctuary
8	Guru Ghasidas Tiger Reserve
9	Halali Reservoir
10	Kanha National Park
11	Madhav National Park
12	Mahaveer Swami Wildlife Sanctuary (Lalitpur)
13	Pachmarhi Biosphere Reserve
14	Panna National Park
15	Pench Tiger Reserve Region 1
16	Pench Tiger Reserve Region 2
17	Rangawa Reservoir
18	Ratapani Wildlife Sanctuary
19	Sailana Kharmor Sanctuary
20	Sardarpur Wildlife Sanctuary
21	Sirpur Lake
22	Toranmal Reserve Forest
23	Yeshwantsagar Reservoir

Table 2: Forest Fire Prone Regions of Madhya Pradesh





Key Biodiversity Areas (KBAs) of Maharashtra



Regional Biodiversity of Maharashtra

Source: FSI, 2021

Maharashtra is one of the top five states in the country which has been observing a significant increase in forest cover since 2019. It is comprised of three physiographic zones including the Deccan plateau, Western Ghats, and West Coast. The total forest cover area of the state is 50,798 sq. km which is 16.51% of the state's geographical area.

The three physiographic zones of Maharashtra sustain a unique biodiversity with high endemism. Among the 642 species of vertebrates, it is observed that 165 species are endemic to India and 26 species are endemic to the state of Maharashtra (FSI, 2021). The mean precipitation and temperature in the region vary from 400 mm to 6,000 mm and 25°C to 27°C respectively. In 2021, the state has shown a significant increase of 20% in forest cover area as compared to 2019. This is particularly important for sustaining the regional flora and fauna.

The state has many unique biodiversity regions in and around the forest cover and hosts a total of thirty-three key biodiversity areas (KBAs) including national parks, creeks, water bodies, wildlife, and bird sanctuaries. The total geographical area of all these KBAs is 20,86,019 sq. km which is shared among its neighbouring states of Madhya Pradesh, Goa, Karnataka etc.

The state has observed increasing threats of forest fire within the region. Maharashtra has been ranked 4th in India after Odisha, Madhya Pradesh, and Chhattisgarh in terms of the number of forest fire incidents in the state. Between the years 2019-20 and 2020-21, around 14,018 and 34,025 numbers of fire incidents were captured using the Suomi-NPP (SNPP) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellites. The Gadchiroli districts of the state observed maximum fire incidents in the year 2020-21 which was nearly one-third of the total fire incidents in the state.

The location map is shown in Figure 4 and the list of all the KBAs present in the state is shown in Table 3. The forest fire-prone classes and their classification with their geographical area are presented in Table 3.

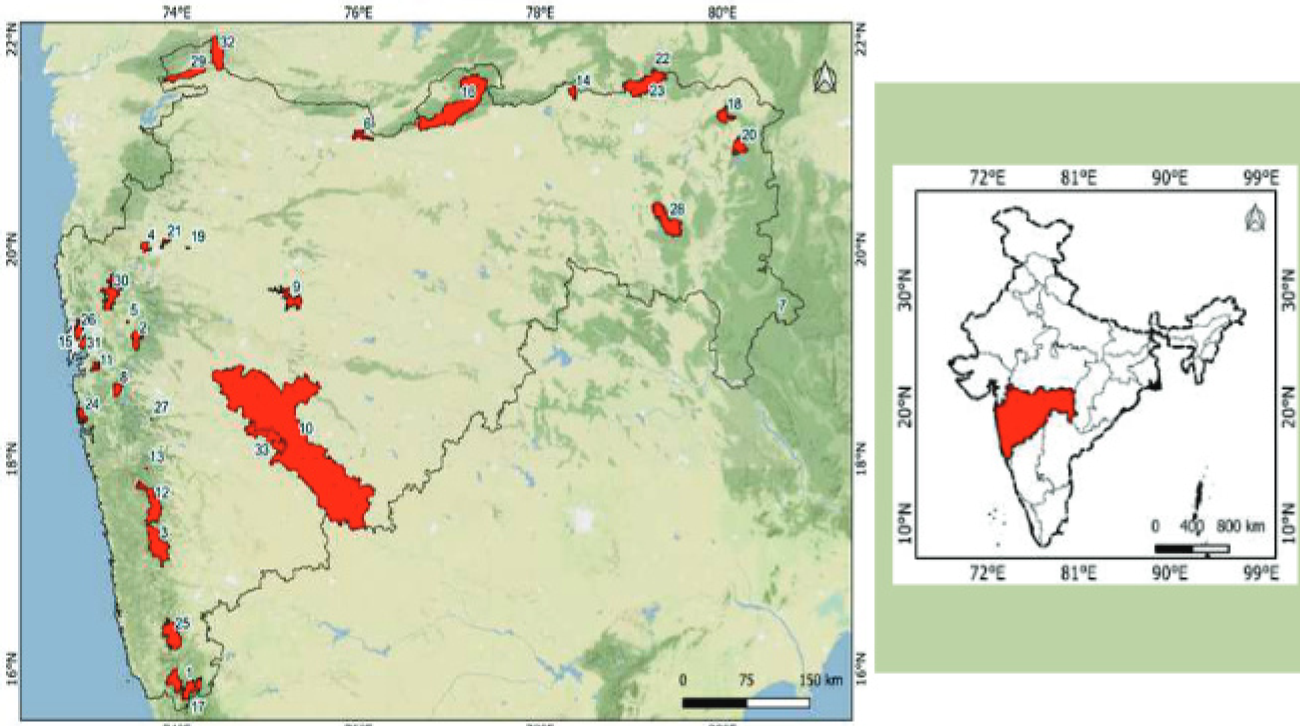
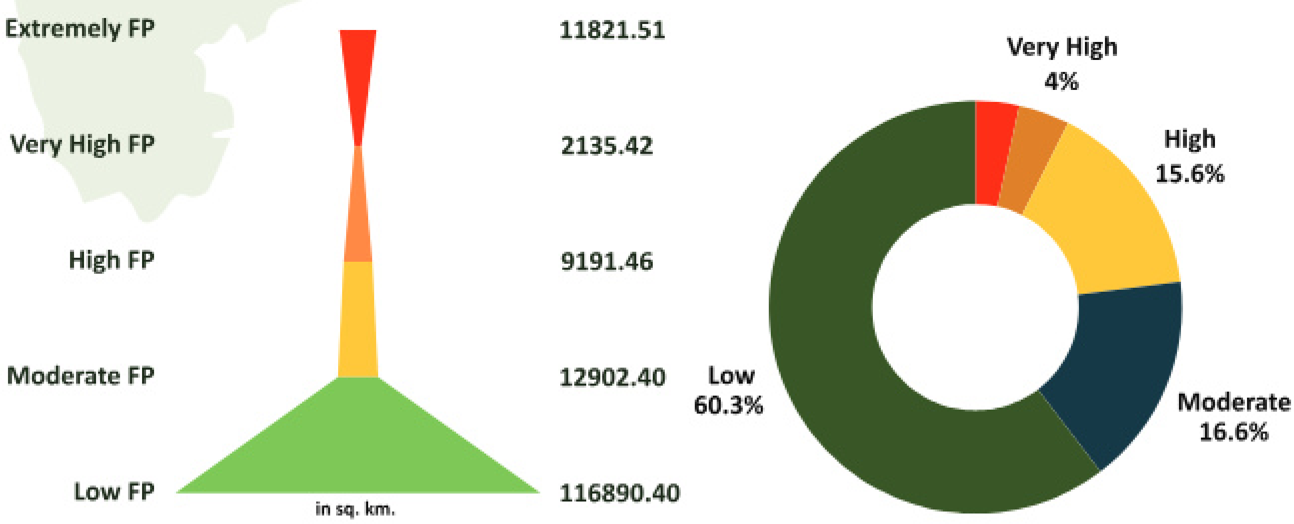


Fig. 4. Location map of KBAs of Maharashtra

Table 3: KBAs of Maharashtra

Sl. No.	KBAs in Maharashtra
1	Amboli-Tilari Reserve Forest
2	Bhimashankar Wildlife Sanctuary
3	Chandoli National Park
4	Gangapur Dam and grasslands
5	Harishchandragad-Kalsubai Wildlife Sanctuary
6	Hatnur Dam
7	Indravati National Park and Tiger Reserve
8	INS - Shivaji and adjoining areas, Lonavla
9	Jaikwadi Wildlife Sanctuary
10	Jawaharlal Nehru Bustard Sanctuary
11	Karnala Bird Sanctuary
12	Koyna Wildlife Sanctuary
13	Mahabaleshwar Reserve Forest
14	Mahendri Reserve Forest
15	Mahul - Sewree Creek
16	Melghat Tiger Reserve
17	Mhadei Wildlife Sanctuary and area
18	Nagzira Wildlife Sanctuary
19	Nandur Madhmeshwar Wildlife Sanctuary
20	Navegaon National Park
21	Ozar and adjoining grassland
22	Pench Tiger Reserve Region 1
23	Pench Tiger Reserve Region 2
24	Phansad Wildlife Sanctuary
25	Radhanagari Wildlife Sanctuary
26	Sanjay Gandhi National Park
27	Sinhgarh
28	Tadoba National Park and Andhari Tiger Reserve
29	Taloda Reserve Forest
30	Tansa Wildlife Sanctuary
31	Thane Creek
32	Toranmal Reserve Forest
33	Ujjani Reservoir

Table 4: Forest Fire Prone Regions of Maharashtra



4. DATASETS AND METHODOLOGY

In this section we described in detailed the procedure for data collection for different datasets and the methodology adopted for data assessment in different time periods for analyzing threats in KBAs of Central India using statistical analysis of four major variables i.e., forest loss, forest fire, and nighttime lights.

DATA EXTRACTION AND DATASETS

The imaging datasets were analysed using Google Earth Engine (GEE), which is a web-based, cloud-based environment (https://earthengine.google.com/). The JavaScript code that can be found at https://github.com/AlisonBeresford/KBA-Monitoring.git was used to carry out a variety of activities, ranging from the extraction of data to the alteration of data. The study looked at all KBAs where the 'region' was specified as Central India (Madhya Pradesh and Maharashtra). These shapefiles were then imported into GEE as a feature collection and further processed with JavaScript programmes that were publicly accessible online. The details of the datasets are described in Table 5.

This study computed the proportion of land covered by trees for the year 2000, extracted tree cover, and then selected pixels in which the tree cover percentage was more than 50. Then, the boundaries of KBA were overlapped with this (above-mentioned) layer to calculate the amount of land covered by trees for the same 2000 at every site.

The "loss year" band from 2001 to 2020 was used to build a layer for each year, to determine whether tree cover was lost in that specific year for each tree-cover pixel. Following this, the yearly loss layers were overlapped with the boundaries of KBA to establish the total area of every KBA that had lost tree cover in each year. The study also computed the proportion of lost tree cover at every site yearwise, compared to the total area covered by trees in 2000.

The FIRMS was used to get the fire datasets. These datasets have a spatial and temporal resolution of one kilometer and one day respectively, and indicate the locations of active flames with the movement of the MODIS satellite over them. When the span of fires is greater than one pixel with a size of 1 kilometer, a new fire event is noted for every pixel, and when flames persist for over one day, a new fire incident is noted for every day as the fire continues. The data download was inclusive for the years from 2001 to 2020. After reclassifying each daily image as a binary raster (fire/no fire), yearly summary maps displaying the total number of fire incidents for every year were constructed.

The KBA boundaries were then placed on top of these maps, and the total number of fire incidents detected at every site throughout the course of the years was calculated. The total number of fire incidents that occurred at every site during each year was then divided by the entire area of each site to arrive at a standard number of yearly fire occurrences per square kilometer.

There were two unique night-light data sources used, and each one covered a distinct time period. The DMSP OLS Night-time Lights Time Series was used between 1992 and 2013. This system has a resolution of 30 arc seconds for measuring NIR emission and visible sources at night. "Stable lights" bands were used for the process to exclude transitory incidents such as fires, which were erased, and the detected background noises were changed with zero values.

The VIIRS Stray Light Corrected Night-time Day/Night Band Composites were used between 2014 and 2020. This was performed weekly with a resolution of 15 arc seconds to determine the average radiance. In addition, there were correction techniques for stray light. In this case, neither the background values nor the transient phenomena such as fires, boats, or the aurora were removed.
Any comparisons across time periods were tough to do due to the dissimilar techniques that were used to generate the two datasets. After producing mean images for each year for both datasets, these images were intersected with the KBAs to get an average value for each year for each KBA for steady lights (from 1992 to 2013) and average radiance (from 2014 to 2020)."

INUNDATION MAPPING

The shapefiles and site maps of the wetlands can be downloaded from the official Ramsar website (https://rsis.ramsar.org/ris-search/?pagetab=0). The datasets used for this study are Landsat 5 TM, 7 ETM, and 8 OLI surface reflectance products from 1991 to 2020 from USGS (https://earthexplorer.usgs.gov/) and are mirrored in the GEE data catalogue (https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LT05_C01_T1_SR; https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LE07_C01_T1_SR; https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C01_T1_SR).
The ECMWF reanalysis data (ERA5 monthly) is used for climate data analysis by modifying the code available on the Earth Engine Data Catalog (https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_MONTHLY). The elevation and other details of wetlands are downloaded through the "Ramsar Sites Information Service" website at https://rsis.ramsar.org/.

Table 5: Details of Datasets Used for the Study of KBAs in Central India

Data	Source	Resolution	Time Period
Fire data	Fire Information for Resource Management System (FIRMS)	Temporal of 1 day and spatial of 1 km.	2001-2020
Tree cover and its change	Hansen Global Forest Change dataset	1 arc second (30m at the equator)	2001-2020
Stable night-lights	Defense Meteorological Program Operational Line Scan System (DMSP OLS) Night-time Lights Time Series	30 arc seconds	1992-2013
Average radiance night-time light	Visible Infrared Imaging Radiometer Suite (VIIRS) Stray Light Corrected Nighttime Day/Night Band Composites	15 arc seconds	2014-2020

STATISTICAL ANALYSIS FOR KBAs

The linear trends for all the threat indicators (the percentage of forest loss, the number of fire occurrences, steady night-time lights, and average radiance) were determined for each KBA. These trends were derived using time series data. To determine whether or not a specific time series dataset possesses a monotonic linear trend, the Mann-Kendall test was used for the data in the series. The test has a non-parametric design, which means that it applies to any data distribution at all. It is possible to test the null hypothesis, H0Ho, against one of the following three alternative hypotheses, HaHa: (i) there is a monotonic downward trend, (ii) there is a monotonic upward trend, or (iii) there is either an upward monotonic trend or a downward monotonic trend. The null hypothesis, H0Ho, states that there is no monotonic trend.

It is a rigorous test for identifying trends, and it finds widespread use in the study of climatological, hydrological, financial, and environmental time series. This was accomplished with the help of the "lmList" function that is included in the "lme4" package (Bates et al., 2019) for R 3.4.3. (R Core Development Team, 2017).

The indicator value served as the dependent variable in each scenario, the year served as the independent variable, the KBA identity (SitRec ID) served as the accumulating factor, and the sums of squares for the residuals. In addition, extraction of the significance of every trend is done using models with a p-value less than 0.05 and categorised changes as positive, negative, or non-significant. In addition, we estimated the annual average number of fires per sq. km for each KBA, as well as the cumulative loss of tree cover by 2020 as a percentage of tree cover in 2000. In addition to examining changes in KBAs on an individual level, KBAs were categorised according to terrestrial ecoregions (Olson et al., 2001) to examine the global trends of change.

Therefore, the study conducted the same trend assessment for terrestrial ecoregions that was done for individual KBAs. This helped in determining the tendency in every indicator over a period for every of the land ecoregions in Central India that are represented by KBAs. Again, the significance of each pattern was established. For each ecoregion, we also estimated the median values for the average number of fires per sq. km per annum, the percentage of tree cover in 2000, constant nighttime illumination in 2013, and average radiance in 2020 inside KBAs.

METHODOLOGY FOR INUNDATION MAPPING

To generate accurate inundation maps, it is necessary to mask clouds and cloud shadows in the Landsat images. This involves removing pixels that are classified as cloud or cloud shadows on the Landsat cloud mask band, which is done using the gap-filling method (Goyal et al., 2023b). The masked pixels were then filled with the median value for the pixel from a year before or after the scene's date. To generate accurate inundation maps, it is necessary to mask clouds and cloud shadows in the Landsat images. This involves removing pixels that are classified as cloud or cloud shadows on the Landsat cloud mask band, which is done using the gap-filling method (Goyal et al., 2023b). The masked pixels were then filled with the median value for the pixel from a year before or after the scene's date. Afterwards, a gap-filling method was applied to cloud-masked images for Landsat composites (Gupta et al., 2023). The SWIR band (B7) was chosen for each scenario, and composites were created for each year using all available scenes from June to September. For each pixel in the study area, the corresponding pixel values from all the scenes of that year were evaluated, and the median value was designated as the value of the corresponding pixel in the composites to be generated.

If the SWIR band is missing for some composites, they were manually filtered and removed from the image collection. The resulting composites were then used to create inundation maps by digitizing wet and dry areas for each site and calculating a composite-specific SWIR threshold using equation (1) (Rakkasagi et al., 2024). The classifier compares each pixel's SWIR value to its threshold, and the pixels are classified as either dry or inundated, resulting in an inundation map with pixels changed to either 0 or 1 values.

SWIR_threshold=SWIR_wet+0.3 (SWIR_dry-SWIR_wet)

The classifier compares each pixel's SWIR value to its SWIR threshold for each composite. The pixels having SWIR values less than or equal to SWIR threshold are classified as inundated, while pixels having SWIR values larger than or equal to SWIR threshold are classified as dry.”

5. RESULTS

This section will present the outcomes for forest fire, forest loss, stable night lights, and average radiance trends for the twenty-six and thirty-three KBAs present in each of the Madhya Pradesh and Maharashtra states respectively.

KBAs TREND ANALYSIS FOR MADHYA PRADESH

Madhya Pradesh lies at the heart of India and has an abundance of flora and fauna spread across 23 KBA. A few examples of major KBAs in this region are Bandhavgarh National Park, Barna Reservoir, Bhoj wetland etc.

Average radiance showed only a positive trend in all the sites. Forest fire and stable lights also showed a general trend with majorly being positive with few significant (Figures 5, 6, 7 & 8 and Table 6). Sites with no data were not included in the analysis.

Table 6: Nature of Trends Observed in the KBAs of Madhya Pradesh

Threat Indicators	Significant positive trend	Positive trend	Negative trend	Significant negative trend
Forest Loss	0 (0 %)	0 (0 %)	4 (15.38 %)	16 (61.53 %)
Forest Fire	5 (19.23 %)	12 (46.15 %)	4 (15.38 %)	3 (11.53 %)
Stable lights	4 (15.38 %)	9 (34.61 %)	7 (26.92 %)	5 (19.23 %)
Average Radiance	7 (26.92 %)	19 (73.07 %)	0 (0 %)	0 (0 %)

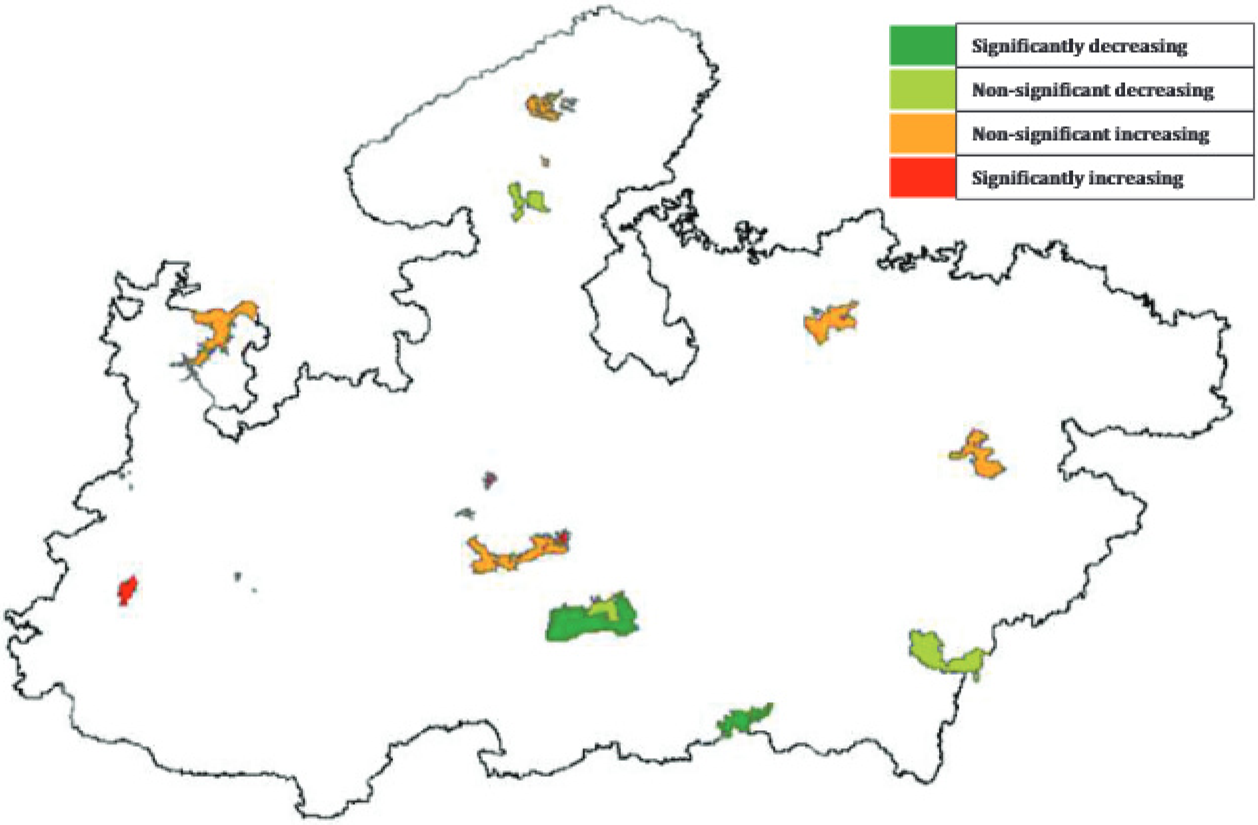


Fig. 5. Forest loss trend from 2001 to 2020 for Madhya Pradesh

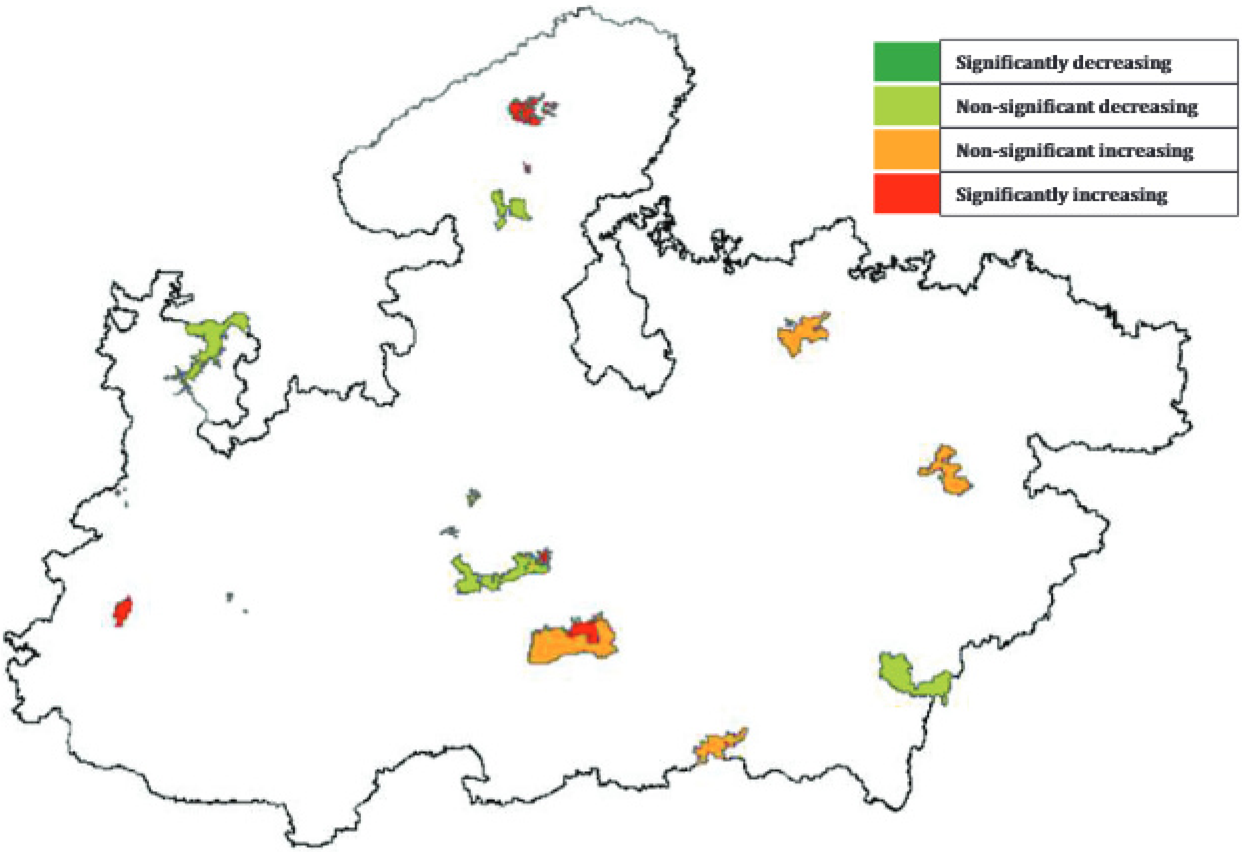


Fig. 6. Forest Fire trend from 2001 to 2020 for Madhya Pradesh

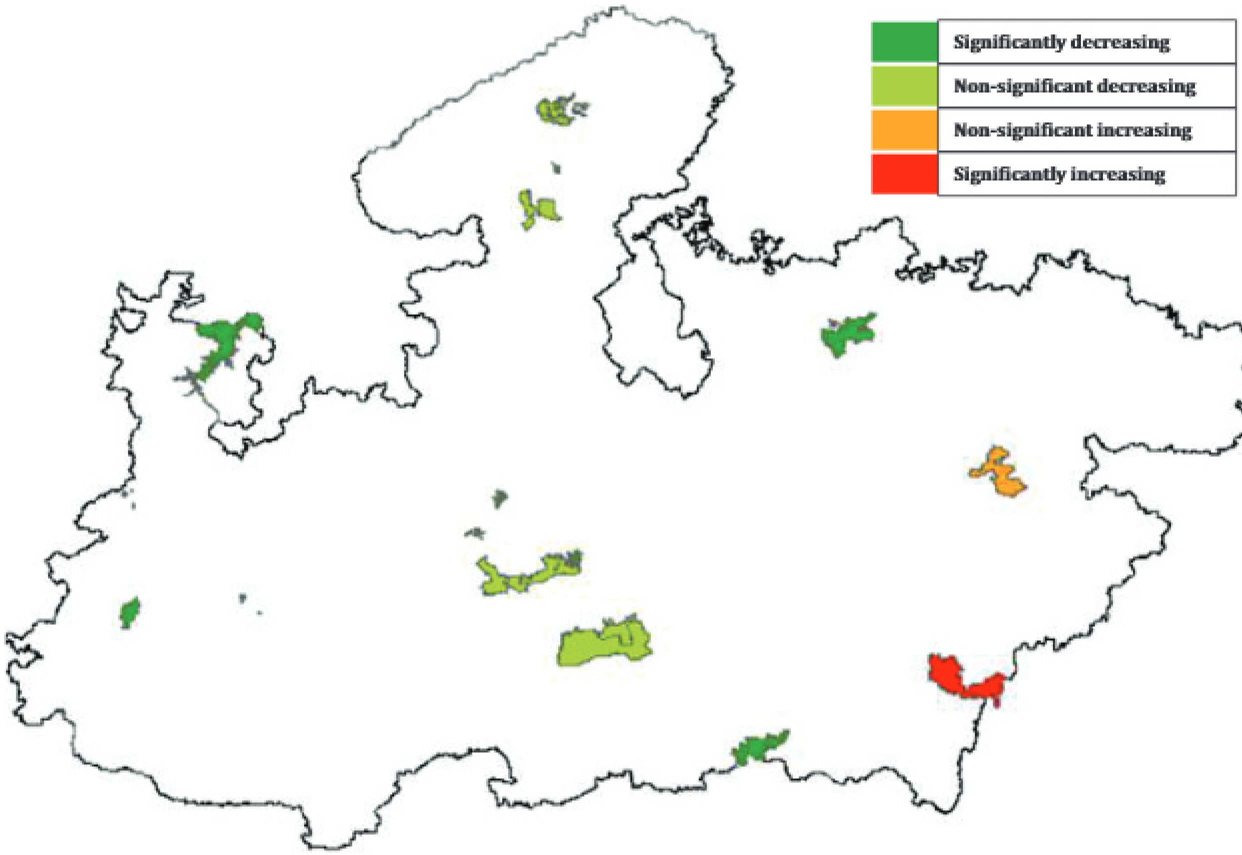


Fig. 7. Stable night lights trend from 2001 to 2020 for Madhya Pradesh

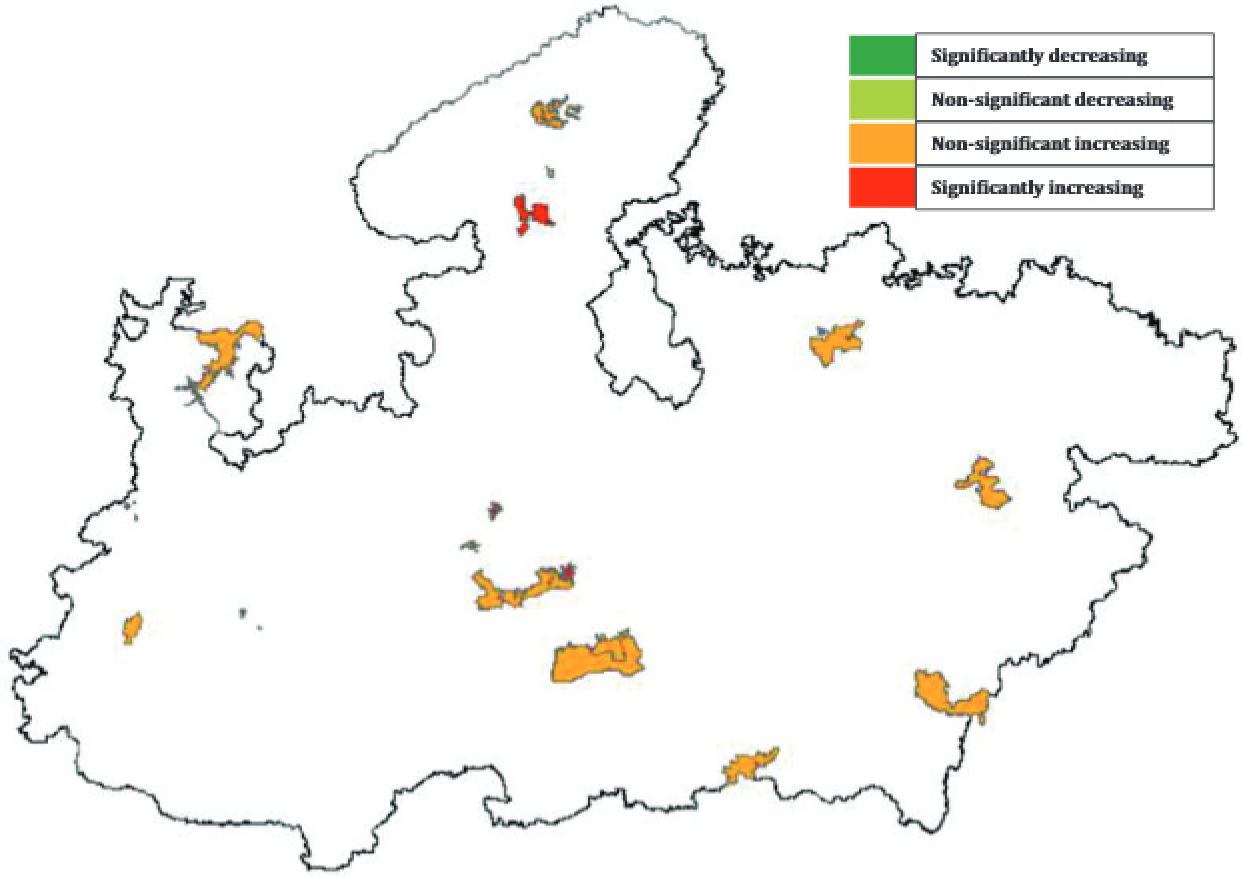


Fig. 8. Average–radiance trend from 2001 to 2020 for Madhya Pradesh

KBAs TREND ANALYSIS FOR MAHARASHTRA

Maharashtra, which spans over a wide geographic area has a huge variety of plant and animal diversity. It has a total of 33 KBA sites, and some major KBAs in the region include Indravati National Park and Tiger Reserve, Jaikwadi Wildlife Sanctuary, Jawaharlal Nehru Bustard Sanctuary, Mahul-Sewree Creek, Melghat Tiger Reserve etc. Forest fires here show a general trend with the majority of sites showing a positive trend in the night-time lights for both stable lights and average radiance.

Majority of the KBAs show a negative trend in forest loss which can be attributed to forest conservation measures (Figures 9, 10, 11 & 12 and Table 7). Sites with no data were not included in this analysis.

Table 7: Nature of Trends Observed in the KBAs of Maharashtra

Threat Indicator	Significant positive trend	Positive trend	Negative trend	Significant negative trend
Forest Loss	2 (6.06%)	0 (0%)	11 (33.33%)	9 (27.27%)
Forest Fire	2 (6.06%)	10 (30.3%)	14 (42.42%)	5 (15.15%)
Stable lights	15 (45.45%)	13 (39.39%)	3 (9.09%)	2 (6.06%)
Average Radiance	9 (27.27%)	22 (66.67%)	1 (3.03%)	0 (0%)

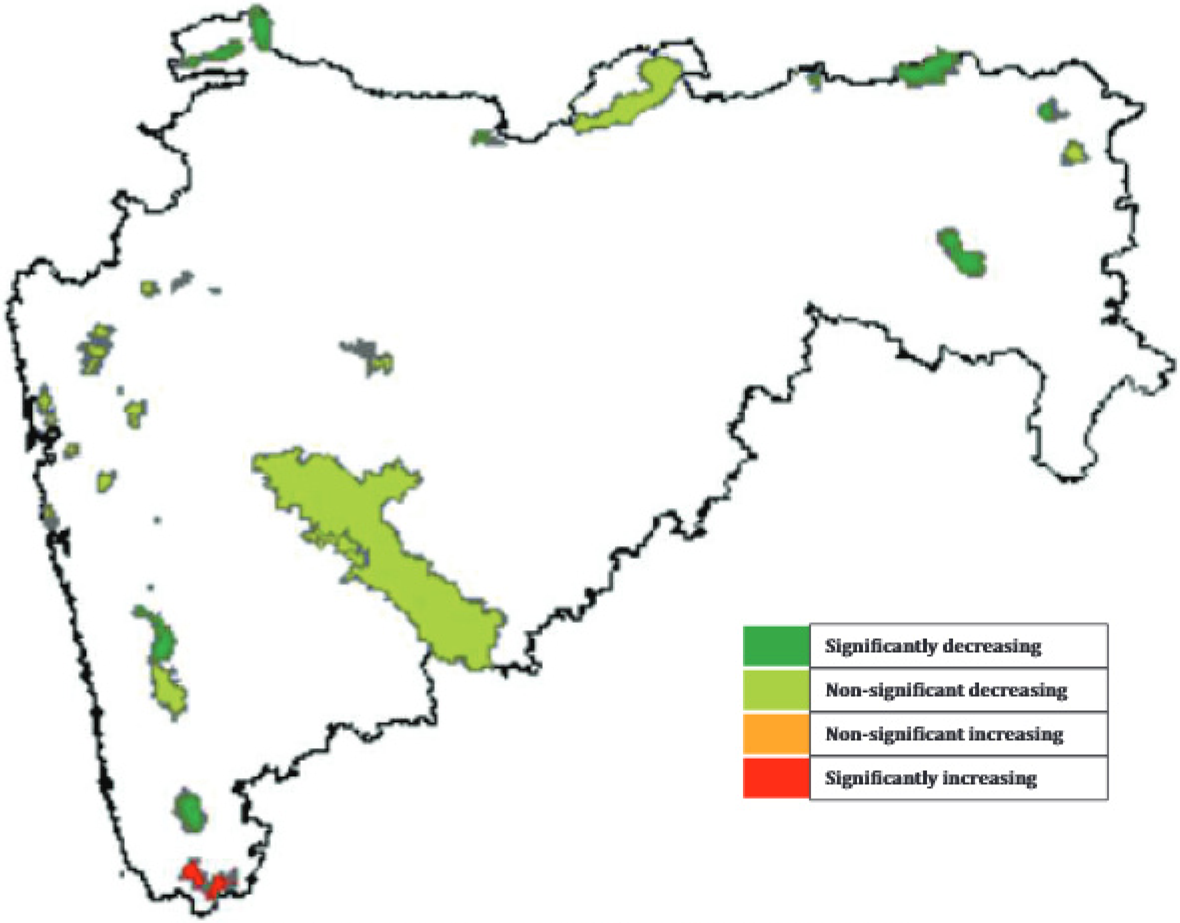


Fig. 9. Forest loss trend from 2001 to 2020 for Maharashtra

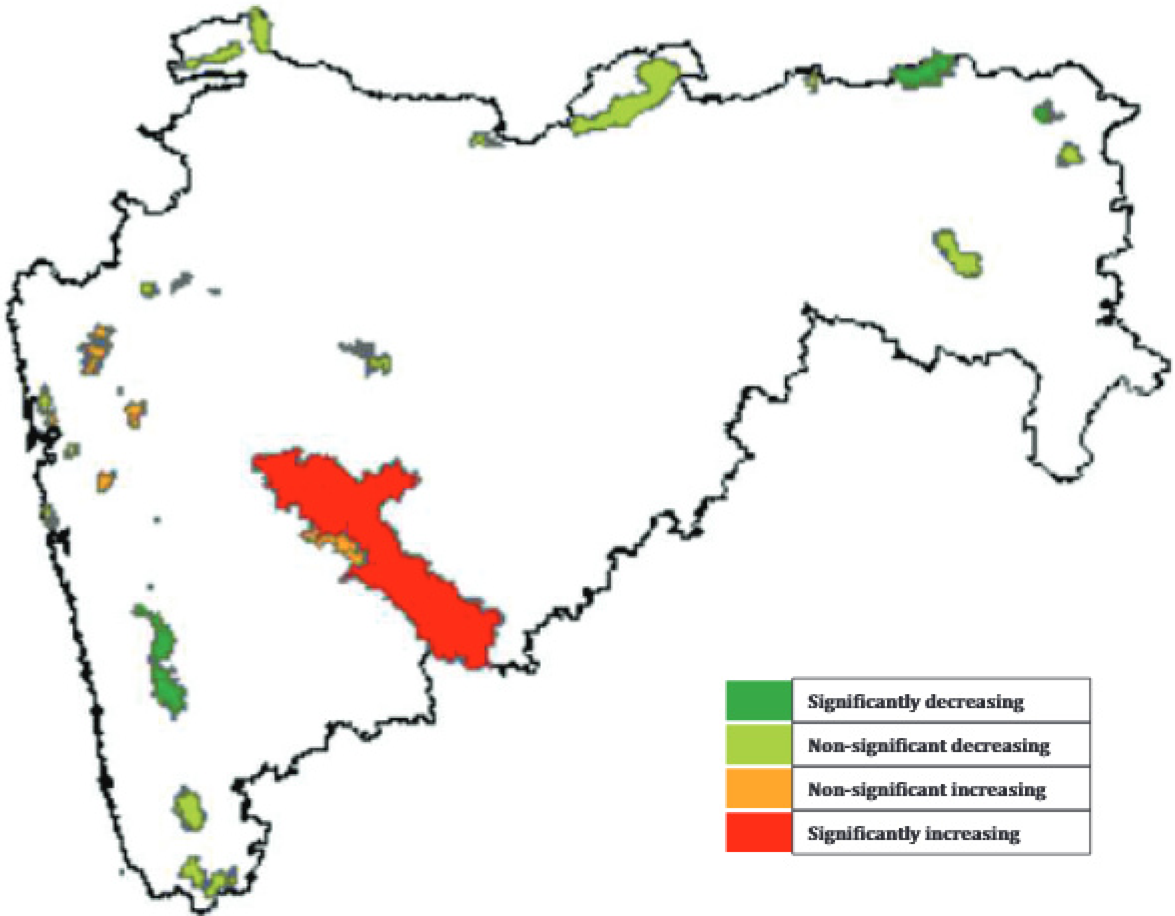


Fig. 10. Forest Fire trend from 2001 to 2020 for Maharashtra

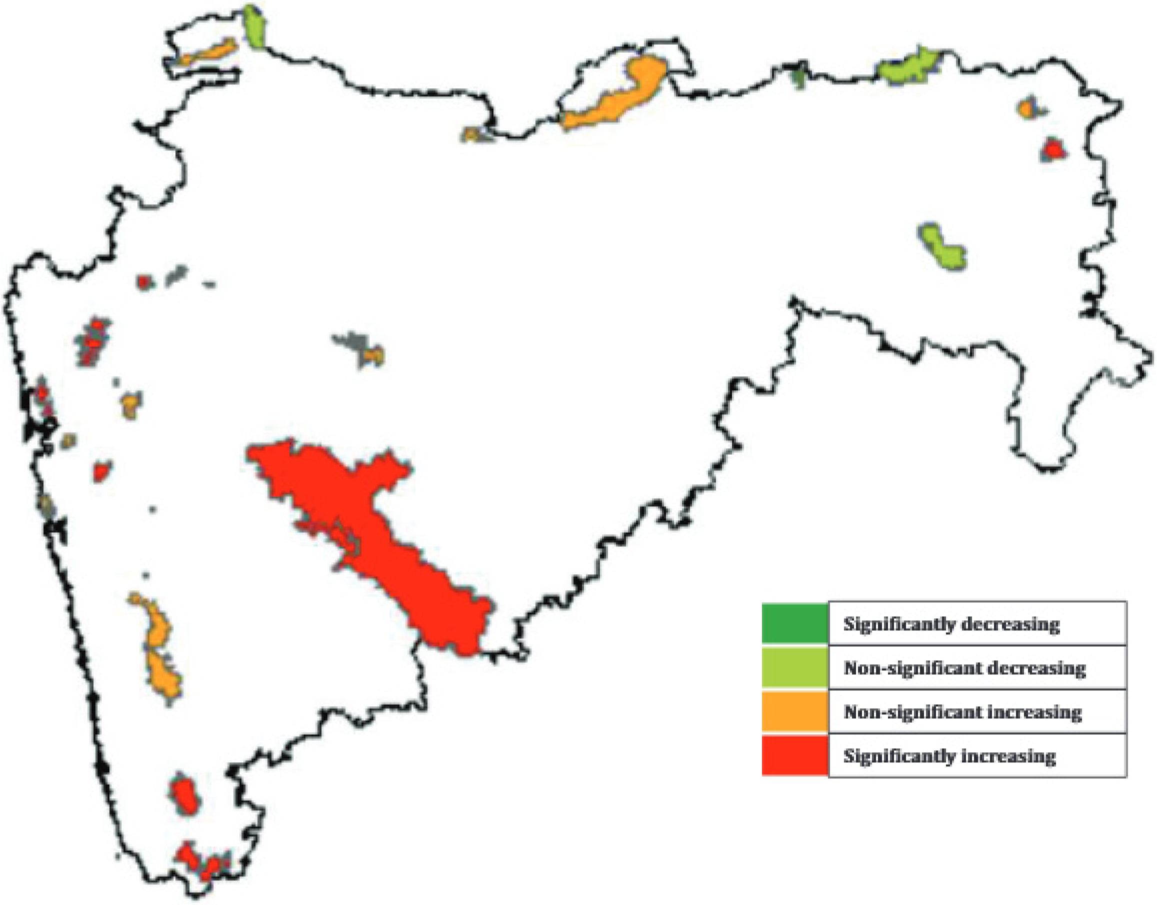


Fig. 11. Stable night lights trend from 2001 to 2020 for Maharashtra

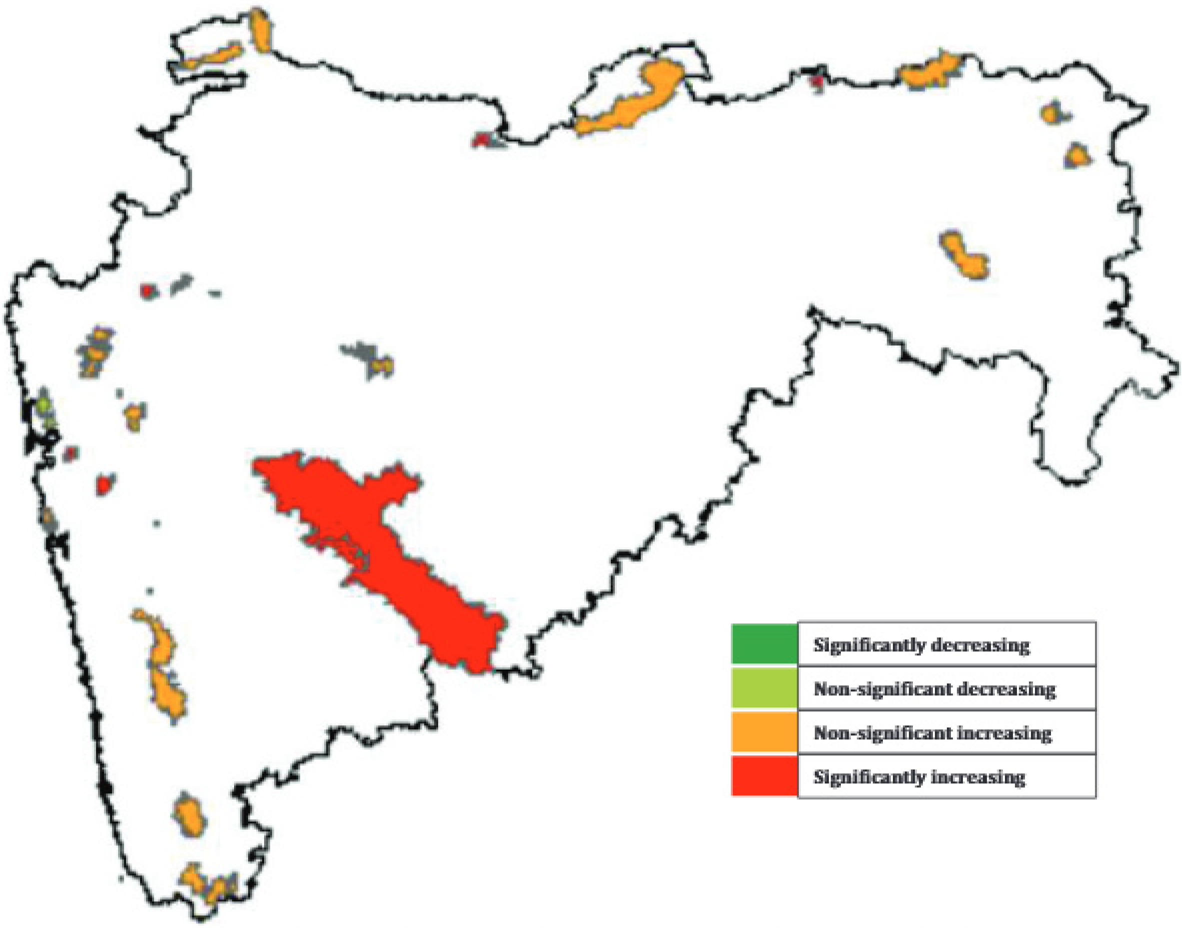


Fig. 12. Average–radiance trend from 2001 to 2020 for Maharashtra

INUNDATION MAPPING FOR CENTRAL INDIA

The inundation pattern indicates that the maximum and minimum inundated area for the Sakya Sagar wetland were in the years 2015 and 2020, respectively. Similarly, the inundation pattern shows that the maximum and minimum inundated areas for Sirpur Wetland were during 1996 and 2006. Likewise, the inundation pattern indicates that the maximum and minimum inundated areas of Bhoj Wetland were in 1996 and 2016. Also, the inundation pattern shows that the maximum and minimum inundated areas of Nandur Madhameshwar were during 2001 and 2019, respectively.

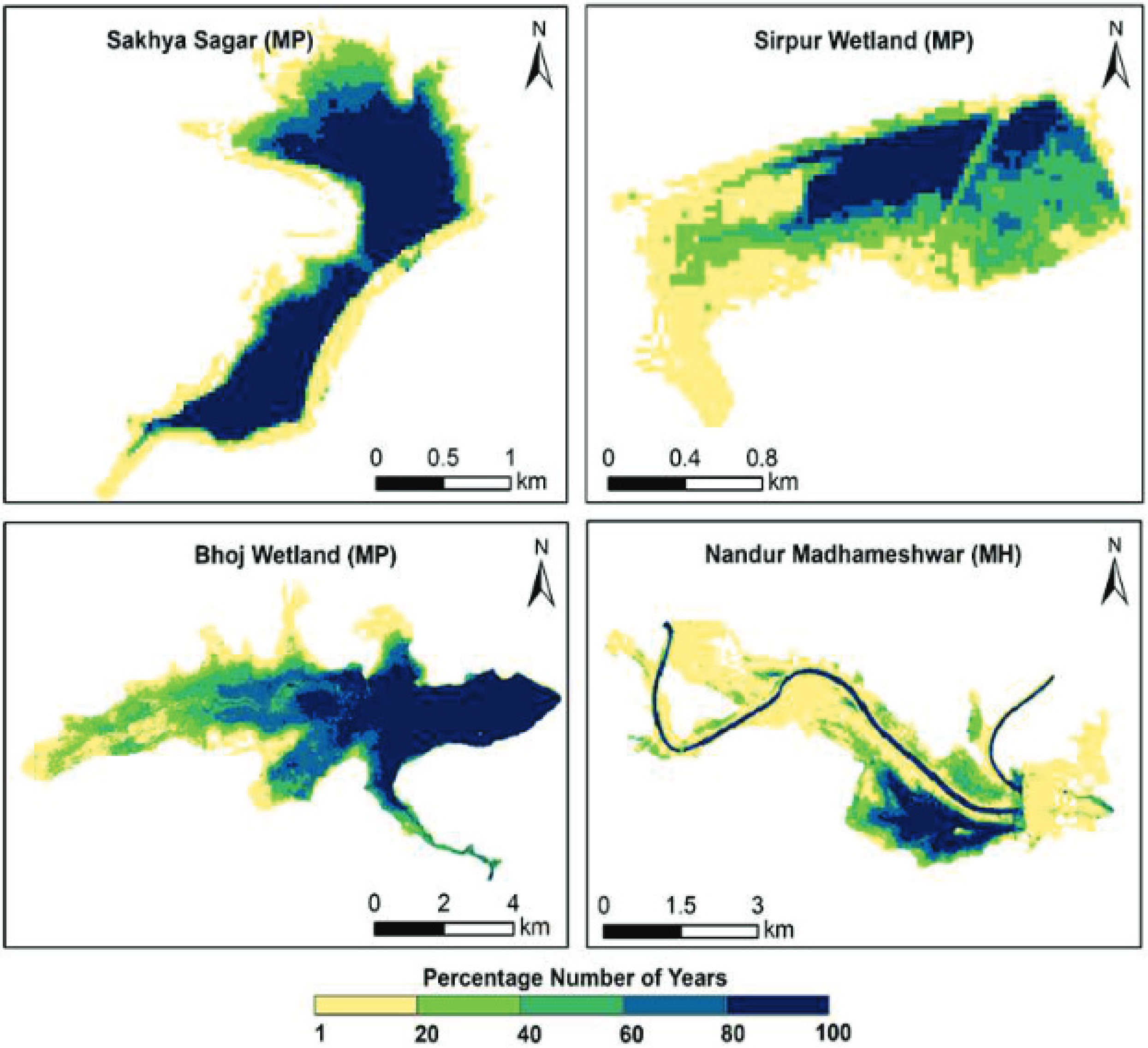


Fig. 13. Inundation maps represent the number of years each pixel inundated during the period 1991–2020 (June to September). The legend represents the value of 80–100% (dark blue) of the pixels inundated in all available timesteps and 1–20% (yellow) as not inundated

6. DISCUSSIONS AND CONCLUSIONS

The findings of the study in the forms of change in indicators of three unique threats to KBAs throughout Central India indicate a complex pattern in the pressures exerted in differing degrees on specific sites and ecoregions. This precluded in the accurate calibration variations in indicators with changes on the ground. Although it is currently well-recognized that remote sensing techniques can be used for monitoring sites a majority of the research focuses on a particular data type or measure of change that cannot be indicative of the cumulative pressures a site encounters. Even while the data indicate a positive link between the rise in the rate of forest fires and the rate at which forests are being burned, there was no correlation between night-time lighting and any of the other two variables.

This supports the argument for monitoring KBAs using several data sources and warning indicators. Even though this has been a topic of controversy in the past, its implementation has been seldom. Ground-based measurements will continue to be essential for finding pressures that are difficult to notice from a distance. A recent analysis indicated that hunting and related forms of disturbance are the most common risks to protected areas throughout the world. It is crucial to build a monitoring system that provides both field and remote-sensing-based evaluations for locations considered to be of global relevance for conservation. This system must also contain KBAs with an approach that should be made available to community land administrators and decision-makers, as well as for establishing international, regional, and domestic priorities and allocating resources.

Handling the enormous size of satellite images sometimes poses a considerable hurdle for many conservation end-users due to logistical blockages. This research showcases a relatively smooth approach using GEE for obtaining many remotely sensed variables that could be evaluated for varied pressures on a web of locations. Making use of the widely available and well-established datasets, this study demonstrates that such an approach is possible. Similarly, it is expected that a prolonged time series of three indicators will develop into a gradually significant aspect of understanding and interpreting such patterns.

It is envisaged that in the coming years, new long-term datasets relevant to a range of stresses will be available. As the case may be, they may be included in the monitoring systems, allowing for the incremental creation of near-perfect images of the pressures behaving on these sites. Worldwide standardized products are particularly useful since they permit rapid comparisons of threats in various regions of the globe.

However, they should be treated with care, and users should be aware of the limitations accompanying any dataset before using it. It is known that the accuracy of worldwide tree cover maps is susceptible to some degree of spatial fluctuation and that the loss of trees on sites is not necessarily seen as a terrible thing. Certain residential and commercial projects are not equipped with nighttime lighting (Small et al., 2005), while some nighttime lights do not always indicate residential and commercial development. Conducting this inquiry using GEE, a cloud-based computer platform and data repository provided several advantages that should not be neglected. There were no fees involved with using the platform or any data accessed using it.

It was unnecessary to download, save, or process the data locally since everything, including storage and processing, was performed online. In the past, access to local computer resources and information technology infrastructure limited the capabilities of several people (De Klerk and Buchanan, 2017). If we put annotated code in a shared repository and make it available to other users, we anticipate that they will be able to conduct analogous research at scales that meet their needs.
Scalability is a major advantage of the present method since monitoring at several scales may be necessary for conservation. "

Analysis done at a KBA level gives a better idea of the seriousness of the threat indicators. The analysis carried-out for Madhya Pradesh and Maharashtra gave a greater insight of nature. No KBA in Madhya Pradesh shows a positive trend for forest loss. Night-time lights only show increasing trends for all the sites for 2014-2020. As the region spans deserts, plains, forests, mountains, and lakes, thus the results showed a large variation. There was a significant positive relationship between the trend of fire frequency and the trend in percentage forest loss of KBAs. However, no significant relationships were found between trends in stable night-time lights and trends in either fire frequency or percentage forest loss.

7. NOTE FOR POLICY MAKERS

Policy making for KBAs to address the threats of forest loss, forest fires, and night lights requires a combination of regulatory and incentive-based approaches. Here are some steps that can be taken:

1 Develop land-use policies

Land-use policies can help regulate forest loss and fragmentation by designating certain areas as protected forests or wildlife corridors. These policies can also encourage sustainable forestry practices, such as reduced impact logging and reforestation programs.

2 Implement fire prevention measures

To address the threat of forest fires, policies should be developed to prevent and control wildfires. The policies should thus be supported by and include early warning systems, fire suppression techniques, and community-based fire prevention programs.

3 Reduce night lights

Night lights can disrupt the natural behavior of nocturnal animals, and impact their ability to navigate, forage, and reproduce. Policies that reduce the use of artificial lights at night can help mitigate these impacts. This can include zoning regulations for outdoor lighting, the use of energy-efficient lighting, and public awareness campaigns.

4 Provide incentives for conservation

Incentives can help encourage landowners, communities, and businesses to participate in conservation efforts. This can include financial incentives such as tax breaks, grants, and subsidies for sustainable land-use practices and conservation projects.

5 Monitor and enforce policies

Policies are only effective if they are properly monitored and enforced. Regular monitoring of KBAs can help detect and respond to threats, while penalties for non-compliance can help deter illegal activities.

8. RECOMMENDATIONS FOR POLICY AND LEGAL MECHANISMS

This project on KBAs has enhanced the understanding of biodiversity and its vulnerability in the Central India, with a focus on crucial areas and species that require protection. Consequently, prompt measures are necessary to sustain the efforts made and realize the project's complete potential. Therefore, it is suggested that the subsequent critical tasks are executed in the near and intermediate future:

- The database and maps of KBAs should be incorporated into national, state, and district spatial development plans, as well as marine spatial planning.
- Example 1: Creating a connection with the national authorities of land and territorial development to ensure recognition of KBAs as components of the national ecological structure. This means that development projects that endanger the essential biodiversity elements that prompted the creation of KBAs should avoid these areas.
- Example 2: Establishing a connection with the related authorities of the sea/marine, inland waters, and fisheries to incorporate KBAs into the marine spatial plan. This means that KBAs will be recognized as areas where development projects that endanger the essential biodiversity elements that prompted the creation of KBAs should be avoided.
- National legislation should be developed to acknowledge KBAs as regions of significant biodiversity value that necessitates conservation efforts to protect their biodiversity components.
- Environmental Impact Assessments (EIAs) should include guidelines to recognize KBAs as vital biodiversity areas that must be protected or avoided.
- Incorporating KBAs into the new regulation for biodiversity offsets associated with the EIA regulation, identifying them as areas that development projects should avoid and as preferred areas for receiving biodiversity offsets, particularly when establishing new conservation areas.
- KBAs should be given preference as areas for receiving biodiversity offsets.
- KBAs should be included in initiatives aimed at expanding Protected Areas or creating new ones.
- KBAs should be incorporated into the revision of the Biological Diversity Conservation Strategy and Action Plan.

9. REFERENCES

1. Abdulla, F., Farahat, S., 2020. Impact of Climate Change on the Performance of Wastewater Treatment Plant: Case study Central Irbid WWTP (Jordan). Procedia Manuf. 44, 205–212. https://doi.org/10.1016/j.promfg.2020.02.223
2. Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R.H.B., Singman, H., Dai, B., Scheipl, F., Grothendieck, G., Green, P., Fox, J., 2019. lme4, R package. Documentation available at https://cran.rproject. org/web/packages/lme4/lme4
3. Beresford, A.E., Donald, P.F., Buchanan, G.M., 2020. Repeatable and standardised monitoring of threats to Key Biodiversity Areas in Africa using Google Earth Engine. Ecol. Indic. 109, 105763. https://doi.org/10.1016/j.ecolind.2019.105763
4. BirdLife International, 2006. Monitoring Important Bird Areas: A Global Framework (version 1.2). BirdLife International, Cambridge, UK.
5. Brink, A.B., Schmidt, C., Szantoi, Z., 2018. Introduction to remote sensing for conservation practitioners. In: Leidner, A.K., Buchanan, G.M. (Eds.), Satellite Remote Sensing for Conservation Action: Case Studies from Aquatic and Terrestrial Ecosystems. Cambridge University Press, Cambridge, UK.
6. Buchanan, G.M., Fishpool, L.D.C., Evans, M.I., Butchart, S.H.M., 2013. Comparing field-based monitoring and remote-sensing, using deforestation from logging at Important. Bird Areas as a case study. Biol. Conserv. 167, 334–338.
7. Butler, R.A., 2008. Fire monitoring by satellite becomes key conservation tool: an interview with GIS experts at Conservation International and the University of Maryland. Conservation International. Available at https://news.mongabay.com/2008/03/firemonitoring- by-satellite-becomes-key conservation-tool/
8. Chen, S., Woodcock, C.E., Bullock, E.L., Arévalo, P., Torchinava, P., Peng, S., Olofsson, P., 2021. Monitoring temperate forest degradation on Google Earth Engine using Landsat time series analysis. Remote Sens. Environ. 265, 112648.
9. Davies, D.K., Ilavajhala, S., Wong, M.M., Justice, C.O., 2009. Fire Information for Resource Management System: archiving and distributing MODIS active fire data. IEEE Trans. Geosci. Remote Sens. 47, 72–79.
10. De Klerk, H.M., Buchanan, G.M., 2017. Remote sensing training in African conservation. Remote Sens. Ecol. Conserv. 3, 1–14.
11. De Sy, V., Herold, M., Achard, F., Asner, G.P., Held, A., Kellndorfer, J., Verbesselt, J., 2012. Synergies of multiple remote sensing data sources for REDD+ monitoring. Curr. Opin. Environ. Sustain. 4, 696–706.
12. Dottori, F., Szewczyk, W., Ciscar, J.-C., Zhao, F., Alfieri, L., Hirabayashi, Y., Bianchi, A., Mongelli, I., Frieler, K., Betts, R.A., Feyen, L., 2018. Increased human and economic losses from river flooding with anthropogenic warming. Nat. Clim. Chang. 8, 781–786. https://doi.org/10.1038/s41558-018-0257-z
13. Down to Earth, 2016. India simply does not acknowledge forest drought. https://www.downtoearth.org.in/news/forests/a-forest-drought-no-one-is-talking-about-54947
14. Dudley, N., Boucher, J.L., Cuttelod, A., Brooks, T.M., and Langhammer, P.F. (Eds). 2014. Applications of Key Biodiversity Areas: end-user consultations. Cambridge, UK and Gland, Switzerland: IUCN.
15. Duveiller, G., Filipponi, F., Ceglar, A., Bojanowski, J., Alkama, R., Cescatti, A., 2021. Revealing the widespread potential of forests to increase low level cloud cover. Nat. Commun. 12, 4337. https://doi.org/10.1038/s41467-021-24551-5
16. Europe, F., 1993. Resolution H1, general guidelines for the sustainable forest management of forests in Europe, 16-17 June 1993, Helsinki, Finland, in: Second Ministerial Conference on the Protection of Forests in Europe, Madrid, Spain.
17. FSI, 2021. ISFR 2021.
18. Goyal, M.K., Gupta, A.K., Das, J., Jain, V., Rakkasagi, S., 2023a. Heatwave magnitude impact over Indian cities: CMIP 6 projections. Theor. Appl. Climatol. 154, 959–971. https://doi.org/10.1007/s00704-023-04599-7
19. Goyal, M.K., Gupta, A.K., Jha, S., Rakkasagi, S., Jain, V., 2022. Climate change impact on precipitation extremes over Indian cities: Non-stationary analysis. Technol. Forecast. Soc. Change 180, 121685. https://doi.org/https://doi.org/10.1016/j.techfore.2022.121685

20. Goyal, M.K., Rakkasagi, S., Shaga, S., Zhang, T.C., Surampalli, R.Y., Dubey, S., 2023b. Spatiotemporal-based automated inundation mapping of Ramsar wetlands using Google Earth Engine. Sci. Rep. 13, 17324. https://doi.org/10.1038/s41598-023-43910-4

21. Gupta, V., Rakkasagi, S., Rajpoot, S., Imanni, H.S. El, Singh, S., 2023. Spatiotemporal analysis of Imja Lake to estimate the downstream flood hazard using the SHIVEK approach. Acta Geophys. https://doi.org/10.1007/s11600-023-01124-2

22. Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013. Highresolution global maps of 21s century forest cover change. Science 342, 850–853.

23. Inman, V.L., Lyons, M.B., 2020. Automated Inundation Mapping Over Large Areas Using Landsat Data and Google Earth Engine. Remote Sens. 12, 1348. https://doi.org/10.3390/rs12081348

24. IUCN, 2016. A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0, first ed. IUCN, Gland, Switzerland. https://portals.iucn.org/library/sites/library/files/documents/2016-048.pdf

25. IUCN, 2021. Deforestation and forest degradation. IUCN. https://www.iucn.org/sites/default/files/2022-04/deforestation-forest_degradation_issues_brief_2021.pdf

26. Joppa, L., O'Connor, B., Visconti, P., Smith, C., Geldmann, J., Mann, M.H., Watson, J.E.M., Butchart, S.H.M., Virah-Sawmy, M., Halpern, B.S., Ahmed, S.E., Balmford, A., Sutherland, W.J., Harfoot, M., Hilton-Taylor, C., Foden, W., Di Minin, E., Pagad, S., Genovesi, P., Hutton, J., Burgess, N.D., 2016. Filling in biodiversity threat gaps. Science 352, 415–418.

27. Kotwal, P.C., Omprakash, M.D., Gairola, S., Dugaya, D., 2008. Ecological indicators: Imperative to sustainable forest management. Ecol. Indic. 8, 104–107.

28. Koulgi, P.S., Clinton, N., Karanth, K.K., 2019. Extensive vegetation browning and drying in forests of India's Tiger Reserves. Sci. Rep. 9, 1–12.

29. Kumar, D., Thakur, C.L., Bhardwaj, D.R., Sharma, N., Sharma, H., Sharma, P., 2021. Sustainable Forest Management a Global Review. Int. J. Curr. Microbiol. App. Sci 10, 2521–2528.

30. Leidner, A.K., Buchanan, G.M., 2018. Satellite Remote Sensing for Conservation Action: Case Studies from Aquatic and Terrestrial Ecosystems. Cambridge University Press, Cambridge, UK.

31. Mackey, B., DellaSala, D.A., Kormos, C., Lindenmayer, D., Kumpel, N., Zimmerman, B., Hugh, S., Young, V., Foley, S., Arsenis, K., 2015. Policy options for the world's primary forests in multilateral environmental agreements. Conserv. Lett. 8, 139–147.

32. Magurran, A.E., Baillie, S.R., Buckland, S.T., Dick, J.M., Elston, D.A., Scott, E.M., Smith, R.I., Somerfield, P.J., Watt, A.D., 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends Ecol. Evol. 25, 574–582.

33. Margules CR, Pressey RL. 2000. Systematic conservation planning. Nature 405: 243–253.

34. MoEF&CC, 2022. RAMSAR Wetland Sites. ENVIS Cent. Wildl. Prot. Areas, Minist. Environ. For. Gov. India. URL http://www.wiienvis.nic.in/Database/ramsar_wetland_sites_8224.aspx

35. Nandy, S., Saranya, M., Srinet, R., 2022. Spatio-temporal variability of water use efficiency and its drivers in major forest formations in India. Remote Sens. Environ. 269, 112791. https://doi.org/10.1016/j.rse.2021.112791

36. Olson, D.M., Dinerstein, E., Wikramana, E.D., Burgess, N.D., Powell, G.V.N., Underwood,E.C., D'amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F.,Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R., 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51,933–938.

37. Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., Hermans, K., Jobbagy, E., Kurz, W., Li, D., 2019. Land Degradation: IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse gas fluxes in Terrestrial Ecosystems, in: IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse Gas Fluxes in Terrestrial Ecosystems. Intergovernmental Panel on Climate Change (IPCC), pp. 345–436.

38. Park Williams, A., Allen, C.D., Macalady, A.K., Griffin, D., Woodhouse, C.A., Meko, D.M., Swetnam, T.W., Rauscher, S.A., Seager, R., Grissino-Mayer, H.D., Dean, J.S., Cook, E.R., Gangodagamage, C., Cai, M., McDowell, N.G., 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nat. Clim. Chang. 3, 292–297. https://doi.org/10.1038/nclimate1693

39. Pekel, J.F., Cottam, A., Gorelick, N., Belward, A.S., 2016. High resolution mapping of global surface water and its long-term changes. Nature 540, 418–422.

40. Rakkasagi, S., Goyal, M.K., Jha, S., 2024. Evaluating the future risk of coastal Ramsar wetlands in India to extreme rainfalls using fuzzy logic. J. Hydrol. 632, 130869. https://doi.org/10.1016/j.jhydrol.2024.130869

41. Rakkasagi, S., Poonia, V., Goyal, M.K., 2023. Flash drought as a new climate threat: drought indices, insights from a study in India and implications for future research. J. Water Clim. Chang. https://doi.org/10.2166/wcc.2023.347

42. Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D., Cooke, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. 94, 849–873. https://doi.org/10.1111/brv.12480

43. Ross, M.R. V., Topp, S.N., Appling, A.P., Yang, X., Kuhn, C., Butman, D., Simard, M., Pavelsky, T.M., 2019. AquaSat: A Data Set to Enable Remote Sensing of Water Quality for Inland Waters. Water Resour. Res. 55, 10012–10025. https://doi.org/10.1029/2019WR024883

44. Rose, R.A., Byler, D., Eastman, J.R., Fleishman, E., Geller, G., Goetz, S., Guild, L., Hamilton, H., Hansen, M., Headley, R., Hewson, J., 2015. Ten ways remote sensing can contribute to conservation. Conserv. Biol. 29, 350–359.

45. Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C.R., Neugarten, R., Butchart, S.H., Collen, B.E., Cox, N., Master, L.L., O'Connor, S.H., Wilkie, D., 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv. Biol. 22, 897–911.

46. Schulze, K., Knights, K., Coad, L., Geldman, J., Leveringto, F., Eassom, A., Marr, M., Butchart, S.H.M., Hockings, M., Burgess, N.D., 2017. An assessment of threats to terrestrial protected areas. Conserv. Lett. 11. https://doi.org/10.1111/conl.12435.

47. Schumann, G., Di Baldassarre, G., Bates, P.D., 2009. The Utility of Spaceborne Radar to Render Flood Inundation Maps Based on Multialgorithm Ensembles. IEEE Trans. Geosci. Remote Sens. 47, 2801–2807. https://doi.org/10.1109/TGRS.2009.2017937

48. Shirzaei, M., Bürgmann, R., 2018. Global climate change and local land subsidence exacerbate inundation risk to the San Francisco Bay Area. Sci. Adv. 4. https://doi.org/10.1126/sciadv.aap9234

49. Shumilova, O., Tockner, K., Thieme, M., Koska, A., Zarfl, C., 2018. Global Water Transfer Megaprojects: A Potential Solution for the Water-Food-Energy Nexus? Front. Environ. Sci. 6. https://doi.org/10.3389/fenvs.2018.00150

50. Small, C., Pozzi, F., Elvidge, C.D., 2005. Spatial analysis of global urban extent from DMSP-OLS night lights. Remote Sens. Environ. 96, 277–291.

51. Strayer, D.L., Dudgeon, D., 2010. Freshwater biodiversity conservation: recent progress and future challenges. J. North Am. Benthol. Soc. 29, 344–358. https://doi.org/10.1899/08-171.1

52. Stolton, S., Dudley, N., 2016. METT Handbook: A guide to using the Management Effectiveness Tracking Tool (METT). WWF-UK, Woking, UK.

53. Sun, Z., Behrens, P., Tukker, A., Bruckner, M., Scherer, L., 2022. Global Human Consumption Threatens Key Biodiversity Areas. Environ. Sci. Technol. 56, 9003–9014. https://doi.org/10.1021/acs.est.2c00506

54. Sustainable Development Goals, 2021. Goal 15 | Department of Economic and Social Affairs. United Nation. https://sdgs.un.org/goals/goal15

55. Tabor, K., Hewson, J., 2018. The evolution of remote sensing applications vital to effective biodiversity conservation and sustainable development. In: Leidner, A.K., Buchanan, G.M. (Eds.), Satellite Remote Sensing for Conservation Action. Cambridge University Press, Cambridge, pp. 274–300.

56. Thakur, S., Dhyani, R., Negi, V.S., Patley, M.K., Rawal, R.S., Bhatt, I.D., Yadava, A.K., 2021. Spatial forest vulnerability profile of major forest types in Indian Western Himalaya. For. Ecol. Manage. 497, 119527. https://doi.org/10.1016/j.foreco.2021.119527

57. Tracewski, Ł., Butchart, S.H.M., Donald, P.F., Evans, M., Fishpool, D.C., Buchanan, G., 2016. Patterns of twentyfirst century forest loss across a global network of important sites for biodiversity. Remote Sens. Ecol. Conserv. 2, 37–44.

58. The KBA Partnership, 2018. Guidelines on Business and KBAs: Managing Risk to Biodiversity. Gland: IUCN. 24pp, 2018.

59. Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., Steininger, M., 2003. Remote sensing for biodiversity science and conservation. Trends Ecol. Evol. 18,306–314.

60. UNICEF, 2021. Water and the global climate crisis: 10 things you should know | UNICEF. https://www.unicef.org/stories/water-and-climate-change-10-things-you-should-know

61. United Nations, 2021a. Ecosystem restoration for people, nature and climate Becoming #GenerationRestoration.

62. United Nations, 2021b. What is Ecosystem Restoration? | UN Decade on Restoration. United Nations. https://www.decadeonrestoration.org/what-ecosystem-restoration

63. Van Rees, C.B., Waylen, K.A., Schmidt-Kloiber, A., Thackeray, S.J., Kalinkat, G., Martens, K., Domisch, S., Lillebø, A.I., Hermoso, V., Grossart, H., Schinegger, R., Decleer, K., Adriaens, T., Denys, L., Jarić, I., Janse, J.H., Monaghan, M.T., De Wever, A., Geijzendorffer, I., Adamescu, M.C., Jähnig, S.C., 2021. Safeguarding freshwater life beyond 2020: Recommendations for the new global biodiversity framework from the European experience. Conserv. Lett. 14. https://doi.org/10.1111/conl.12771

64. Wolski, P., Murray-Hudson, M., Thito, K., Cassidy, L., 2017. Keeping it simple: Monitoring flood extent in large data-poor wetlands using MODIS SWIR data. Int. J. Appl. Earth Obs. Geoinf. 57, 224–234. https://doi.org/10.1016/j.jag.2017.01.005

65. WWF, 2021. Living Planet Index. WWF. https://livingplanet.panda.org/en-US/

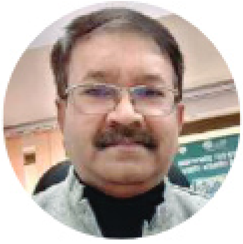
66. WWF, 2020a. Bending the curve of biodiversity loss living planet report 2020. WWF 1–83.

67. WWF, 2020b. Living Planet Report | Impact on Freshwater. WWF. https://www.wwf.org.uk/what-wedo/protecting-our-rivers-lakes-and-freshwater

68. Yin, G., Mariethoz, G., McCabe, M., 2016. Gap-Filling of Landsat 7 Imagery Using the Direct Sampling Method. Remote Sens. 9, 12. https://doi.org/10.3390/rs9010012

69. Zhang, Q., Seto, K.C., 2011. Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data. Remote Sens. Environ. 115, 2320–2329.

ABOUT THE AUTHORS



Prof. Manish K Goyal
Dean Infrastructure,
IIT Indore

Prof. Anil K Gupta
Head,ECDRM, NIDM
Project Director, CAP-RES

Ms. Pritha Acharya
Research Associate,
CAP-RES, NIDM

ABOUT CAP-RES PROJECT

"Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES)" aims at developing and implementing capacity building including a knowledge and training support system for wider use by related institutions and training centres across sectors and regions. The CAP-RES focuses on three specific regional contexts, i.e. Indian Himalaya Region (special reference to North East), Coastal region and Central-western region. Region specific climate-related hazard complex, including flood, drought, water scarcity, forest fire, cyclone/storm surge, coastal erosion, slope erosion/landslide, windstorms, heat wave, disease epidemics, industrial/chemical risks, etc.

CAP-RES aims at value-addition to programme sub-areas of the NKMCC by engaging with the institutions/research centres and network of experts, researchers and practitioners, across the following 5 key sub-sets of the project focus:

- Green Growth and Disaster Risk Reduction
- Resilient Agriculture Systems
- Public Health Resilience
- Climate Proofing Disaster Relief and Recovery
- Environmental Policy Instrument in Disaster Risk Reduction

SOME PUBLICATIONS UNDER CAP-RES

Design & Photo Credit: Ms Pritha Acharya, Research Associate, CAP-RES, NIDM

Resilient India - Disaster free India

National Institute of Disaster Management
Ministry of Home Affairs, Govt. of India
Website: https://www.nidm.gov.in

ISBN 978-81-986279-2-6