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A COMPREHENSIVE REVIEW OF TRENDS IN THE EVOLUTION OF FOREST

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Introduction

Forests hold immense significance for the well-being of our planet and all its inhabitants. Forests are crucial for the health of the planet, supporting life in various ways (Turner-Skoff and Cavender, 2019). Preserving and sustainably managing forests is essential for the well-being of current and future generations (Ali, 2023). The phrase "mother of all" is often used metaphorically to emphasize the importance, origin, or fundamental nature of something. When it comes to calling the forest the "mother of all," it might be highlighting the vital role forests play in supporting life on Earth. Forests are incredibly important ecosystems that provide a multitude of benefits (Bhat, 2023). They produce oxygen, store carbon, support biodiversity, and offer resources like wood and various plant-based products. Additionally, forests play a crucial role in regulating the climate, preventing soil erosion, and purifying water. (Brockerhoff, 2017).

In a poetic sense, you could consider the forest as a nurturing and sustaining force, akin to a mother, providing the essentials for life and fostering the well-being of the planet. It's a beautiful way to acknowledge the interconnectedness of nature and our dependence on these ecosystems for our survival and prosperity (Martin et al., 2016). Forests are integral to numerous applied sectors, each playing a crucial role in sustaining life and fostering ecological balance (Brockerhoff, 2017). In the water sector, forests act as natural watersheds, regulating and purifying water. They help maintain consistent water flow, prevent soil erosion, and serve as a source for rivers and streams. Forests are vital for wildlife, providing habitats for countless species. The diverse ecosystems within forests support a wide range of flora and fauna, contributing to global biodiversity (FAO and UNEP, 2020). In agriculture, forests influence climate patterns, impacting rainfall and temperature, which in turn affect crop yields. The timber industry relies on forests for wood and other products, while non-timber forest resources contribute to various sectors, including medicine, food, and traditional practices. Additionally, forests play a pivotal role in carbon sequestration, mitigating climate change effects. Indigenous communities often have cultural ties to forests, relying on them for livelihoods and preserving traditional knowledge (Ogar, et al., 2020). In essence, forests are intertwined with water management, wildlife conservation, agriculture, industry, and cultural heritage, highlighting their multidimensional significance for a sustainable and balanced planet.

Evolutionary trajectory of earth's forests from ancient to beyond

About 420 million years ago, during the Silurian Period, ancient plants and arthropods began to occupy the land (Johnson, 2023). Over the millions of years that followed, these land colonizers developed and adapted to their new habitat. The first forests were dominated by giant horsetails, club mosses, and ferns that stood up to 40 feet tall. Terrestrial vegetation of the Silurian and Early Devonian was typically short and restricted to a narrow band along the water's edge. But by the early Middle Devonian (Eifelian), taller, arborescent forms evolved independently within the cormose lycopsids, cladoxylopsids and progymnosperms. The first known forests on Earth arose in the Late Devonian (approximately 419.2 to 358.9 million years ago), with the evolution of Archaeopteris which was a plant that was both tree-like and fern-like, growing to 10 meters (33 ft) in height. It quickly spread throughout the world, from the equator to subpolar latitudes;(The first forest, 2016) and it formed the first forest by being the first species known to cast shade due to its fronds and by forming soil from its roots. Archaeopteris was deciduous, dropping its fronds onto the forest floor, the shade, soil, and forest duff from the dropped fronds creating the first forest. (The first forest, 2016) The shed organic matter altered the freshwater environment, slowing its flow and providing food. This promoted freshwater fish. (The first forest, 2016)

Life on Earth continued to evolve, and in the late Paleozoic era (538.8 to 251.9 million years ago), gymnosperms appeared (Feng, 2017). By the Triassic Period (245-208 million year ago), gymnosperms dominated the Earth's forests. In the Cretaceous Period (144-65 million year ago), the first flowering plants (angiosperms) appeared. They evolved together with insects, birds, and mammals and radiated rapidly, dominating the landscape by the end of the Period. The landscape changed again during the Pleistocene Ice Ages — the surface of the planet that had been dominated by tropical forests for millions of years changed, and temperate forests spread in the Northern Hemisphere (Ellis and Palmer, 2016). In Paleogene period (66 to 23 million years ago) Ferns were initially abundant following the K-T extinction, but flowering plants and conifers soon took over as they returned to abundance. Deciduous trees dominated swamp forests in North America from middle latitudes to the Arctic Ocean. The onset of the Neogene Period (23 to 2.6 million years ago) marked a pivotal shift as expansive forests yielded to the emergence of widespread grasslands and savannahs. This transformation created novel ecological opportunities and sustenance, propelling the evolutionary trajectory of mammals and birds. The grasslands and savannahs presented new niches and abundant food sources, influencing the development of diverse species. This shift in ecosystems during the Neogene spurred significant adaptations among fauna, fostering the evolution of mammals and birds to thrive in the evolving landscapes. The interplay between changing environments and emerging ecological niches shaped the course of life during this transformative period. - The Neogene Period started with the replacement of vast areas of forest by grasslands and savannahs. New food sources and niches on the grasslands and savannahs fostered further evolution of mammals and birds. During the Quaternary Period (2.6 to 0 million years ago) the forests with which we are familiar seldom maintained a constant species composition for more than 2000 or 3000 years at a time (Davis, 1981). During the Quaternary Period (2.6 million years ago to the present), Earth witnessed significant changes in its forests (Elias, 2013). Ice ages and interglacial periods influenced the distribution and composition of forests globally. Glacial advances led to the contraction of forests, while warmer interglacial periods saw their expansion (Shao, 2022). These climatic shifts shaped the composition of flora and fauna within forests. Additionally, human activities, including the emergence of Homo sapiens, began to impact forests through practices like fire management and eventually deforestation. The Quaternary Period marks a dynamic era for forests, responding to both natural climatic fluctuations and human interventions.

Gilboa forest in eastern New York

One of the more famous Middle Devonian sites is the Gilboa "Forest" in eastern New York State. The arrangement of mudstones, coarse sandstone and tree stumps suggest that this site was a natural levee subject to successive destructive floods interspersed with stable periods in which soils accumulated and the vegetation recovered (Sona, 2023). Plants at Gilboa included ground cover, shrubs and medium-sized trees. One aborescent lycopsid, *Lepidosigillaria,* may have reached 5 m in height. *Eospermatopteris*, a tree of uncertain affinity, may have been 9 m tall. A common cladoxylopsid, *Pseudosporochnus*, was about 3 m tall. The vegetation at Gilboa may have reached considerable heights, but it didn't exhibit some important characteristics of modern forests. For one, the vegetation was apparently still restricted to a narrow band along the water's edge. This narrow band, combined with the absence of webbed leaves, indicate that there was relatively little shade and litter production. In addition, the Gilboa vegetation lacked deeply penetrating root systems that would have stabilized stream banks and enhanced pedogenesis (Lukasz, 2020). Nonetheless, Middle Devonian vegetation such as the Gilboa "Forest" probably moderated the physical environment of freshwater ecosystems and enriched them with organic matter.

The Arrival of *Archaeopteris*

Vegetation resembling modern forests first occurred with the appearance of *Archaeopteris* in the Late Devonian (Stein, et al., 2020). This remarkable genus has been recorded from virtually all known Devonian land masses and ranged from tropical to sub-polar paleolatitudes. These large trees (20 m or more in height) possessed webbed leaves that produced relatively dense shade. In addition, they possessed a deeper and more extensive root system that greatly accelerated pedogenesis and probably allowed them to colonize drier parts of floodplains and coastal lowlands. The advent of shade and the greater spread of trees created an entirely new terrestrial habitat, the forest biome. This new habitat was characterized by leaf canopy that moderated temperature and humidity regimes and shielded microbes and invertebrates from ultraviolet light. The seasonal duration of these moderated conditions, however, is unclear. We know *Archaeopteris* was deciduous, but not whether its leaves were shed once a year or throughout the year (Berthaud, et al., 1999). If they were shed throughout the year then the forest floor would have been continuously moderated. But if they were shed seasonally, then the forest floor would have been exposed for part of the year. In either case, *Archaeopteris* forests produced what must have been an unprecedented amount of organic matter for microbial decomposers and invertebrate detritivores. However, evidence for any increase in the diversity or abundance of terrestrial detritivores is lacking, in large part because Late Devonian terrestrial invertebrates are poorly known. While the impact of terrestrial plant production on invertebrate detritivores remains unclear, other consequences are evident in Late Devonian sediments. One of these is the first appearance of coals. No coal deposits have been found at Red Hill, possibly because of its seasonal climate, but similar age coals have been found elsewhere in the paleocontinent Euramerica (North America and part of Western Europe). Another consequence is wildfire. Red Hill is one of the two earliest localities for which we have direct evidence of wildfires (Liu, et al., 2021). In this case, the primary "victim" appeared to have been *Rhacophyton*, an ancient "fern" that was co-dominant with *Archaeopteris* at Red Hill. These fires appeared to have been low intensity blazes that burned low-lying material (i.e., shrubs), but spared the trees. The first forests probably also had profound influences on aquatic systems. They contributed to the moderation of flow regimes and stabilization of stream habitats (Shah, et al., 2022). They also probably greatly enriched streams with substantial increases of organic matter, primarily in the form of detritus. Some of this would result from plant material falling directly into the water, but most of the organic matter created by the forests would probably enter via flooding (Sao, et al., 2023). The rise in forests is also associated with global changes of marine systems (Perry, 2010). The widespread deposition of black marine shales during the late Middle Devonian (Givetian) and Late Devonian has been attributed to a dramatic increase in the influx of terrestrial organic matter (Dunkel, et al. 2022). In turn, these black shales are associated with the Late Devonian Mass Extinction.

The *Archaeopteris* forests of the Late Devonian probably transformed terrestrial, freshwater and marine ecosystems (The first forest, 2016). But another striking characteristic of these ancient forests is their apparent lack of diversity. Arborescent forms are overwhelmingly dominated by a single genus, *Archaeopteris*. Several leaf species of this climatically and geographically widespread genus are known, but it’s now clear whether they represent biological species or merely leaf-taxa of fewer true species. Arborescent forms are otherwise represented by a group of cormose lycopsids, which were apparently restricted to wetter sites (Stein, et al., 2020).

Rhacophyton is the other dominant plant in most *Archaeopteris* forests as well as several Late Devonian wetlands (Capel, et al., 2022). It’s not known outside of North America and Western Europe, but this may be a result of our ignorance of Gondwana macrofloral assemblages rather than a geographic restriction of this apparently prolific plant. Seed plants make their first appearance in the Famennian (late Late Devonian), but they appear to have been pioneer species that succeeded only in disturbed sites.

Another striking characteristic of the Late Devonian forests is the apparent disappearance of the forest biome following the extinction of *Archaeopteris* near the end of the Devonian. An increasingly diverse assemblage of seed plants, ancient "ferns" (zygopterids), sphenopsids (relatives of horsetails) and arborescent lycopsids occur in the earliest Carboniferous. Arborescent lycopsids (e.g., *Cyclostigma* and *Lepidodendropsis*) dominated many wetland sites, but floodplain and coastal lowland assemblages were characterized primarily by low-growing seed plants and zygopterids. Trees apparently didn’t become dominant again until much later in the Carboniferous.

Evolution and status of present forest

The ongoing evolution of forests represents a complex interplay between natural processes and human influences, and this delicate balance has significant implications for the state of the global environment. Human activities, driven by factors such as population growth and economic development, have become powerful agents of change alongside natural forces. Climate fluctuations, a key driver of forest dynamics, contribute to alterations in temperature and precipitation patterns, impacting the distribution and health of various forest types (Sarah, et al., 2020).

Tropical rainforests, characterized by their unparalleled biodiversity and luxuriant vegetation, face considerable threats stemming from human activities (Morris, 2010). Deforestation, driven by the expansion of agriculture and logging, poses a severe risk to these ecosystems (Ortiz, et al., 2021). The loss of large areas of rainforest not only disrupts intricate ecological balances but also contributes to global carbon emissions (Ometto, et al., 2022). Efforts to address these challenges include conservation initiatives, sustainable land-use practices, and reforestation projects aimed at mitigating the impact of deforestation (Dieng, et al., 2023). Similarly, temperate forests, which experience distinct seasonal changes, find themselves in a state of flux due to climate change. As temperatures rise and weather patterns become less predictable, these forests undergo shifts in species composition and altered migration patterns of animals. These changes have cascading effects on ecosystem dynamics, affecting everything from nutrient cycling to the availability of resources for various species. Boreal forests in northern latitudes, traditionally adapted to cold climates, are witnessing transformations due to global warming. Warming temperatures lead to shifts in vegetation zones, impacting the types of trees that can thrive in these environments. Moreover, the increased frequency and intensity of wildfires in these regions further contribute to the evolution of boreal ecosystems, with potential consequences for carbon storage and the release of greenhouse gases. Coastal ecosystems, particularly mangrove forests, face unique challenges as urbanization encroaches upon these critical habitats (Akram, 2023). Rising sea levels, a consequence of climate change, pose a direct threat to the existence of mangroves, which play a vital role in protecting coastlines, providing nurseries for marine life, and supporting diverse ecosystems. Conservation efforts aimed at preserving mangroves involve a combination of habitat restoration, sustainable coastal development practices, and measures to mitigate the impacts of climate change (Ellison, et al., 2020). The diversity of forest types globally underscores their multifaceted roles in maintaining ecological balance. Deciduous forests, with trees that shed their leaves seasonally, contribute to nutrient cycling and provide habitat for a wide range of wildlife. Coniferous forests, dominated by evergreen trees with needle-like leaves, play a crucial role in carbon sequestration and are often found in colder climates. Montane forests, situated in mountainous regions, showcase adaptations to harsh environmental conditions and are crucial for regulating water flow in watersheds.

Forest report according to FAO and CPF. 2022

Global Forest Resources Assessment led by the Food and Agriculture Organization of the United Nations (FAO) found that forests covered 4.06 billion hectares (10.0 billion acres; 40.6 million square kilometres; 15.7 million square miles), or approximately 31 percent of the world's land area in 2020 (The State of the World's Forests 2020).

“Proportion of Total Land Area Covered by Forests”. Globally, the percentage of land covered by forests decreased from 31.9 percent in 2000 to 31.2 percent in 2020. In just 20 years, this amounts to a net loss of about 100 million hectares of global forest cover.

“**Rate of Annual Change in Forest Area”.** The yearly forest-area change rate decreased somewhat between 2000 and 2020, going from -0.13 percent to -0.12 percent. Globally, the yearly loss of forests has decreased as a result, from -5.2 million ha in 2000–2010 to -4.7 million hectares in 2010–2020.

“**Percentage of Forest Area Encompassed by Legally Designated Protected Areas”** Around 18% of the world's forest land (726 million hectares) is found in officially recognised protected areas, including game reserves, national parks, and conservation areas. Globally, the amount of forests in protected areas grew by 191 million hectares between 1990 and 2020; however, from 2010 to 2020, the annual growth rate of this area decreased.

“Primary Forest Area Dynamics”. 1.11 billion hectares, or almost one-third (34%) of the total forest area of the 146 countries and territories that reported to the FAO for its 2020 Global Forest Resources Assessment (FRA), were anticipated to be primary forests worldwide in 2020. Between 1990 and 2020, the primary forest area worldwide shrank by 81.3 million hectares, with an estimated 1.27 million hectares lost annually between 2010 and 2020. Western and Central Africa experienced the greatest rate of loss between 2010 and 2020 (from 97 million hectares to 88 million ha), followed by South America (from 301 million ha to 298 million ha).

“Percentage of Disturbed Forest Area”. The total forest area affected by disturbances in 2015 (the most recent year for which data are available globally) was 30.2 million hectares in 62 countries and territories (1.4 percent of those countries' total forest area) for insects; 6.60 million hectares in 51 countries and territories (0.4 percent of those countries' total forest area) for diseases; 3.83 million hectares in 48 countries and territories (0.3 percent of those countries' total forest area) for severe weather events; and 98 million hectares in 118 countries and territories (3 percent of those countries' total forest area) for forest fires.

"Extent of Degraded Forest Area". FRA 2020 received reports from 58 countries, or 38% of the world's total forest area, indicating that they kept an eye on the area of damaged forest. The inability to establish a globally accepted definition of forest degradation prevents data on the area of degraded forest from being combined on a regional or global scale.

"Aboveground Biomass within Forests". With the highest value found in Latin America and the Caribbean, the aboveground biomass in the world's forests was expected to have increased to approximately 118 tonnes per ha in 2020 from roughly 117 tonnes per ha in 2010.

"Forest Area Dedicated to Protective Functions through Managed Objectives". In 2020, the global area allocated primarily for safeguarding soils and water was approximately 398 million hectares, covering 141 countries and territories that reported to FRA 2020, representing 82 percent of the total forest area. This marked a notable increase of 119 million hectares compared to 1990, encompassing 131 countries and territories with time-series data on this aspect.

Europe holds the largest portion of forested land designated for soil and water protection, accounting for 171 million hectares (18 percent of the region's total forest area). Asia follows closely with 132 million hectares (22 percent of the forest area), the highest proportion among all regions. Simultaneously, the area specifically designated for biodiversity conservation in 2020 was estimated at 424 million hectares, covering 165 countries and representing 91 percent of the world's forest area. Africa boasts the largest area dedicated to this purpose, amounting to 107 million hectares, while Europe has the lowest proportion at 4 percent.

"Employment in the Forest Sector". Between 2017 and 2019, the global workforce in the forest sector was estimated at approximately 33 million people, with a significant concentration of 80 percent in Asia and Africa. Over the course of the decade leading up to 2019, there was an observable decline in employment within the forest sector, a trend largely driven by a decrease in the number of individuals employed in subsectors related to wood-based manufacturing.

"Number of Individuals in Extreme Poverty Dependent on Forests". In 2019, an estimated 3.27 billion people globally lived within 1 km of a forest, constituting 75 percent of the total rural population. Additionally, around 4.17 billion people, or 95 percent of the total rural population, were situated within 5 km of a forest. Efforts are currently underway to develop methodologies that integrate poverty data with information on forest proximity, marking the next phase in reporting on this indicator.

"Percentage of Forest Area Covered by Long-Term Management Plans". As of 2020, the global area of forest covered by management plans has expanded by 233 million hectares since 2000, reaching a total of 2.05 billion hectares. This growth is evident across all regions. Notably, a significant proportion of forests in Europe, specifically 96 percent, have established management plans. In contrast, management plans cover less than 25 percent of forests in Africa and less than 20 percent of forests in South America. This discrepancy highlights regional variations in the adoption of forest management strategies, with Europe demonstrating a higher prevalence of such plans compared to Africa and South America.

"Forest Area Certified under Independent Verification for Forest Management". In 2021, the combined reported net certified forest area by the two primary certification bodies amounted to 463 million hectares. Notably, nearly 60 percent of this certified forest area is concentrated in three countries: Canada, accounting for 165 million hectares, the Russian Federation with 72.3 million hectares, and the United States of America covering 39.8 million hectares. These figures underscore the significant presence and contribution of these three countries to the certified forest landscape on a global scale.

“Traceability Systems for Wood Products: A Existence Analysis”. In 2020, 94 countries and territories reported the implementation of national-level traceability systems for wood products to FRA 2020, while an additional three reported the existence of such systems at the subnational level. Collectively, these 97 countries and territories represent 84 percent of the total global forest area. This data emphasizes a widespread effort to establish traceability mechanisms for wood products, signifying a significant commitment on both national and subnational levels across the reported regions.

A Glimpse into the Future of our Forests

The current scenario of forests worldwide is marked by a complex interplay of various factors that have led to significant changes from ancient times (Abbass, et al., 2022). While forests have always undergone natural evolution, the present era is witnessing unprecedented challenges driven by human activities, climate change, and global socio-economic dynamics. In the near future, the status of forests is likely to be characterized by a mix of both positive and negative trends (Forzieri, et al., 2022). One major driver of change is deforestation, primarily fueled by expanding agriculture, urbanization, and logging activities (Dieng, et al., 2023). The conversion of forests into agricultural land and urban areas has led to the loss of biodiversity, disruption of ecosystems, and alteration of traditional forest types. Climate change further compounds these issues, causing shifts in temperature and precipitation patterns that affect the distribution and composition of forests globally. Another significant factor is the increasing recognition of the importance of forests for mitigating climate change. There is a growing emphasis on afforestation and reforestation efforts to sequester carbon dioxide from the atmosphere (Waring, et al., 2020). However, the types of forests being created may differ from the ancient ones, as they are often designed to maximize carbon capture rather than replicate the intricate ecosystems of the past. Furthermore, invasive species and diseases pose additional threats to forest health. Globalization has facilitated the movement of species beyond their natural habitats, leading to the displacement of native flora and fauna. The resulting changes in species composition can impact the structure and function of forests, potentially giving rise to novel ecosystems. In the future, technological advancements, including the use of remote sensing and artificial intelligence, may play a crucial role in monitoring and managing forests. Conservation efforts are likely to focus on maintaining and restoring biodiversity, preserving crucial ecosystem services, and promoting sustainable land-use practices. However, the success of these initiatives will depend on addressing the root causes of deforestation, such as unsustainable resource exploitation and the socio-economic factors that drive it.

Conclusion

The journey of Earth's forests, from ancient times to the present, reveals a rich tapestry of evolution, interconnectedness, and profound significance for our planet's well-being. The metaphorical expression of forests as the "mother of all" encapsulates their vital role in sustaining life on Earth. As the cradle of biodiversity, regulators of climate, and providers of essential resources, forests have been integral to the evolutionary trajectory of our planet. The historical evolution of forests, marked by the emergence of complex ecosystems and the pivotal role of species like Archaeopteris, highlights the transformative impact these ancient giants had on terrestrial, freshwater, and marine environments. However, the Late Devonian extinction of Archaeopteris marked a significant shift, paving the way for the rise of diverse seed plants in the Carboniferous. This cyclical pattern of forest evolution and transformation continued through geological epochs, responding to climatic fluctuations and human interventions during the Quaternary Period.

In the contemporary context, the status of global forests faces a complex interplay of challenges and opportunities. Human activities, climate change, and socio-economic dynamics are shaping the future of forests. While deforestation poses a significant threat, there is a growing recognition of the crucial role forests play in mitigating climate change. Afforestation and reforestation efforts, coupled with advancements in technology, offer avenues for sustainable forest management and conservation.

The report by the Food and Agriculture Organization of the United Nations (FAO) and the Collaborative Partnership on Forests (CPF) provides a snapshot of the present state of global forests. The data underscores the need for concerted efforts to address issues such as deforestation, loss of biodiversity, and the impact of disturbances on forest ecosystems. Sustainable forest management, conservation initiatives, and the recognition of the socioeconomic ties to forests are crucial elements in securing the well-being of these vital ecosystems.

Looking ahead, the future of our forests hinges on our ability to address the root causes of environmental degradation, promote sustainable practices, and foster a global commitment to forest conservation.

As we navigate the complexities of the Anthropocene, the preservation of forests is not only an ecological imperative but a moral responsibility to safeguard the intricate balance of life on Earth. In the spirit of acknowledging the "mother of all," let us strive to be stewards of our forests, nurturing and sustaining them for the benefit of current and future generations.

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Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

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Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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THE SOCIO-ECOLOGICAL SIGNIFICANCE OF NON- TIMBER FOREST PRODUCE IN NURTURING TRIBAL LIVELIHOODS: A COMPREHENSIVE REVIEW

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Abstract:

Non-timber forest products (NTFP) are essential for maintaining tribal populations means of subsistence all over the world. The comprehensive study examines the socio-ecological importance of NTFP in tribal lifestyles, taking into account its social, economic, and ecological aspects. Tribal groups' use of NTFP is firmly based in their traditional knowledge and cultural practises, enabling the survival of indigenous knowledge systems and fostering a sense of communal identity. The use and sharing of NTFP strengthen tribal communities social bonds by establishing networks for communication and cooperation.

Economically, NTFP contributes significantly to tribal livelihoods, serving as a source of income and economic resilience. Commercializing NTFP offers opportunities for income generation, entrepreneurship, and poverty alleviation. NTFP-based enterprises promote sustainable development by reducing dependence on unsustainable practices and enhancing local economic autonomy. From an ecological perspective, NTFP harvesting practices align with sustainable resource management. Tribal communities possess intricate ecological knowledge, ensuring the sustainable extraction of NTFP while maintaining forest ecosystem health. Their traditional ecological knowledge contributes to biodiversity conservation and ecosystem protection. Challenges such as deforestation, land encroachment, climate change, and inadequate policy support threaten the sustainable use of NTFP. Intellectual property rights, market access, and fair trade issues hinder equitable benefit-sharing from NTFP trade.

Recognizing the socio-ecological significance of NTFP is crucial. Policies should empower tribal communities, preserve traditional knowledge, promote sustainable harvesting practices, ensure equitable benefit-sharing, and create favourable market conditions for NTFP-based enterprises. Understanding the importance of NTFP in tribal livelihoods is essential for sustainable development, cultural resilience, and conservation efforts. Collaboration between indigenous communities, researchers, policymakers, and stakeholders is vital to address challenges and leverage NTFP's potential for inclusive and sustainable development.

Keywords: Non-timber forest products, Tribal, Livelihood.

1. Introduction:

Forests serve as intricate ecosystems, offering a diverse range of essential goods and services for both human sustenance and ecological equilibrium. Non-Timber Forest Products (NTFPs) are specifically defined as biological resources, excluding timber, and encompassing items gathered by humans in natural habitats (Shackleton et al., 2011). In the midst of this complex network of life, Non-Timber Forest Produce (NTFP) sometimes goes unnoticed and fails to receive the appreciation it deserves. These NTFPs, which do not include timber, cover a wide range of resources obtained from forests, such as fruits, nuts, medicinal plants, resins, fibres and a wide range of other natural products. Even though they may not be as well known on the global market as lumber, NTFPs are crucial to sustaining the livelihoods of indigenous and tribal populations all over the world. A matter of utmost significance within the realms of environmental conservation, social justice, and sustainable development revolves around the socio-ecological importance of Non-Timber Forest Products (NTFPs) in supporting the livelihoods of tribal communities. This in-depth analysis highlights their critical ecological significance in forest ecosystems while shedding light on the complex relationship between NTFP and the welfare of tribal populations.

Non-Timber Forest Products (NTFPs) often encompass plant species of ecological importance, and their sustainable harvesting practices can play a vital role in preserving biodiversity. It is imperative to grasp the ecological interactions between NTFPs and forest ecosystems for effective conservation initiatives. For numerous indigenous and tribal communities, NTFPs are not mere commodities but hold profound cultural and spiritual significance. Preserving these traditions becomes pivotal in safeguarding cultural diversity and heritage. NTFPs serve as a means of income and subsistence for millions of individuals, especially among marginalized indigenous and tribal populations. Recognizing the economic potential of NTFPs can lead to poverty alleviation and sustainable development in these communities. The sustainable harvesting of NTFPs can promote responsible forest management practices, thereby reducing deforestation and habitat degradation, ultimately contributing to the overall health and resilience of forests. Forests, including those serving as sources of NTFPs, play a substantial role in carbon sequestration and climate change mitigation. Understanding the impact of NTFP harvesting on forest carbon stocks is imperative for effective climate action.

Many countries have acknowledged the rights of indigenous and tribal communities to access and manage NTFPs. An examination of the policy and legal frameworks governing NTFPs can shed light on the effectiveness of these measures in safeguarding the interests of tribal communities. Non-Timber Forest Produce (NTFP) encompasses a diverse range of forest-derived resources, excluding timber, and includes items such as edible fruits, medicinal plants, resins, fibers, and more. NTFPs play a pivotal role in tribal livelihoods worldwide. They provide subsistence, income, and cultural significance to indigenous and tribal communities. These resources serve as primary sources of food, medicine, and materials for traditional practices, while also offering economic opportunities. Moreover, sustainable NTFP harvesting practices contribute to forest conservation and help reduce the reliance on timber extraction, making them a crucial element in both tribal well-being and environmental sustainability.

Non-Timber Forest Produce (NTFP) constitutes a rich tapestry of natural resources harvested from forests, excluding timber. This intricate mosaic includes delectable fruits, potent medicinal plants, aromatic resins, versatile fibres, and other treasures. NTFPs are the lifeblood of tribal livelihoods, serving as the sustenance of tradition and the catalyst for economic opportunity. They nourish communities, embody cultural heritage, and infuse spiritual practices. These forest gems, often overshadowed by timber, represent the silent heroes of sustainability, driving both social well-being and ecological harmony. By cherishing and cultivating NTFPs, we honour the resilience of indigenous and tribal cultures while safeguarding the forests that cradle our planet's biodiversity.

Methodology:

For this comprehensive review, a multidisciplinary research approach was applied. The review encompassed a wide range of sources, including peer-reviewed research articles, academic journals, conference papers, books, reports, and grey literature. Findings were synthesized to provide a comprehensive overview, including key trends, challenges, and knowledge gaps.

Comparative analysis considered regional variations and the impact of different NTFPs on tribal livelihoods through case studies. Policy and legal frameworks were assessed to gauge their effectiveness in promoting sustainable NTFP practices. This approach facilitated a holistic exploration of the socio-ecological significance of NTFPs in tribal livelihoods, synthesizing data from diverse sources to provide a comprehensive understanding of the topic.

The literature selection and review process for this comprehensive study adhered to a systematic and rigorous methodology. It commenced with the identification of pertinent databases and the careful selection of keywords. The initial screening process began with the evaluation of titles and abstracts to determine relevance.

Subsequently, a thorough examination of the full texts was carried out to confirm that the chosen sources were in line with the research objectives. To enhance comprehensiveness, a snowballing approach and citation tracking were employed, facilitating the inclusion of additional relevant materials.

Quality assessment criteria were applied to evaluate the credibility and rigor of the chosen literature. Extracted data were synthesized and reviewed to identify recurring themes, contributing to a holistic understanding of the topic.

Non-Timber Forest Produce (NTFP):

Non-Timber Forest Produce (NTFP) refers to a diverse category of natural resources harvested from forests, excluding timber and other woody products. NTFPs encompass a wide range of items crucial to the livelihoods of forest-dependent communities, particularly indigenous and local populations (Belcher et *al.*, 2005).

1. **Edible NTFPs:** Edible NTFPs include forest products harvested for consumption such as Mushroom, wild fruits, nuts, etc. medicinal and dietary supplements, floral products and Honey, etc (Adepoju et *al.*, 2007).

2. **Medicinal Plants:** Medicinal plants encompass plant components such as roots, stems, leaves, tubers, fruits, seeds, and sap, all of which possess medicinal properties and serve as raw materials in the production of contemporary pharmaceuticals (Rusmiati et al., 2021). These medicinal attributes find application in both traditional and modern medicinal practices. Some illustrative examples include neem (Azadirachta indica) and aloe vera (Aloe barbadensis miller), among others.

3. **Resins and Gums:** Certain tree species produce resins or gums, like Gums from Dhawda (*Anogeisus latifolia*), Babool (*Acacia indica*) and Khair (*Acacia catechu*), etc. which are used in incense and traditional healing practices.

4. **Fibers and Textiles:** NTFPs in this category provide materials for crafting traditional items such as baskets, mats, and textiles. Examples include Bamboo, Rattan (Calamus spp.)etc.

5. **Aromatic and Spices:** Plants like vanilla (*Vanilla planifolia*), cardamom (*Elettaria cardamomum*), and cinnamon (Cinnamomum spp.) are considered NTFPs due to their aromatic qualities and uses in perfumes, spices, and incense (Belcher and Schreckenberg, 2007).

6. **Dyes and Colorants:** NTFPs, like Henna (*Lawsonia inermis*), and various plant leaves and barks, are used to extract natural dyes and colorants for textiles and art.

These NTFPs hold ecological, economic, and cultural significance, making their sustainable management vital for the well-being of both forest-dependent communities and forest ecosystems (Shanley et *al.*, 2015; Belcher et *al.*, 2004).

The Ecological Importance of NTFP and Sustainable Harvesting Practices

Non-Timber Forest Produce (NTFP) plays a crucial role in maintaining the ecological balance and overall health of forest ecosystems. Sustainable harvesting practices are essential to ensure the continued availability of NTFPs and the preservation of biodiversity.

1. **Biodiversity Conservation:** Many NTFPs are derived from various plant and animal species, contributing to the overall biodiversity of forests. Sustainable harvesting practices help maintain these species and their habitats (Shanley et *al.*, 2015).
2. **Ecosystem Services:** NTFPs provide a range of ecosystem services, including pollination, nutrient cycling, and habitat provisioning. Sustainable management ensures the continued provision of these services.
3. **Forest Regeneration:** Sustainable harvesting practices often involve selective harvesting or non-destructive methods. This allows harvested plants and trees to regenerate, contributing to forest health and resilience (Belcher et *al.*, 2005).
4. **Reduced Pressure on Timber:** By providing an alternative income source, NTFPs can reduce the pressure on timber resources. This can help prevent deforestation and habitat destruction.
5. **Cultural Significance:** NTFPs are often integral to the cultural practices of indigenous and local communities. Their conservation supports cultural diversity and traditional knowledge (Belcher et *al.*, 2005).

6. **Carbon Sequestration:** Forests, including those where NTFPs are sourced, are vital for carbon sequestration and climate change mitigation. Sustainable management contributes to maintaining and enhancing forests' carbon stocks (Sunderlin et *al.*, 2005).
7. **Pest Control:**
   - Some NTFPs have natural pest-repellent properties. Sustainable use of these resources can reduce the need for chemical pesticides, benefitting both ecosystems and human health (Belcher and Schreckenberg, 2007).

Sustainable Harvesting Practices:

- Sustainable NTFP harvesting practices involve strategies such as:
- **Selective Harvesting:** Targeting specific individuals or species while leaving others untouched.
- **Regulation and Monitoring:** Implementing regulations on harvest levels, seasonal restrictions, and quotas.
- **Community-Based Management:** Involving local communities in decision-making and management.
- **Conservation Zones:** Designating areas within forests where NTFP harvesting is prohibited.
- **Rotation Systems:** Allowing for natural regeneration and recovery periods.
- **Non-Destructive Techniques:** Using methods that minimize damage to plants and trees during harvesting.

By adopting these practices, NTFP harvesting can be sustainable, ensuring that these resources continue to benefit both ecosystems and the livelihoods of forest-dependent communities (Shanley et *al.*, 2015).

4. Tribal Livelihoods:

Socio-Economic and Cultural Characteristics of Tribal Communities

Tribal communities, often referred to as indigenous or aboriginal groups, exhibit distinct socio-economic and cultural characteristics shaped by their unique histories, environments, and traditional lifestyles. These characteristics are essential for understanding their way of life and the challenges they face. Here are key aspects:

1. **Subsistence Agriculture:** Many tribal communities practice subsistence agriculture, relying on traditional farming techniques to grow staple crops like millet, maize, and rice (Das et *al.*, 2009). They often have an intimate knowledge of local ecosystems and practice sustainable agriculture.
2. **Forest Dependence:** Forests play a central role in the lives of many tribal communities. They rely on forests for NTFPs, hunting, and gathering (Agrawal and Chhatre, 2007). This dependence often extends to cultural and spiritual connections with the land (Banerjee et *al.*, 2019).
3. **Livestock Rearing:** Animal husbandry, particularly the rearing of cattle, goats, and poultry, is common among tribal communities, providing additional sources of food and income (Das et *al.*, 2009).
4. **Barter and Local Markets:** Traditional barter systems and local markets are prevalent in many tribal societies. These systems facilitate the exchange of goods and sustain local economies (Haque, 2013).
5. **Self-Governance:** Tribal communities often have their governance systems based on customary laws and traditions. These systems emphasize communal decision-making and are essential for their self-determination.
6. **Language and Culture:** Unique languages, art, music, and dances are integral to tribal identities. These cultural

elements reflect their rich heritage and often face the threat of erosion (Cultural Survival, 2019).

7. **Social Cohesion:** Tribal cultures frequently exhibit strong social ties, a feeling of communal responsibility, and collectivism. This social connection promotes the resiliency of the community.
8. **Traditional Knowledge:** Indigenous knowledge systems encompass traditional ecological knowledge (TEK) and sustainable resource management practices, which are crucial for their survival and the conservation of biodiversity (Berkes et. *al,* 2000).
9. **Vulnerability and Marginalization:** Numerous tribal communities struggle with socioeconomic marginalization, poor access to healthcare, education, and land rights despite their distinctive cultural qualities, leaving them open to outside pressures.

To advance inclusive development, safeguard tribal rights, and encourage sustainable practices that honor their customs and contributions to ecological and cultural variety, it is crucial to comprehend these socioeconomic and cultural traits(Das, 2009; Gadgil and Guha, 1994).

The Historical Relationship between Tribal Communities and Forests

The historical relationship between tribal communities and forests is deeply intertwined, marked by a harmonious coexistence that has endured for centuries. This relationship is characterized by sustainable resource use, spiritual connections to the land, and the preservation of traditional knowledge. However, it has also been marred by colonialism, land encroachments, and challenges to their way of life. Here, we explore this historical connection with citations:

1. **Sustainable Resource Use:** Tribal communities have historically practiced sustainable resource management in forests. Their intimate knowledge of local ecosystems has enabled them to harvest Non-Timber Forest Produce (NTFP) while ensuring the regeneration of plants and trees (Berkes et. *al,* 2000).
2. **Spiritual and Cultural Significance:** Forests hold deep spiritual and cultural importance for many tribal groups. These environments are often seen as sacred spaces, and their flora and fauna are integral to rituals and ceremonies (Banerjee et *al.*, 2019).
3. **Traditional Knowledge:** Indigenous and tribal communities possess extensive traditional ecological knowledge (TEK) about forest ecosystems, including medicinal plants, sustainable hunting practices, and land management techniques (Chatterjee et *al.*, 2007).
4. **Self-Sufficiency:** Tribal communities historically relied on forests for subsistence, obtaining food, shelter, and medicine. This self-sufficiency contributed to their resilience (Agrawal and Ostrom, 2001).
5. **Colonialism and Land Dispossession:** The colonial era saw the dispossession of tribal lands and exploitation of forest resources by colonial powers. Forests were often treated as exploitable resources rather than shared habitats (Gadgil and Guha, 1994).
6. **Modern Challenges:** In contemporary times, tribal communities face threats to their forest-based livelihoods due to deforestation, land encroachments, and external economic pressures (Das, 2009).
7. **Legal Recognition:** Legal recognition of tribal rights over forest resources has improved in recent decades. Many countries have implemented policies to protect these rights and promote sustainable forest management (Siry et *al.*, 2005).

8. **Conservation and Indigenous Stewardship:** There is a growing recognition of the role indigenous and tribal communities play in forest conservation. Their sustainable practices are increasingly seen as critical for maintaining biodiversity and mitigating climate change (Garnett et *al.*, 2018).

The historical relationship between tribal communities and forests is a complex tapestry of sustainable coexistence, cultural significance, and challenges. While colonial legacies and modern pressures have threatened this connection, efforts to recognize and protect tribal rights and traditional knowledge are crucial for preserving both forests and the unique cultures tied to them (Gadgil and Guha, 1994; Berkes et *al.*, 2000).

5. Socio-Ecological Significance:

The Role of Non-Timber Forest Produce (NTFP) in Tribal Livelihoods

Non-Timber Forest Produce (NTFP) plays a multifaceted and vital role in the livelihoods of tribal communities worldwide, encompassing income generation, food security, and cultural practices.

Income Generation: NTFP provides a significant source of income for many tribal households. By harvesting and selling NTFPs such as wild fruits, nuts, medicinal plants, and resins, these communities diversify their income streams and reduce dependence on a single source (Shanley et *al.*, 2015). Income generated from NTFPs often contributes to improved living standards, healthcare access, and education opportunities for tribal families (Belcher et *al.*, 2005).

Food Security: NTFPs are essential components of the diet in many tribal communities. Wild fruits, nuts, mushrooms, and honey collected from forests are important dietary supplements, especially during lean agricultural seasons (Murthy et *al.*, 2016). Their availability enhances food security by providing nutrition and a buffer against crop failures or food shortages.

Cultural Practices: NTFPs hold deep cultural and traditional significance for indigenous and tribal groups. These resources are integral to rituals, ceremonies, and daily life (Rasul, 2017). Medicinal plants among NTFPs are often used in traditional healing practices, reflecting the close relationship between these communities and their natural environment. NTFPs also feature prominently in art, music, and storytelling, preserving cultural heritage and connecting tribal members to their ancestral traditions (Shiva, 1991).

NTFPs are essential components of tribal livelihoods, offering economic stability, nutritional diversity, and cultural resilience. Recognizing the value of NTFPs and promoting sustainable harvesting practices is vital not only for the well-being of tribal communities but also for the conservation of forests and biodiversity (Shanley et *al.*, 2015; Belcher et *al.*, 2005).

The Ecological Impact of NTFP Harvesting on Forest Ecosystems and the Importance of Sustainable Management

Non-Timber Forest Produce (NTFP) harvesting, when unsustainable, can have significant ecological repercussions on forest ecosystems. Understanding and mitigating these impacts are crucial for maintaining biodiversity and overall ecosystem health. Unsustainable NTFP extraction can lead to habitat degradation, reduced species diversity, and disturbances in ecological processes (Shanley et *al.*, 2011).

Habitat Degradation: Unsustainable NTFP harvesting practices, such as overharvesting or habitat destruction during collection, can result in habitat degradation. This can lead to the loss of critical wildlife habitats and disrupt the balance between species that rely on the forest (Belcher and Schrekenberg, 2007).

Reduced Species Diversity: Excessive or unregulated harvesting of NTFPs may target specific species or individuals, leading to reduced species diversity in the forest. This can disrupt ecological relationships, including those involving pollinators and seed dispersers (Reyes-García et *al.*, 2013).

Disruption of Ecological Processes: NTFPs often play roles in ecological processes such as pollination, nutrient cycling, and seed dispersal. Unsustainable harvesting can disrupt these processes, impacting the regeneration and overall health of the forest (Shanley et *al.*, 2011).

Importance of Sustainable Management: Sustainable NTFP management is vital to mitigate these ecological impacts. Sustainable practices involve selective harvesting, regulated collection quotas, and monitoring to ensure the long-term health of the forest ecosystem (Jalonen et *al.*, 2019). Moreover, involving local and indigenous communities in forest management decisions can lead to effective conservation measures as these communities often have a deep understanding of the forests they depend on (Agrawal and Ostrom, 2001).

In conclusion, recognizing the ecological impacts of NTFP harvesting and implementing sustainable management practices are essential for preserving the biodiversity, ecological processes, and long-term sustainability of forest ecosystems. When done responsibly, NTFP harvesting can continue to benefit both human livelihoods and the health of these vital natural environments (Shanley et *al.*, 2011; Belcher and Schrekenberg, 2007).

Challenges Faced:

1. **Overharvesting and Unsustainable Practices:** One of the primary challenges is overharvesting of NTFPs, which can lead to depletion of resources and ecological harm. Unsustainable practices, such as collection of rare or

endangered species, can further exacerbate this issue (Shanley et *al.*, 2015).

2. **Lack of Secure Land Tenure:** Many tribal and indigenous communities lack secure land rights, making it difficult to engage in long-term, sustainable NTFP management. This insecurity can result in conflicts and hinder investments in sustainable practices (Garnett et *al.*, 2018).

3. **Market Access and Value Chains:** Limited market access and weak value chains often prevent tribal communities from getting fair prices for their NTFP products. This can discourage sustainable harvesting practices and limit the economic benefits (Rist et *al.*, 2012).

4. **Climate Change and Shifting Habitats:** Climate change can impact NTFP availability as it alters forest ecosystems. Species distributions may shift, affecting traditional NTFP sources and requiring communities to adapt to changing conditions (Vedeld et *al.*, 2016).

5. **External Pressures and Land Conversion:** Increasing external pressures, such as agriculture and infrastructure development, can lead to deforestation and habitat loss, reducing the availability of NTFPs for tribal communities (Agrawal and Ostrom, 2001).

6. **Limited Access to Education and Training:** Many tribal communities lack access to education and training on sustainable NTFP management and value addition, hindering their ability to optimize NTFP utilization (Rasul, 2017).

Addressing these challenges and promoting successful NTFP management often requires a combination of policy support, secure land tenure, capacity-building, market development, and community engagement. These efforts can help ensure that NTFP management contributes to both the well-being of tribal communities and the conservation of forest ecosystems.

7. **Policy and Legal Frameworks:** Existing policies and legal frameworks related to Non-Timber Forest Produce (NTFP) management and tribal rights vary by country and region. However, the recognition of indigenous and tribal rights and sustainable NTFP management has gained prominence in recent years.

8. **Challenges and Threats:** Regarding obtaining and using Non-Timber Forest Produce (NTFP), tribal people face several obstacles and risks. These risks pose a serious threat to their way of life and the long-term viability of NTFP resources.

Some key challenges and threats are:

1. **Lack of Secure Land Tenure:** Many tribal communities lack secure land rights and ownership over the forests they depend on for NTFP collection. This insecurity can lead to conflicts and hinder sustainable resource management (Garnett et *al.*, 2018).

2. **Legal Restrictions and Regulations:** Government regulations and restrictions on NTFP collection can limit the ability of tribal communities to access and utilize these resources (Duffy and St. John, 2013).

3. **Overharvesting and Unsustainable Practices:** Over-harvesting and unsustainable collection methods can deplete NTFP resources, leading to long-term scarcity (Shanley et al., 2011).

4. **Market Access and Value Chains:** Limited market access and weak value chains can prevent tribal communities from getting fair prices for their NTFP products, discouraging sustainable harvesting practices (Rist et *al.*, 2012).

5. **Climate Change and Shifting Habitats:** Climate change can alter the distribution and availability of NTFPs, making it challenging for tribal communities to predict and access these resources (Vedeld et *al.*, 2016).

6. **External Pressures and Land Conversion:** Increasing external pressures, such as agriculture and infrastructure development, can lead to deforestation and habitat loss, reducing the availability of NTFPs for tribal communities (Agrawal and Ostrom, 2001).

7. **Lack of Access to Education and Training:** Many tribal communities lack access to education and training on sustainable NTFP management and value addition, hindering their ability to optimize NTFP utilization (Rasul, 2017).

8. **Limited Technological Access:** Limited access to modern technology, such as efficient processing equipment or access to online markets, can hinder the competitiveness of NTFP products from tribal communities (Das, 2009).

These challenges and threats highlight the need for comprehensive policies that recognize and protect the rights of tribal communities, promote sustainable NTFP management, and facilitate market access.

Additionally, capacity-building and education programs can help empower these communities to address these challenges and ensure the long-term sustainability of NTFP resources.

Examining issues like deforestation, over-harvesting, and market access concerning Non-Timber Forest Produce (NTFP) provides insight into the complex challenges faced by tribal communities and the impact on both ecosystems and livelihoods. Here is an examination of these issues with citations:

1. Deforestation:

Deforestation, driven by factors like agriculture, infrastructure development, and logging, poses a severe threat to the availability of NTFPs. As forests are cleared, the habitats that sustain NTFPs are lost, impacting both biodiversity and the livelihoods of tribal communities (Agrawal and Ostrom, 2001). A study by Geist and Lambin (2002) emphasizes that deforestation is a significant driver of forest degradation, which directly affects NTFP availability and the well-being of forest-dependent communities.

2. Over-Harvesting:

Over-harvesting of NTFPs, whether due to increased demand or unsustainable collection practices, can lead to the depletion of these resources. This has ecological consequences, affecting the regeneration of NTFP-bearing plants and potentially disrupting forest ecosystems (Shanley et *al.*, 2011).

3. Market Access:

Limited market access and weak value chains can prevent tribal communities from getting fair prices for their NTFP products. This can discourage sustainable harvesting practices and hinder economic development opportunities (Rist et *al.*, 2012). Research by Sills et al. (2015) underscores the importance of addressing market access challenges to improve the economic prospects of forest-dependent communities engaged in NTFP trade.

Addressing these issues necessitates a multi-faceted approach, including policy interventions, capacity-building, and sustainable resource management practices. Ensuring the long-term availability of NTFPs requires a balance between economic development and ecological preservation, along with the empowerment of tribal communities in decision-making processes (Das, 2009; Garnett et *al.*, 2018).

9. **Opportunities and Recommendations:** Enhancing the socio-ecological significance of Non-Timber Forest Produce (NTFP) in tribal livelihoods requires a holistic approach that addresses ecological sustainability, economic empowerment, and cultural preservation.

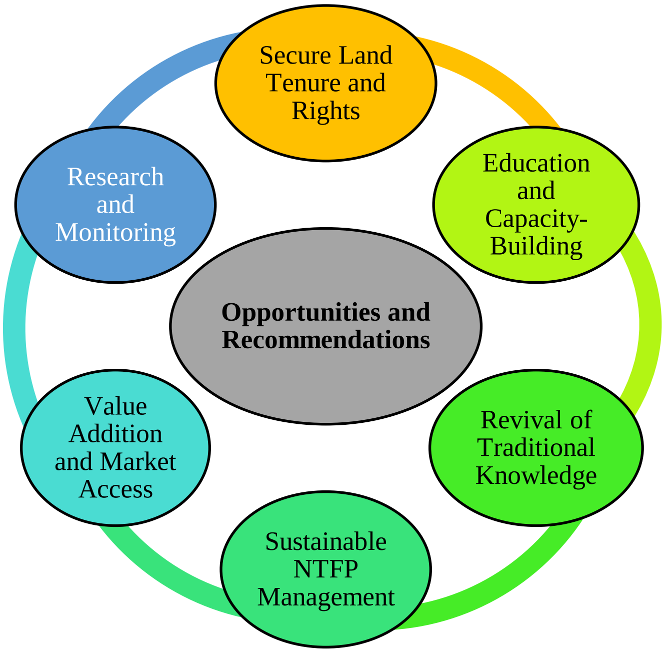

Figure 1. - Chart of Opportunities and Recommendations

1. **Secure Land Tenure and Rights:** Recognize and secure land tenure rights for tribal and indigenous communities to ensure control over forest resources, including NTFPs. The implementation of laws like the Forest Rights Act in India can serve as a model (Government of India, 2006). Kumar et *al.*, (2014) emphasize that secure land tenure is crucial for effective NTFP management and livelihood improvement among tribal communities.
2. **Sustainable NTFP Management:** Promote sustainable NTFP harvesting practices through community-based forest

management initiatives. This involves developing and enforcing regulations to prevent overharvesting and habitat destruction (Shanley et *al.*, 2011). A study by Belcher et *al.*, (2005) highlights the success of community-based NTFP management in ensuring ecological sustainability and economic benefits.

3. **Value Addition and Market Access:** Facilitate value addition to NTFP products through training and infrastructure development. Improve market access and create fair market linkages to ensure that tribal communities receive equitable returns for their products (Sills et *al.*, 2015). Rist et *al.*, (2012) emphasize that market access and value addition are critical for enhancing the economic significance of NTFPs in tribal livelihoods.
4. **Revival of Traditional Knowledge:** Promote the documentation and preservation of traditional ecological knowledge related to NTFPs. Encourage intergenerational transfer of this knowledge to maintain cultural practices and sustainable resource management (Berkes et *al.*, 2000). Research by Reyes-García et *al.*, (2013) underscores the importance of traditional knowledge in NTFP management and conservation.
5. **Education and Capacity-Building:** Provide education and capacity-building programs tailored to tribal communities to enhance their skills in sustainable NTFP management, value addition, and entrepreneurship (Rasul, 2017). Van den Bergh et *al.*, (2009) highlight the role of capacity-building in empowering indigenous communities to manage NTFPs effectively.
6. **Research and Monitoring:** Invest in research and monitoring programs to assess NTFP resources, ecosystem health, and the socio-economic impact of NTFP management. This data can inform policy and decision-making (Shanley et *al.*, 2015). Shanley et *al.*, (2015) stress

the importance of research and monitoring for evidence-based NTFP management.

Opportunities for sustainable Non-Timber Forest Produce (NTFP) management, including community-based approaches, abound and offer significant socio-ecological benefits. These opportunities align with the conservation of natural resources, improved livelihoods for tribal communities, and the preservation of traditional knowledge:

1. **Community-Based Forest Management (CBFM):** Implement community-based forest management approaches, where tribal communities actively participate in NTFP harvesting and management decisions. This empowers communities to sustainably use and conserve NTFPs while fostering a sense of ownership over forest resources (Belcher et *al.*, 2005). Research by Belcher et al. (2005) highlights the success of CBFM in promoting sustainable NTFP management and improving livelihoods among forest-dependent communities.
2. **Certification and Eco-Labelling:** Encourage certification and eco-labelling programs for sustainably harvested NTFPs. These programs can enhance market access and promote responsible NTFP management practices, ensuring that tribal communities receive fair prices (Sills et *al.*, 2015). Sills et *al.*, (2015) emphasize the role of certification in promoting sustainable NTFP management and economic opportunities for communities.
3. **Value Addition and Entrepreneurship:** Promote value addition to NTFP products through training and capacity-building programs. Encourage tribal communities to engage in entrepreneurial ventures like processing, packaging, and marketing of NTFPs, increasing their economic returns (Rasul, 2017). Van den Bergh et *al.*, (2009) highlight the

economic potential of value addition and entrepreneurship in NTFP management.

4. **Traditional Ecological Knowledge (TEK):** Recognize and integrate traditional ecological knowledge (TEK) into NTFP management practices. TEK is often the basis for sustainable resource use and can guide conservation efforts (Berkes et *al.*, 2000). Reyes-García et *al.*, (2013) underscore the importance of TEK in informing sustainable NTFP harvesting practices.
5. **Payment for Ecosystem Services (PES):** Explore Payment for Ecosystem Services (PES) mechanisms to reward tribal communities for their role in conserving forests and NTFP resources. PES programs can provide financial incentives for conservation efforts (Pagiola et *al.*, 2005). Pagiola et *al.*, (2005) discuss the potential of PES programs in recognizing the ecological services provided by tribal communities in NTFP-rich areas.
6. **Research and Collaboration:** Financial support for research partnerships among governmental organizations, non-profit organizations, and tribal groups to better comprehend NTFP resources, ecological dynamics, and socio-economic effects. Research can inform evidence-based NTFP management strategies (Shanley et *al.*, 2015). Shanley et *al.*, (2015) emphasize the value of research collaborations in promoting sustainable NTFP management. Leveraging these opportunities can enhance the socio-ecological significance of NTFPs in tribal livelihoods, contributing to forest conservation, community well-being, and the preservation of cultural heritage.

Discussion:

Based on a scientific investigation, there are a minimum of 150 significant non-timber forest products (NTFPs) in international trade, which play a pivotal role in supporting the livelihoods of approximately 0.25 to 1 billion individuals (Mellow et al., 2020). However, the depletion of natural forests in developing nations presents a pressing issue, resulting in increased poverty and hindered economic growth (Sunderlin et al., 2005). The comprehension of the potential and importance of NTFPs for enhancing livelihoods and conservation has been impeded by the absence of a well-defined theoretical framework and a practical classification of cases (Belcher et al., 2005). Indigenous communities provide alternative insights and knowledge based on their locally derived resource utilization practices (Berkes et al., 2000).

Conclusion:

The comprehensive review of the socio-ecological significance of Non-Timber Forest Produce (NTFP) in nurturing tribal livelihoods reveals several critical findings. First and foremost, NTFPs have a variety of functions in tribal communities, including providing sources of revenue, ensuring food security, and preserving cultural traditions. They offer economic diversification, supporting livelihoods, and act as safety nets during agricultural lean periods. NTFPs also maintain cultural practices, encompassing traditional knowledge and spiritual connections to the land. However, numerous challenges and threats persist, including overharvesting, deforestation, and limited market access. Policies and legal frameworks recognizing tribal rights and promoting sustainable NTFP management have shown promise but require improved implementation and equitable benefit-sharing. Sustainable NTFP management, community-based approaches, and the revival of traditional knowledge emerge as key strategies to enhance the socio-ecological significance of NTFPs, providing opportunities for forest conservation and economic empowerment.

It is impossible to exaggerate the value of non-timber forest products (NTFP) in preserving forests and supporting tribal lives. For tribal communities, NTFPs are not merely resources; they are lifelines. NTFPs provide a sustainable source of income, ensuring economic stability and reducing dependency on a single livelihood avenue. These resources bolster food security, offering nutrition and sustenance during lean agricultural seasons. Moreover, NTFPs hold deep cultural and spiritual significance, preserving ancestral traditions and connecting tribal communities to their land. Simultaneously, NTFPs contribute to forest conservation by incentivizing responsible resource management. When harvested sustainably, NTFPs maintain biodiversity, protect habitats, and foster the regeneration of vital plant species. Recognizing the pivotal role of NTFPs in tribal livelihoods and forest preservation is essential for promoting ecological sustainability, economic empowerment, and the preservation of indigenous cultures. Therefore, sustainable NTFP management should be at the forefront of efforts to ensure both the well-being of tribal communities and the health of our forests.

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■■■

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Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

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Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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FOREST WETLANDS AS NATURE BASED SOLUTION FOR CLIMATE REGULATION, WATER RESOURCE MANAGEMENT AND BIODIVERSITY CONSERVATION

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Abstract:

Wetlands are one of the planet's wealthiest ecosystems, offering numerous valuable advantages to human society while being extremely delicate to environmental changes. Wetlands are important biological and economic systems that contain abundant natural resources and are essential for maintaining several services like hydrological cycle, carbon sequestration, and biodiversity. According to the National Wetland Inventory and Assessment (and ISRO), in India, wetlands comprise of an area over 1 lakh, 52 thousand and 6 hundred square kilometers covering 4.63 percent of the overall geographical area. The wetland has several benefits like maintaining diversity, providing food, fresh water, etc., environment regulation with enrichment of cultural values and support internal processes that maintain ecosystem functioning, resilience, and capacities to produce directly consumed services and hence being a great nature-based solution for different ecological, hydrological and forest diversity issues. Despite the significant values in the field of ecology, hydrology, and socio-economic points provided by them, wetlands are facing various threats from natural as well as anthropogenic induced factors even

in densely forested areas. In this chapter, we have tried to justify the importance of forest-surrounded wetlands as a nature-based solution that provides various ecosystem services either directly or indirectly for the benefit of the human population which comprises its positive impacts on the regulation of climate for mitigation of climate change scenarios, managing hydrological resources for water security and conserve important floral and faunal species. These positive impacts evaluate the importance of forest wetlands and provide insights into planning, conservation, and sustainable management of wetland resources.

Keywords-wetland; biodiversity; climate; forest**;** water resource.

Introduction

Wetlands may be defined as the most productive ecosystems on the Earth, providing lots of important services to mankind but are highly sensitive. ‘Wetlands are area of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters', as defined by Ramsar convention of 1971. Each of the services offered by wetlands, which support immense diversity, is defined by their genesis, geographic location, water regime and chemistry, dominant species present, and soil and sediment features [1, 2]. Globally, the areal extent of wetland ecosystems ranges from 917 million hectares (mha) [3] to more than 1275 mha with an estimated economic value of about US$15 trillion a year [4]. There are currently more than 2,200 Ramsar Sites recognised worldwide, covering 2.1 million square kilometres of these global wetlands. According to the National Wetland Inventory and Assessment (compiled by the Indian Space Research Organisation), over 1,52,600 square kilometres, or 4.63 percent of the nation's total land area, are covered by wetlands in India [5].

They can be found in every climatic region, from warm deserts to frigid tundra, and at every elevation, from ocean level to around 6000 meters in the Himalaya. Wherever water collects for long periods of time, allowing the succession of plants and animals specifically adapted to the aquatic environment, wetland formation occurs. Presence of water throughout the year is not a criterion and its depth may also fluctuate [6]. Therefore, wetland areas can be found in or near bodies of water, such as shallow or deep lakes, transient ponds, streams, springs, and rivers. Wetlands are defined as " lands that connect aquatic with terrestrial ecosystems when the water table is frequently at or near the surface or when the land is submerged in shallow water," and they compulsorily contain at least one of the following three points: a) The substrate is primarily undrained hydric soil; b) at least occasionally, the land supports primarily hydrophytes; and c) at a point during the progressive season of each year, the substrate is non-soil and is covered by shallow water [7]. Despite the fact that the continents are surrounded by water on all sides, there is just a small amount of fresh water available—less than 1%. Only 0.0001% of the available fresh water is shared by the 6.45% of the world's surface that is made up by wetlands.

Importance of Wetlands

Importance of wetlands for human and nearby forest has grown recently as the population-based pressures have increased recently due to rapid increase in the population [8, 9]. The wetland offers a variety of advantages, including meeting basic demands (food, fresh water, etc.), regulating the environment, and enhancing culture [10, 11]. Additionally, support ecosystems' internal processes so they can continue to function, be resilient, and be able to provide more directly consumed services [12]. Carbon sequestration, erosion management, and other important services are of particular relevance. Flood water storage (storing water during periods of severe rain and flooding and then gradually releasing the water to minimise downstream damage); recharge of groundwater is the process through which stored surface water seeps into the earth and replenishes aquifers, which then slowly release water to nearby surface water bodies, such as streams, to supply water during times of low flow; water filtration (catch sediments, use extra nutrients in runoff, and decompose many toxins in water); economic benefits and recreation have also achieved growth in recent times (cultural heritage, visited for leisure, hiking, bird viewing, wildlife photography, and hunting).

Figure 1. Global recognition of importance of wetlands.

(*Source: https://twitter.com/IUCN)*

Threats To Wetlands

Wetlands are threatened by a number of man-made reasons, despite the significant ecological, hydrological, and socioeconomic roles they serve [13]. Due to anthropogenic concerns, even wetlands that are legally protected are not entirely free from degradation [14]. Moreover, a lot of wetlands in rural and suburban areas haven't covered either by the Wild Life Protection Act, 1972 or Indian Forest Act, 1927.

Figure 2. Major threats to wetlands. (*Source: https://www.ramsar.org/resources/recognising-and-assessing-threats-to-the-site)*

These wetlands face multiple threats, thus proper attention should be paid to their conservation and management. In India, there are many different types of wetlands that are dynamic and affected by both natural and anthropogenic activities. These wetlands require regular monitoring and updates on their status through planning for conservation and sustainable management, which is important in view of the increasing pressure [15].

Wetlands in India

Wetland habitats in India are supported and maintained by the country's geography and climate patterns. Examples of natural wetlands in India include the coral reefs, marine wetlands, high-altitude Himalayan lakes, wetlands in the floodplains of the river systems, saline and transitory wetlands, coastal wetlands, mangrove swamps, etc. With the exception of forbogs, fens, and traditional salt marshes, Indian wetlands are home to a variety of ecological types. In addition to the natural wetlands, there are a lot of man-made wetlands that were created to meet needs for fresh water supply, irrigation, electricity generation, fisheries culture, and flood control, among other things. These wetlands significantly increase the richness of the fauna and flora [11]. In addition, countless tanks, shallow ponds, and reservoirs all contribute to the biodiversity of wetlands.

Table 1. Wetland categories found in India.

	Wetland Category	Total wetland area (ha)	% of wetland area
1.	Inland wetlands- Natural	6623067	43.40
2.	Inland wetlands- Man-made	3941832	25.83
	Total – Inland	***10564899***	***69.22***
3.	Coastal wetlands- Natural	3703971	24.27
4.	Coastal wetlands- Man-made	436145	2.86
	Total – Coastal	***4140116***	***27.13***
	Sub- Total	**14705015**	**96.36**
	Wetlands (< 2.25 ha)	***555557***	***3.64***
	Total	**15260572**	**100**
Source: National Wetland Inventory and Assessment, India			

Forest Wetlands for Climate Regulation

Wetlands can be said as one of the most valuable and prolific ecosystems on the planet. Wetland systems are sensitive to variations in the amount and quality of their water resource. Climate change is anticipated to significantly impact wetlands via modifications to highly variable hydrological systems worldwide. Wetlands are a complex system that encounters wet and dry phases in cycles over the course of seasons, years, and decades. The multitude of advantages wetland habitats offer to human society were emphasized by the Millennium Ecosystem Assessment [4]. Climate regulation is one of the most crucial environmental functions that connect wetlands to human well-being [16]. Wetlands are increasingly acknowledged to be important climate regulators additionally in the sequestration and storage of carbon [17]. Wetlands are involved in multiple facets of climate regulation beyond just the kinetics of carbon. In addition, to serve as a sink for greenhouse emissions, wetlands have the ability to regulate local and regional climate as well. Wetlands are one of the major uncharted territories for element dynamics as well as matter fluxes in the near future in a world that is suffering from global climate change [18].

A. Wetland and Carbon

Globally wetlands occupy 6% of the total land area yet contain around 12% of the world's carbon reserves, contributing significantly to the global carbon cycle [19, 20]. From the poles to the equator, vegetated wetlands serve as important carbon sinks. The carbon density of terrestrial ecosystems is highest in wetlands which account for 20–25% of the organic soil carbon worldwide [21]. Mangroves are considered as one of the major forest wetland habitats with the highest concentrations of carbon in accordance with the current biogeochemical and physical circumstances being very favorable for carbon retention over the long term. Global assessments indicate that these systems are substantial carbon sinks as they could store up to 19.9 Gigatons of organic carbon [22]. The quantity of carbon retained in wetland soils is strongly correlated with climate. The role of tropical forest wetlands has garnered a great deal of attention in climatic budgets on a global scale. According to estimates, as much as 88.5 Gigatons of carbon (ranging from 81.5–91.8 GtC), equivalent to 17–19 percentage of the worldwide wetland carbon stock are stored in tropical peatlands [23]. Wetland has the potential to store a considerable amount of carbon in its soils and standing aquatic or semi aquatic vegetation. Wetlands are essential pertaining to the carbon complex and thus, they have a great potential to mitigate the harmful impacts of climate change.

B. Wetland and Greenhouse Gases

One crucial aspect of wetlands is their ability to act as a source and sink of greenhouse emissions. Wetlands are essential for regulating the climate since they can alter the levels of greenhouse gases in the atmosphere such as carbon dioxide, nitrous oxide and methane [24]. Different wetlands produce and emit GHGs at varying rates in accordance with the dominant biogeochemical processes. In the anaerobic soils that predominate in wetlands, CH_4 can also be produced along with CO_2. So, wetlands can be an innate CH_4 source. Wetlands often emit less N_2O into the air. Although due to groundwater contamination or adjacent uplands leaching where substantial nitrogen infusions are present, wetlands may produce N_2O emissions. Wetlands that hold a considerable amount of water throughout the year, maintaining anoxic conditions, will typically produce less N_2O emissions and more CH_4 emissions. The risk of rising CH_4 emissions has been cited to argue against restoring wetlands. Nevertheless, it is crucial to comprehend the potential GHG fluxes to avoid unfavorable results. Therefore, at any wetland, the primary GHG emission controls are climatic conditions and the accessibility of nutrients along with the period of waterlogging and water table elevation.

C. Wetland and Local Climate

Wetlands have a localized impact on climate by transferring energy and dissipating it. Wetland affects fluctuations in temperature and impacts variation in precipitation intensity and frequency. Wetlands have been predicted to have a localized cooling influence on the environment and can lower temperatures thereby up to 5^0 C compared to the surroundings [25]. Since water is frequently present in wetlands, energy input is converted into latent heat of evaporation, however, on dry grounds solar energy is transformed into perceptible heat increasing the ambient air temperature noticeably. Wetlands serve as the first line of defence against severe weather conditions and create a physical barrier to lessen the force and speed of floodwaters. Wetlands offer a coping mechanism to guard against storms. Wetlands may assist in providing water during dry spells. Wetland provides a reliable and realistic approach for mitigating the effects of climate change.

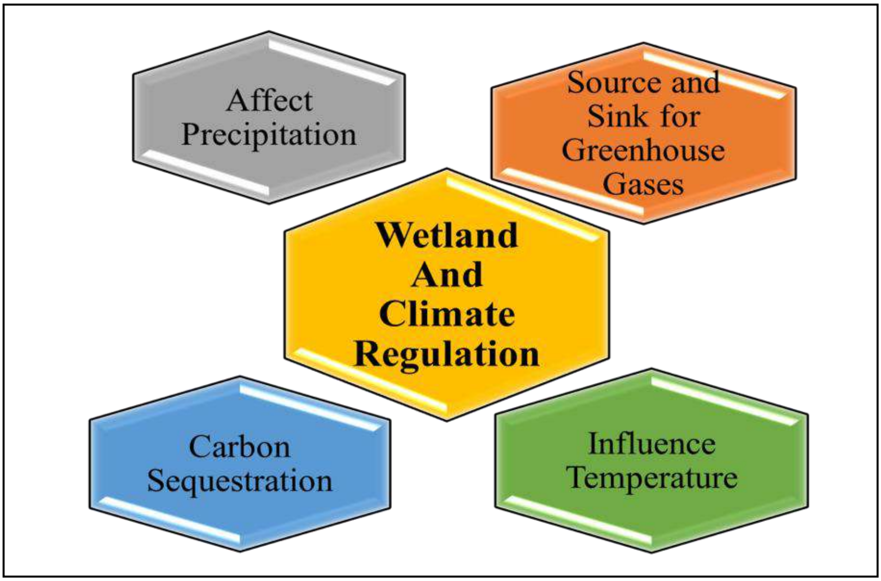

Figure 3: Multiple Aspects of Climate Regulation through Wetland.

Wetland habitats are essential to both nature and mankind. They are frequently the landscape's most valuable ecosystems. Effective and sustainable wetland resource management is becoming more difficult and crucial but it is essential to protect, preserve and conserve the wetland as they are continually being lost due to improper management yet it is increasingly clear that the services, they offer are indispensable for society. Due to their crucial function in regulating the climate, activities for managing wetlands and restoring them are being incorporated into local, regional and international levels which aspire to both prevent and respond to climate change [26]. Wetlands can act as a "safety net" against the effects of climate change if they are globally preserved, safeguarded, and restored [27].

Forest Wetlands For Water Conservation

Wetlands are the ideal natural option for risk reduction and adaptation while preserving both flood and drought-related climatic extremes. Water and land are divided by areas known as wetlands. They can be freshwater or saltwater and exist in a transitional zone that is occasionally wet and occasionally dry. Normally, the Wetlands will remain moist during rain occurrences. Wetlands can be either natural or man-made, and the water they contain can be either still or moving, fresh, brackish, or salty. Even subsurface wetlands exist. Swamps, marshes, bogs, and fens are the principal types of wetlands.

Depending on the kind of wetlands, the specific characteristics of the soil and water, and any associated biotic impacts, wetland ecosystems are linked to a broad and complicated array of direct and indirect uses. Water supply sources and the harvesting of wetland resources like plants and fish are examples of direct applications. Environmental processes include floodwater retention, groundwater recharge and outflow, climate mitigation, and nutrient abatement produce indirect benefits. [28]. Wetlands have been identified as crucial to human existence based on the significant environmental and sustainability benefits. By maintaining the wetlands, future challenges relating to food security, clean water security, and energy security, human well-being, natural catastrophe risk reduction and climate change resilience can be met. [29].

A. Water Purification

Natural wetlands provide a variety of purposes that are advantageous to both people and wildlife. The filtering of water is one of its most crucial roles. As water moves slowly through a wetland, many of the sediments that carry contaminants and nutrients also do so. As a result, the suspended solids in the water become trapped by the plants and settle out. Other contaminants are rendered inert or changed into less soluble forms that plants can absorb.

B. Flood Protection

Water spreads out and moves through a lot of vegetation as it enters a wetland through a stream channel or surface runoff. Water flow has slowed down, which may reduce the likelihood of a significant flood. The effectiveness of wetlands are at reducing flood damage depends on several factors, including the size of the area, the type and health of the vegetation, the slope, the location of the wetland in the flood path, and the saturation of the wetland soils prior to flooding. A standard one-acre marsh may hold three acre feet, or one million gallons, of water [30]. As the flow of water get reduced by wetland via storing more water by infiltration than terrestrial land, the chances of causing flood get reduce.

C. Ground Water Recharge

Some freshwater wetlands exist where groundwater recharges from surface water reaching an underground aquifer. Wetlands are more frequently the locations where groundwater seeps to the surface of the land, like springs. During the dry summer months, the groundwater discharge may be crucial for maintaining stream flows for fish, animals, plants, and other organisms living in or close to the stream. It might be important as an essential source of water for the community as well.

D. Trap Sediments that contain Contaminate and Pollutants

The surface of the marsh may get covered in floating debris as the flow develops at a slower rate. The accumulating sediments can then be held in place by the roots of marsh plants. If the water flows through wetlands, up to 90% of the sediments in runoff or streamflow may be eliminated. Since toxins like heavy metals are linked to soil particles, the sediment that settles in wetlands also enhances the quality of the water.

Forest Wetlands For Biodiversity Conservation

Wetlands are crucial for maintaining a number of natural cycles and serving as a home for a range of animals. The phrase "kidneys of the landscape" is frequently used to characterise wetlands [31]. Wetlands play important ecological roles in the preservation of biodiversity, hydrological equilibrium, and human wellbeing. More than 40% of all plant and animal species have habitats in surface freshwater wetland areas around the world. Wetland microhabitats offer abundant and high-quality food sources and shelter for avifauna populations all year long. Wetlands have sometimes been referred to as "biological super systems" because of the enormous amounts of food they produce and the extraordinary degree of biodiversity they support. They are equally as diverse and abundant in species as coral reefs and rainforests. They are ideal for the growth of creatures that form the base of the food chain on our planet due to their shallow water, high nutrient content, and high primary productivity (amount of biomass generated).

A. Floral Diversity Conservation

Wetland plant communities serve as effective indicators of the health of wetlands because they include species with a range of ecological tolerances and adaptations, as well as reflecting the biological integrity of wetlands [32]. Wetland plants are any species that can be regularly seen growing in wetlands of any kind, on or in the water, or when soils are flooded or saturated for long enough for anaerobic conditions to form in the root zone. The vital habitat that wetland provides for plant diversity is essential for maintaining the water cycle, nutrient cycle, carbon sequestration, storage/retention and purification of water, waste treatment, and pollution control[33]. In order to assess the effects of human interference on wetlands, different plant species respond to environmental change in different ways [34].

Figure 4. Floral diversity supported by wetlands.

(*Source: GPWC, Bemetara ©Abhishek Maitry)*

B. Faunal Diversity Conservation

Wetlands are vital habitats for migratory species and a large proportion of waterbirds worldwide [35, 36]. Nearly all water birds in the world use wetlands as breeding and foraging areas [37]. Waterbirds that migrate use wetlands throughout their range, which occasionally stretches almost from pole to pole. To save the habitats that migratory birds rely on for feeding, breeding, and rest stops as they travel between and between continents, multi-national coordination of conservation efforts for wetlands is required. Wetlands not only assist other animal species, but they also give other species the environment they need to cohabit peacefully within an ecosystem [38]. For the conservation and management of wetlands as well as their sustainable living, the current knowledge on faunal variety in wetland is of enormous value.

Figure 5. Faunal diversity supported by wetlands.

(*Source: GPWC, Bemetara ©Abhishek Maitry)*

Conclusion

The wetland provides a variety of benefits, including as diversity, the fulfilment of fundamental biophysical demands (such as food and fresh water), environmental control, and cultural enrichment. It is a fantastic natural solution for numerous ecological, hydrological, and forest diversity issues because it supports internal processes in ecosystems that sustain their functioning, resilience, and capabilities to create more directly consumed services. Climate control is one of the most significant environmental services that connects wetlands to human wellbeing. Wetlands are now seen as essential climate controllers that aid in the sequestration and storage of carbon. Wetland ecosystems are connected to a wide and complex range of direct and indirect uses, depending on the kind of wetlands, the characteristics of the soil and water, and any associated biotic impacts. Examples of direct uses include water supply sources and the harvesting of wetland resources like plants and fish. Indirect benefits are produced by environmental processes such as nutrient abatement, groundwater recharge, and floodwater retention. Additionally, wetlands produce a staggering amount of food and sustain a high degree of biodiversity, earning them the label "biological super systems" in certain quarters. They have a diversity and abundance of organisms that rival coral reefs and rainforests. These beneficial effects assess the value of forest wetlands as a natural approach to managing water resources, regulating climate, and preserving biodiversity. They also offer insights into the management of wetland resources in terms of planning, conservation, and sustainable management.

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■■■

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Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

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Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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ASSESSMENT OF FISH DIVERSITY AND ANTHROPOGENIC PRESSURE ON KOPRA WETLAND OF BILASPUR DISTRICT OF CHHATTISGARH

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Introduction

Wetlands have a significant role in groundwater recharging, recreation, the retention of pollutants, and the survival of several aquatic plant and animal species (Crisman 2001). A number of variables, including food availability, risks from poaching and hunting, the size of the wetland (Paracuellos, 2006), and abiotic changes in the wetlands (Jaksic 2004), have an impact on the water-dependent avifauna and their habitat. These biotic elements are dependent on the hydrology and seasons of a wetland habitat. A number of organisms have their natural habitat in the freshwater ecosystem. According to Simon and Lyons (1995), fishes are highly sensitive to environmental changes. Fishes are essential to the survival and maintenance of the aquatic ecosystem. As a result of their long existence and Septo-temporal influence, fish serve as a bio-monitoring instrument. IUCN estimates that there are 868 species of fish in India's freshwater ecosystem, of which 192 are endemic and 327 are threatened (Lakra et al., 2010).

Reservoirs often provide new habitats for fish species that were not present in the original river or stream. They can support a diverse range of aquatic plants, insects, and other organisms, which in turn attract various fish species. Reservoirs typically have abundant food resources, such as plankton, algae, and aquatic invertebrates. This can lead to increased productivity and provide a food source for a wide variety of fish species. Reservoirs can facilitate the expansion of fish species' ranges by creating new water bodies connected to existing river systems. This can enhance fish diversity by allowing species to colonize previously inaccessible areas. Reservoirs often provide new habitats for fish species that were not present in the original river or stream. They can support a diverse range of aquatic plants, insects, and other organisms, which in turn attract various fish species. Reservoirs typically have abundant food resources, such as plankton, algae, and aquatic invertebrates. This can lead to increased productivity and provide a food source for a wide variety of fish species. Reservoirs can facilitate the expansion of fish species' ranges by creating new water bodies connected to existing river systems. This can enhance fish diversity by allowing species to colonize previously inaccessible areas. The water quality of a reservoir can vary depending on various factors, including its location, surrounding land use, water sources, and management practices.

The habitat of freshwater fishes may be destroyed or altered by natural disasters, anthropogenic activity, and pollution (Sarkar, 2021). According to Cowx (2002), these pose the biggest challenges to aquatic ecosystems. Mass fish species mortality and significant population size reduction are brought on by overfishing or indiscriminate fishing (including the use of mosquito net, dynamite, and electrofishing) (Sarkar et al., 2008). Exotic fish introductions could result in the spread of new parasites and diseases into previously uninhabited areas. Finally, the introduction of exotic fishes may cause the population size of native fish species to decline. They can enhance conflict between exotic and indigenous fishes. The feeding river system, weathering and geochemical processes taking place in the catchments, as well as anthropogenic sources, all contribute to the composition of reservoir water. The disintegration of the rock matrix in response to reactive rains containing dissolved carbon dioxide largely controls the composition of reservoir waters naturally; nevertheless, human intervention could induce aberrations in natural water chemistry at any point or location in the drainage basin. The primary resources exploited for inland fisheries may be reservoirs and lakes. For the use of freshwater reservoirs and sustainable as well as economical management, an important component is understanding the variety of the fish fauna (Battul et al. 2007). India's lakes are home to a wide range of fish species, which in turn encourages the commercial use of fishery resources.

A reservoir is a body of water that is created by either pumping water into an artificial impoundment that is completely surrounded by man-made embankments to form a fully bunded dam (a river reservoir) or, less frequently, by the accumulation of flowing water behind a built dam. Despite the debate and criticism they spark, more reservoirs must be built as the need for water increases globally.

Anthropogenic pressure refers to the impact or influence that human activities have on the environment. Reservoirs, which are artificial bodies of water created by the construction of dams, can be subject to various anthropogenic pressures. Reservoirs are often built to provide a reliable water supply for human consumption, agriculture, and industrial use. The extraction of water from reservoirs can put pressure on their water levels, leading to reduced storage capacity and potential water scarcity. Human activities near or within the catchment area of a reservoir can result in the introduction of pollutants. Industrial discharges, agricultural runoff, and improper waste disposal can contaminate the water in reservoirs, affecting their quality and making them less suitable for various purpose. The construction of dams and reservoirs can interrupt the natural flow of rivers, causing sediment to accumulate in the reservoirs. Over time, this sedimentation reduces the storage capacity of the reservoir, affecting its efficiency and lifespan. It is important to note that the specific anthropogenic pressures on reservoirs can vary depending on the region, local regulations, and the nature of human activities in the vicinity of the reservoir. The fresh water reservoirs made with this purpose are underutilized and except water utility management no further use of such water sheets is done.

In India, there are 3.15 million acres are covered by 19,370 reservoirs in 15 states. In 25 years, it's anticipated that the area would increase in size to 6 million acres. 1.707 million hectares of the state of Chhattisgarh are covered by water. In Chhattisgarh, 54% of the total water distributed area is in the form of reservoirs. There are 1,690 reservoirs (85,188 ha) total in the state, of which 1,657 (37,432 ha) are small, 21 (25,610 ha) are medium, and 12 (22,146 ha) are large, covering 56.72 percent, 20.83 percent, and 22.45 percent of the total land area, respectively. (Annon, 2008). In comparison to their potential, fish production from these resources in India is now relatively low (on average about 20 kg/ha/yr). This is a result of improper management and exploitation practises, as well as a lack of knowledge of reservoir ecology.

The state of Chhattisgarh contains 27,823 wetlands (including those smaller than 2.25 ha), covering 337,966 ha, or about 2.5% of the state's overall land area. According to http://chtenvis.nic.in/Forest.html, the three main forms of wetlands are reservoirs (90,389 ha), tanks/ponds (40,226 ha), and rivers/streams, which account for around 53% of all wetlands (179,088 ha). The Kopra Wetland is a special habitat matrix that varies seasonally.

Kopra reservoir is one of the suitable habitats for water-birds and fishes near Bilaspur city, Chhattisgarh and it was established in the year 1993 in the Mahanadi basin for the purpose of irrigation.

The main purpose of establishing this dam was to provide irrigation facilities to surrounding villages for the purpose of agriculture. These reservoir play a crucial role in the overall development of the region by providing water resources for agriculture, drinking water supply, and supporting the local ecology. Reservoir contribute significantly to the socio-economic growth of Bilaspur district in Chhattisgarh (India-WRIS 2014).

The present study is based on the documentation and estimation of fish diversity, water quality of Kopra wetland and how the diversity changes throughout the year with a focus on the pre-monsoon season. By performing the community interaction, fisherman community interaction and socio-economic survey in kopra and khairadhih villages. Kopra village is located in south west of the kopra reservoir and khairadhih village located in north east of the kopra reservoir.

Objective :-

1. Survey of pre-monsoon Fish diversity of Kopra reservoir of Bilaspur district.

2. To evaluate the water quality of the Kopra reservoir.

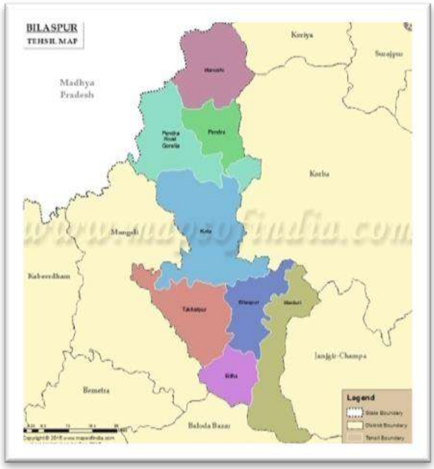
3. To study the anthropogenic pressure on the reservoir.

Material and Methodology

Description of study area :- Bilaspur district is located in the state of Chhattisgarh, India. The district is known for its rich natural resources, including several reservoirs that serve as important water sources and provide irrigation and drinking water to the region. In the Mahanadi basin, the Kopra reservoir was built in the years 2000–2001 for irrigation purposes. This wetland is seasonal, and its GPS coordinates are 22°304000 N to 22°401500 N latitude and 82°203000 E to 82°303100 E longitude. The Kopra wetland is located in the Sakri Village of the Bilaspur district of Chhattisgarh, India, on the Raipur-Bilaspur bypass. The distance to

Bilaspur city is about 10 kilometres. The wetland has a length of 1680 metres and a total volume content of 113 TCM (India-WRIS 2012).

Sampling sites as a map:-



Map.1 : kopra reservoir map of Bilaspur.

Method:

Survey of Kopra dam and nearby area was carried out from April 2023 to July 2023. The survey was done based on a general interview of fisherman and local peoples. Primary data was collected through personal interviews of fisher community families. Samples were collected at regular intervals with fishermen community interaction and local village peoples. Evening 5pm fishermen lay the fishing nets in water. After overnight, in the early morning fishermen take out the fishing nets. Collected fishes all identified by its colour patterns, Spots, size, shape, position of fins or the number of scales in a specific series and designs have been noted when they are in fresh condition. And took some pictures for identification and confirmation of species. than prepared a list of fishes in field diary with its local names. The length and depth of the head, the position and diameter of the eyes, the length of the snout, the maximum and minimum breadth and girth, and the lengths of the pre dorsal fin, pre pectoral fin, pre anal fin, and pre caudal fin are among the morphological characteristics. Characteristics that can be described include the body's profile and shape, the skin's texture and colour, the position and shape of the mouth, the lips, the snout, and the jaws, as well as scales and the lateral line system. median fins' form, size, and kind; paired and caudal fins' fin rays and formula; tail; and distinctive markings. A field kit with measurement tools like rope, preserver and a digital camera.

Water samples are collected from different points on kopra reservoir. The water quality Parameters such as water pH, oxygen reduction potential-ORP, Dissolved Oxygen-DO, Total Dissolved Solids-TDS, temperature, Conductivity are measured by multi-parameter instrument. During general interviews with village people observations have been noted and observed how they depend on reservoir and asked some question for relate the anthropogenic presser on Kopra reservoir. And also collected samples of ground water from near villages; Kopra village and Khairadhih village.

Result

Data analysis:-

Survey of pre-monsoon Fish diversity of Kopra reservoir of Bilaspur district.

The collected data show different types fish species are present in Kopra reservoir. Total 27 species, 11 family and 6 order of fishes are present. In this species 14 species are LR-nt (lower risk near threatened), 8 species are VU (Vulnerable), 1 species are LR-Ic (lower risk least concern and 3 species are EN (endangered species).

To evaluate the water quality of the Kopra reservoir.

Reservoir water quality refers to the chemical, physical, and biological characteristics of water in a reservoir. The quality of reservoir water is important because it directly impacts the ecosystem within and around the reservoir, as well as the suitability of the water for various uses such as drinking water supply, irrigation, industrial processes, and recreation.

Here are some key factors that affect reservoir water quality:

- Temperature: Reservoir water temperature can influence the growth and survival of aquatic organisms. Higher temperatures can lead to reduced oxygen levels, increased algal growth, and changes in species composition. A average temperature in kopra reservoir water is 32˚C in summer season and in rainy season temperature is 26˚C. and ground water temperature are 26.58 kopra and 26.79 is khairadhih village.

- Dissolved Oxygen (DO): DO is essential for the survival of aquatic organisms. It enters the water through atmospheric diffusion and photosynthesis by aquatic plants. Factors such as temperature, organic matter decomposition, and algal blooms can affect DO levels. Low DO concentrations can lead to fish kills and other negative impacts on aquatic life.DO is essential for the survival of aquatic organisms. It is the amount of oxygen dissolved in the water, and it is necessary for fish and other aquatic organisms to respire. Low DO levels can result from pollution, high temperatures, or excessive algal growth. Average DO in kopra reservoir water 7.32 in ppm. Kopra village water DO is and 5.81 ppm DO , is kharadhih water DO and 5.01ppm DO.
- pH: pH is a measure of the acidity or alkalinity of water. It can influence the availability of nutrients and the toxicity of certain substances to aquatic organisms. Most aquatic species thrive within a specific pH range, and significant deviations from that range can harm them. The pH level indicates the acidity or alkalinity of water. It is an important factor that affects the survival and growth of aquatic organisms. Some species are more sensitive to changes in pH than others. in kopra reservoir water pH is 9.2 water is slightly basic or alkaline. In terms of water quality, a pH of 9.2 is generally considered acceptable and safe for most purposes. Kopra village ground water pH is 7.68 and khairadhih village ground pH is 7.28. However, the ideal pH for drinking water is typically in the neutral range of 6.5 to 8.5. Water with a pH slightly above or below this range is still generally safe to drink.

- ORP: stands for Oxidation-Reduction Potential, which is a measure of the ability of a substance to oxidize or reduce another substance. In the context of water, ORP refers to the water's potential to either gain or lose electrons during a chemical reaction. It is typically measured in millivolts (mV). In kopra reservoir -24. ORP. And kopra village ground water -9.3, khairadhih village ground water -2.9. A positive ORP value indicates that the water has the potential to oxidize substances, while a negative ORP value suggests that the water has the potential to reduce substance effect the taste and could potentially indicate other water quality issues.
- Water conductivity: also known as electrical conductivity (EC), is a measure of the ability of water to conduct an electrical current. It is a fundamental parameter used to assess the overall quality and purity of water. Conductivity is typically measured in units of Siemens per meter (S/m) or micro siemens per centimeter (µS/cm). kopra reservoir water EC is 240µS/cm and kopra village ground water 809µS/cm and khairadhih village ground water 2403µS/cm . The electrical conductivity of water is influenced by the presence of dissolved ions, such as salts and minerals. When these ions are dissolved in water, they become charged particles called ions. These ions facilitate the flow of electrical current through the water. According parameter khairadhih groung water conductivity is very high, Water conductivity of 2403 µS/cm (microsiemens per centimeter) indicates that the water has a relatively high level of dissolved salts or ions. Conductivity is a measure of how well water can conduct an electrical current, and it is influenced by the presence of dissolved substances.
- TDS: stands for Total Dissolved Solids, and it is a measure of the total concentration of all dissolved substances in water. These substances can include minerals, salts, metals, organic compounds, and other dissolved solids. TDS is typically

measured in units of milligrams per liter (mg/L) or parts per million (ppm). In kopra reservoir water TDS is 104.74ppm, kopra village ground water TDS is 404 ppm, khairadhih village ground water is 1202ppm. The measurement of TDS provides important information about the overall quality of water, as it reflects the total amount of dissolved substances present. Generally, higher TDS levels can indicate a higher concentration of dissolved solids in the water.1204 ppm (parts per million) indicates the presence of various dissolved substances in the water, such as salts, minerals, metals, and other ions. The TDS level can have several implications,

- Biological Contaminants: Reservoirs may be affected by pathogens, such as bacteria, viruses, and parasites, which can be introduced through sewage discharge, animal waste, or other sources. Proper disinfection and water treatment are necessary to ensure safe drinking water. Bacterial and Pathogen Contamination: Reservoirs can be susceptible to bacterial contamination, such as from fecal coliform bacteria, which can indicate the presence of harmful pathogens. This can occur due to inadequate wastewater treatment or the runoff of animal waste from agricultural activities. Reservoirs can be susceptible to bacterial contamination, such as from fecal coliform bacteria, which can indicate the presence of harmful pathogens. This can occur due to inadequate wastewater treatment or the runoff of animal waste from agricultural activities.

Monitoring and managing reservoir water quality is crucial to maintain a healthy ecosystem and to ensure the safety of water supplies. Water resource management agencies often conduct regular water quality testing, implement pollution control measures, and enforce regulations to protect reservoirs and the surrounding environment. To ensure and maintain good reservoir water quality, regular monitoring, testing, and appropriate management practices are necessary. This includes implementing water treatment processes, regulating pollutant discharges, and implementing conservation measures to protect the watershed and prevent pollution sources from entering the reservoir.

3. To study the anthropogenic pressure on the reservoir:-

Anthropogenic pressure refers to the impact and influence of human activities on the environment. These pressures can have various forms and can affect different aspects of the environment, including air, water, land, and ecosystems. Here are some examples of anthropogenic pressures

- Pollution: Human activities such as industrial processes, transportation, agriculture, and waste disposal can release pollutants into the environment. This includes air pollution from vehicle emissions and industrial smokestacks, water pollution from chemical runoff and wastewater discharge, and soil contamination from improper waste disposal. Kopra reservoir is free from pollution like industrial processes or other activities, it's very peaceful place and human interaptions is very less. That's why in kopra reservoir is one of the highly bird diversity wetland.
- Deforestation: Clearing forests for agricultural purposes, urban development, or logging contributes to deforestation. This results in the loss of habitats for numerous plant and animal species, disrupts ecosystems and contributes to climate change by reducing the capacity of forests to absorb carbon dioxide. In kopra reservoir deforestation activity is less.
- Overfishing: Overfishing occurs when fishing practices exceed sustainable levels, depleting fish populations and disrupting marine ecosystems. It can result in the collapse of fish stocks, affecting the livelihoods of communities

dependent on fishing and the overall health of marine ecosystems. There on overfishing done in Kopra reservoir.

- Habitat Destruction: Human activities, such as urbanization, agriculture, and infrastructure development, can lead to the destruction and fragmentation of natural habitats. This results in the loss of biodiversity, as many species depend on specific habitats for their survival.
- Land Use Changes: Conversion of natural landscapes, such as forests or grasslands, into agricultural fields, urban areas, or industrial zones, alters the natural balance of ecosystems. This can lead to habitat loss, soil erosion, and changes in water availability. Addressing anthropogenic pressures requires sustainable practices, environmental regulations, conservation efforts, and the adoption of cleaner technologies. It involves promoting resource efficiency, reducing pollution, protecting natural habitats, and mitigating climate change through measures such as renewable energy adoption and carbon sequestration. part of the Kopra reservoir has been excluded due to construction of the NH130 highway. For such reason pollution increases at high rate, ecosystem has been disturbed and feeding habits of fauna shifted. And main component disturbed by this were aquatic vertebrates.

Fig no.4 kopra reservoir

Tables and graph :-

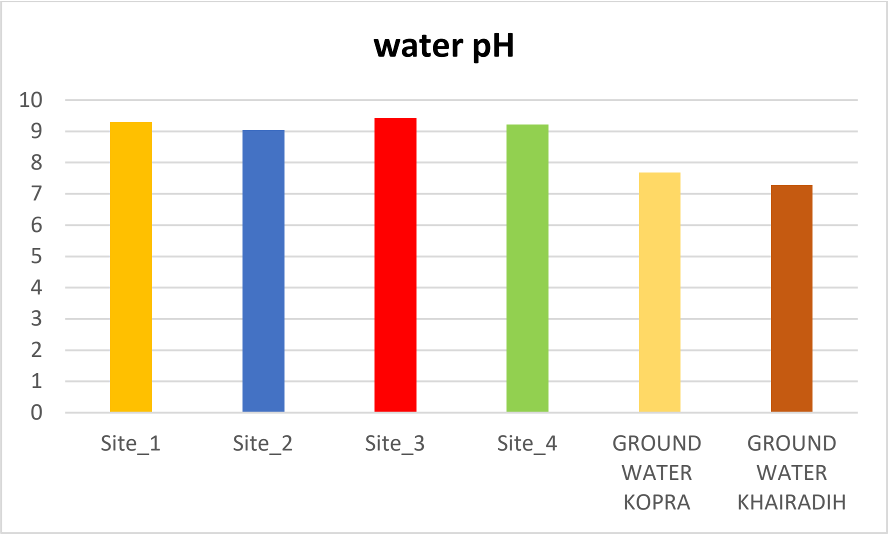
Table no. 1:-List of fish diversity of kopra reservoir-

S.N	**Common/ local name**	**zoological name**	**Family**	**order**	**IUCN status**
1	Tilapia	*Oreochromis mossambicus*	cichlidae	cichliformes	LR-nt
2	Catla	*Catla catla*			LR-nt
3	Mrigal	*Cirrhinus mrigala*			LR-nt
4	Borai/Reba	*Cirrhinus reba*			VU
5	Komal carp	*Cyprinus carpio*	cyprinidae	cyriniformes	VU
6	Bata	*Labeo bata*			LR-nt
7	Kamach/Kariya	*Labeo calbasu*			LR-nt
8	Rohu	*Labea rohita*			LR-ic
9	Bata	*Labeo boggut*			LR-nt
10	Amachaini	*Labeo dyocheilus*			
11	Kotri	*Puntius chola*			LR-nt
12	Puthia/Kotra	*Puntius saranasarana*			VU
13	JarhiKotra	*Puntius sophore*			LR-nt
14	Sanwal/Sol	*Channa marulius*			VU
15	Khoksi	*Channa punctatus*	channidae	ophiecephaliformes	LR-nt
16	Bhunda	*Channa striatus*			LR-nt
17	Kevai	*Anabus testudineus*	anabantidae		LR-nt
18	Chital	*Chitala chitala*	notopteridae	osteoglossiformes	EN
19	Patola	*Notopterus notopterus*			EN
20	Mongri/Mangur	*Clarias batrachus*	claridae		VU
21	Singhi	*Heteropneustes*	saccobranc		VU

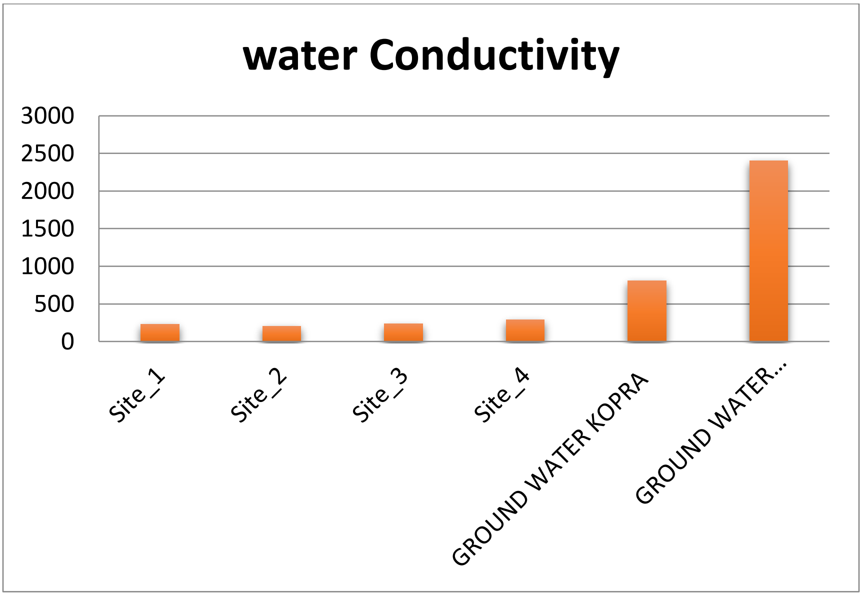
		fossilis	hidae	siluriformes	
22	Tengna	*Mystus gulio*	bagridae		LR-nt
23	Botia	*Ompok bimaculatus*			EN
24	Padhan/lonch	*Wallago attu*	siluridae		LR-nt
25	Kewai	*Heteropneustes fossilis*	heteropneustidae		VU
26	Bami	*Mastacembelus armatus*	mastacembelidae	synbranchiforms	VU
27	Choti Bami	*Mastacembelus pancalus*			LR-nt
Abbreviation-EN=endangered; LR-ic=Lower risk least concern; LR-nt=Lower risk near threatened; VU-vulnerable					

Table no.2 water quality parameters:-

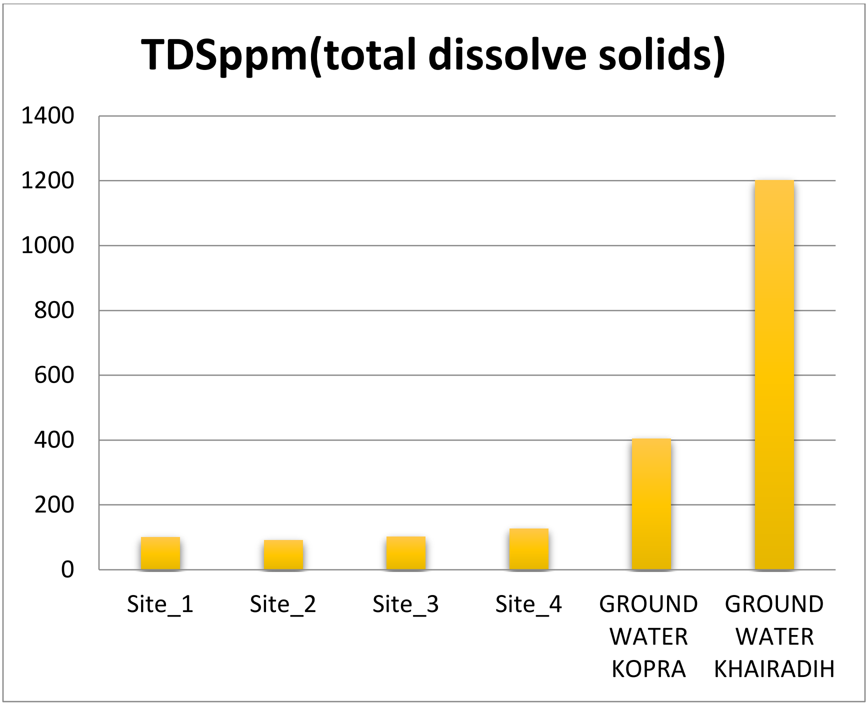
Name sites	**Temperature**	**pH**	**DO ppm**	**conductivity**	**ORP(oxygen reduction potential)**	**TDS ppm (total dissolve solids)**
Site_1	33.11	9.3	7.08	231	-17.7	100
Site_2	31.7	9.04	7.45	205	-20.7	91
Site_3	32.24	9.42	7.37	235	-32.2	102
Site_4	32.6	9.22	7.28	289	-25.8	126
Ground water kopra	26.58	7.68	5.81	809	-9.3	404
Ground water khairadih	26.79	7.28	5.01	2403	-2.9	1202



Ghaph no.2 showing the kopra reservoir and both villages groung water pH



Graph no.5 showing the kopra reservoir and villages ground water conductivity



Graph no. 7 showing the kopra reservoir water and villages ground water TDS

Reservoirs play a crucial role in maintaining healthy aquatic ecosystems, supporting biodiversity, and providing recreational opportunities for anglers and nature enthusiasts. High water quality is vital for supporting diverse fish populations. Clean and well-oxygenated water is essential for the survival of various fish species.kopra reservoir is contains high number of fish diversity and Consideration of water level fluctuations, as some fish species rely on specific water depths and seasonal variations for breeding and feeding. Without anthropogenic inputs such as pollution, industrial runoff, or agricultural discharges, the water quality remains high and free from harmful contaminants. This leads to better oxygen levels, clear water, and suitable conditions for aquatic life. Reservoirs without anthropogenic activity would likely have unobstructed migration routes for fish, facilitating natural movements between different habitats and contributing to gene flow among populations. Implementing responsible and sustainable fishing practices helps maintain fish populations at healthy levels. Fishing regulations, such as catch limits and size restrictions, can prevent overfishing and ensure the sustainability of fish populations. Overall, kopra reservoir well-managed fish diversity reservoir, balance the needs of human use, conservation, and ecological health. Reservoir is essential to work towards preserving the natural balance and diversity of fish species to ensure the reservoir's long-term sustainability and the well-being of the surrounding ecosystem.

Discussion:- A total of 27 species representing 11 family and 6 order (table 1). Were recorded; of 14 species are LR-nt(lower risk near threatened), 8 species are VU (Vulnerable), 1 species are LR-Ic (lower risk least concern and 3 species are EN (endangered species). some following fish species found in kopra reservoir. *Labeo rohita, Labeo gonius*, and *Ompok bimaculatus* are the principal shallow-water fishes, whereas *Catla catla*, *Chita lachitala*, and *Notopterus notopterus* are the principal deep-water fishes, respectively. The collected fish have been divided into three groups based on their eating habits: bottom feeders *Labeo calbasu, L. bata, Labeo gonius*, and *Cirhinnus mrigala*; medium feeders *Labe orohita*, *Wallego attu*, and *Mystes* sps.

Water parameters are collected from different sites representing on (table 2), reservoir water Temperature is 32.4˚C, pH is 9.24, DO is 7.32ppm, conductivity-240, ORP -24.1µS/cm, TDS 104.75ppm. kopra village ground water parameters are 26.58˚C, pH is 7.68 , DO is 5.81ppm , conductivity 809, ORP -9.31µS/cm, TDS 404ppm. Khairadih village ground water is very hard water temperature is 26.79˚C, pH 7.28, DO 5.01ppm, conductivity of water is 2403, ORP is-2.91µS/cm, TDS of water is 1202ppm. TDS includes a wide range of dissolved substances, such as minerals (e.g., calcium, magnesium, potassium), salts (e.g., sodium chloride), metals (e.g., iron, manganese), and other organic and inorganic compounds. In some cases, elevated TDS levels may be naturally occurring and might not necessarily be harmful to health. For example, certain minerals in water can contribute to its taste and have some health benefits. khairadhih village peoples for drinking water and cooking purpose use kopra reservoir , they only use for bathing and washing purposes of ground water. Mostly khairadhih village peoples are directly and indirectly depended on kopra reservoir.

Sakara, Sarseni, Amsena, and Medpara village inhabitants use reservoir water for irrigation. A few villages use kopra reservoir water for irrigation during the kharif crop season. Not a lot of anthropogenic pressure on reservoirs is observed. The kopra reservoir is a pressure-free, pollution-free reservoir. The reservoir lies away from populated areas and is only partially shielded from the state highway's and an agricultural field's heavy traffic. The reservoir is used for both household and agricultural purposes.

Kopra reservoir is rich in fish diversity but the conversation of it very important,from last 1 year fishermens suffering with aquatic plants high amount of aquatic plants spread across the areas in reservoir. Due to aquatic plants fish net does not disperse in water properly. Some days fisher man get less fish.

Conclution:-

There are a total of 27 species in the kopra reservoir, representing 11 families and 6 orders (table 1). 14 species were identified; of those, LR-nt (lower risk near threatened) species, VU (vulnerable) species, LR-Ic (lower risk least concern) species, and EN (endangered species) species were documented. In the kopra reservoir, the following fish species can be found. Deepwater fish include *Catla catla, Chitala chitala*, and *Notopterus notopterus* among others, whereas the principal shallow water fish are *Labeo rohita, Labeo gonius*, and *Ombok bimaculatus*. The collected fish have been divided into three groups based on their eating habits:

surface feeders *Catla catla*, middle feeders *Labeo rohita*, *Wallego attu,* and Mystessps, and bottom feeders *Labeo calbasu, L.bata, Labeogonius, and Cirhinnus mrigala*. Regarding fish diversity in other natural waters, more research is required. It must be aware of the threats facing our inland waters' biodiversity as well as the factors contributing to their deterioration. It must continue to develop and use techniques for estimating the ecosystems' environmental, social, and economic values and the effects these values have on inland waterways' biodiversity. In order to define biodiversity in operational terms and to create and test robust inventory, evaluation, and monitoring techniques across a variety of geographical scales, researchers and managers must collaborate. After assessment of water quality of Kopra Reservoir there are many different parameters found water pH, DO, TDS, ORP and temperature of reservoir water and ground water of kopra and khairadhih villages. Khairadhih water parameters are highly increased parameters, water contains TDS and ORP is more. the water from this village is very unsafe and must be used only after suitable treatment process.

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■■■

Dr. Ajay Kumar Singh With over 15 years of research experience in forest watershed management, remote sensing & GIS, landscape dynamics, and forest biodiversity, Dr. Ajay Kumar Singh currently holds the position of Assistant Professor at Guru Ghasidas University in Bilaspur, Chhattisgarh, India. He is the recipient of multiple prestigious awards, including Young Scientist of the Year in 2022, 2019, and Environmental Biologist of the Year in 2017.

Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

Sudhir Ranjan Choudhury, an Indian researcher, currently pursuing a Ph.D. in Forestry, Wildlife, and Environmental Sciences from Guru Ghasidas University. With a robust background in Forestry, Biodiversity, GIS, Remote Sensing, and Conservation of Natural Resources, he has actively engaged in various training programs and workshops to enhance his expertise. His scholarly pursuits extend to participation in conferences and seminars dedicated to water resource management, biodiversity, and conservation. The editor, Mr. Choudhury has contributed significantly to the field of environmental science. His research publications, focusing on diversity, taxonomy, and conservation, have found a place in various reputable journals. Notably, his impactful work has been cited in numerous publications, attesting to its relevance and influence in the academic domain. In recognition of his contributions, Mr. Choudhury was honored with the Young Scientist Associate Award-2023, underscoring his dedication and achievements.

Ashutosh Anand is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildlife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.

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WILDLIFE MANAGEMENT AND CONSERVATION IN A CHANGING WORLD

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Abstract:

Wildlife management is crucial for ensuring the long-term survival and well-being of wildlife and their habitats in a changing world. It is important for conserving biodiversity, maintaining ecosystem functioning, promoting sustainable resource management, mitigating conflicts, supporting local economies, and advancing scientific knowledge. Wildlife management and conservation are crucial aspects of addressing the challenges that arise in a changing world. As human activities continue to impact ecosystems and species around the globe, it is essential to adapt new approaches to ensure the long-term survival and well-being of wildlife populations. The field of wildlife management is continuously evolving, and there have been many developments in recent years. This article highlights the recent approaches for wildlife management.

Keywords: Wildlife management, conservation, technology, conflict mitigation, adaptation.

Introduction:

Wildlife refers to all non-domesticated animal species, including mammals, birds, reptiles, amphibians, fish, and invertebrates, living in their natural habitats (Chandrakar, 2018). Wildlife management involves the application of scientific principles and practices to ensure the conservation, sustainable use, and well-being of wildlife populations and their habitats. It encompasses a range of activities, including population monitoring, habitat management, disease control, hunting and fishing regulations, and education and outreach (Gopal, 2011).

Wildlife management plays a critical role in conserving and sustaining biodiversity, protecting ecosystems, and promoting the well-being of both wildlife and human populations. Wildlife management is essential for preserving biodiversity, which is crucial for the stability and resilience of ecosystems. It involves protecting and managing wildlife populations, habitats, and ecosystems to ensure the survival of diverse species (Gibson et al., 2011). Wildlife species play important roles in maintaining ecosystem balance and functioning. By regulating population dynamics, controlling prey species, dispersing seeds, and cycling nutrients, wildlife contribute to the overall health and stability of ecosystems (Sekercioglu et al., 2004). Wildlife management helps ensure the sustainable use of wildlife resources, such as hunting and fishing. It involves setting regulations and guidelines to prevent overexploitation, maintain healthy populations, and support the long-term availability of wildlife for future generations (Nuno et al., 2013). Wildlife management helps mitigate conflicts between humans and wildlife. By understanding and addressing the causes of conflicts, implementing preventive measures, and developing strategies for coexistence, wildlife management promotes harmonious interactions between wildlife and local communities (Dickman, 2010). Effective wildlife management can provide economic benefits through nature-based tourism and ecotourism. By protecting and conserving wildlife and their habitats, it creates opportunities for sustainable tourism, generating revenue, employment, and supporting local economies (Naidoo & Adamowicz, 2006). Wildlife management contributes to scientific research and knowledge generation. By studying wildlife populations, behavior, and ecological interactions, it expands our understanding of ecosystems, supports evidence-based decision-making, and advances conservation science (Beier et al., 2017).

Traditional wildlife management methods encompass a range of practices that have been employed by communities and cultures around the world to conserve and sustainably utilize wildlife. Many traditional societies have established rules and regulations regarding hunting practices to ensure sustainable harvests. These regulations may include restrictions on hunting seasons, bag limits (the number of animals that can be harvested), and the use of certain hunting methods (Lindsey et al., 2007). Creating Wildlife sanctuaries and protected areas is a common traditional method for conserving wildlife (Chandrakar, 2012). These protected areas are designated spaces where hunting or other human activities are restricted or prohibited. They provide safe havens for wildlife to thrive and reproduce (Chandrakar et al., 2016). Traditional habitat management involves the deliberate manipulation of habitats to benefit wildlife. Practices such as controlled burning, selective tree cutting, or the creation of water sources can help maintain or enhance suitable habitats (Boyd, 2000). The indigenous and local communities often possess extensive knowledge about the behavior, habitat requirements, and population dynamics of wildlife in their regions. This traditional ecological knowledge is passed down through generations and can be invaluable in understanding and managing wildlife populations (Berkes, 2008). Many traditional societies have cultural practices and taboos associated with specific wildlife species. These practices and taboos may serve as conservation tools by regulating the use of certain animals or their habitats (Alvard, 1995). These traditional wildlife management methods have been effective, but in this changing world, they may need to be adapted and integrated with modern scientific approaches to address the challenges of changing landscapes, climate change, and increasing human impacts on wildlife populations.

2. Recent Trends In Wildlife Management:

Wildlife management practices are continually evolving and adapting to meet the challenges posed by various factors, including changes in ecological understanding, societal values, and environmental conditions. Wildlife management recognizes the importance of incorporating diverse stakeholder perspectives. This includes engaging local communities, indigenous peoples, NGOs, scientists, and policymakers in decision-making processes to ensure that management practices reflect a range of values, needs, and knowledge systems (Gore et al., 2019). Advances in technology play a significant role in shaping wildlife management practices. Techniques such as remote sensing, genetic analysis, and data modeling contribute to improved monitoring, assessment, and decision-making processes in wildlife management (Cushman et al., 2010). This dynamic approach ensures that wildlife management practices remain effective and responsive to the challenges and opportunities presented in a changing world.

Fig. Approaches of wildlife management

3. Conservation Technology:

The use of technology has been increasingly integrated into wildlife management practices. For example, remote sensing techniques, such as satellite imagery and drones, are being utilized to monitor wildlife populations, track migration patterns, and detect illegal activities like poaching. Additionally, camera traps and GPS tracking devices are employed to gather data on animal behavior and movements.

A. Remote Sensing and Satellite Imagery: Remote sensing and satellite imagery are powerful tools for wildlife management, providing valuable information about the distribution, abundance, and behavior of various animal species (Pettorelli et al., 2018). These technologies allow researchers and conservationists to monitor ecosystems, track wildlife populations, and assess habitat conditions on a large scale (Pettorelli et al., 2014).

Remote sensing involves collecting data about an object or area from a distance, typically using aircraft or satellite-based sensors. It encompasses a range of techniques, including the use of visible, infrared, and thermal sensors. In wildlife management, remote sensing is employed to study various aspects of animal ecology, such as habitat mapping, animal movement patterns, and population dynamics (Pimm et al., 1995; Nagendra, 2001).

Satellite imagery refers to the visual representation of Earth's surface captured by satellites orbiting the planet. Satellites equipped with various sensors capture images at different wavelengths, providing valuable information about land cover, vegetation, and environmental conditions. Satellite imagery is extensively used in wildlife management to monitor habitats, detect changes, and estimate population sizes (Strimas-Mackey et al. 2018).

B. Camera Traps: Camera traps are an essential tool in wildlife management, providing valuable information about animal populations, behavior, and habitat use (O'Connell et al., 2010). These devices consist of motion-activated cameras that capture images or videos of animals as they pass by. Camera trapping allows researchers and conservationists to collect data on species presence, abundance, activity patterns, and more (Rovero et al., 2013).

Camera traps have revolutionized wildlife research and monitoring. They are strategically placed in various habitats, such as forests, grasslands, and wetlands, to capture images or videos of animals in their natural environments. Camera trapping is a non-invasive technique that minimally disturbs wildlife, making it particularly useful for studying elusive and nocturnal species (O'Connell et al., 2011).

Camera traps provide researchers with a wealth of data on wildlife populations and behaviors. The images or videos captured by the cameras are analyzed to identify species, estimate abundance, assess activity patterns, and study other ecological parameters (Swinnen et al., 2019). Advanced techniques, such as machine learning and computer vision, are employed to automate the identification and classification of species in camera traps data (Meek et al., 2015).

C. Drones (Unmanned Aerial Vehicles - UAVs): Drones, also known as Unmanned Aerial Vehicles (UAVs), have emerged as a powerful tool for wildlife management and conservation. These remote-controlled aircraft equipped with high-resolution cameras and thermal imaging sensors enable researchers and conservationists to gather valuable data on wildlife populations, habitat conditions, and ecological processes (Hodgson et al., 2018).

Drones allow for efficient and cost-effective aerial surveys of wildlife populations. They can capture high-resolution imagery or videos, providing detailed information on species distribution, abundance, and habitat use. Aerial monitoring with drones also enables the detection of changes in vegetation, land cover, and other environmental parameters relevant to wildlife management (Hodgson et al., 2018).

Drones offer a non-invasive approach to data collection in wildlife research. Compared to traditional methods like helicopter or ground surveys, drones produce minimal disturbance to wildlife, reducing stress and potential biases in behavior observations. They can access challenging or remote terrain, enabling the monitoring of species in inaccessible areas (Torres et al., 2009).

Drones equipped with GPS and telemetry systems can be used to track and monitor the movements of individual animals. This technology is particularly useful for studying migratory species, monitoring endangered populations, and detecting illegal activities like poaching or habitat destruction (Cagnacci et al., 2010). Drones can aid in identifying and protecting critical wildlife habitats as well (Kays et al., 2015).

D. GPS Tracking: GPS (Global Positioning System) tracking is a valuable technology used in wildlife management for monitoring and tracking the movements and behaviors of animals. GPS tracking devices equipped with small, lightweight GPS receivers are attached to animals, allowing researchers to collect precise location data. This information helps in understanding animal behavior, migration patterns, habitat selection, and population dynamics (Kays et al., 2015).

GPS tracking devices use signals from satellites to determine the precise location of an animal at regular intervals. These devices are designed to be lightweight and durable, ensuring minimal impact on the animal's behavior and well-being. The collected GPS data is typically stored in the device or transmitted remotely for analysis (Cagnacci et al., 2010).

GPS tracking provides crucial insights into the movement patterns and behavior of wildlife. It allows researchers to study home range sizes, habitat use, migration routes, foraging behaviors, and interactions between individuals or species. This information helps in understanding ecological processes, resource selection, and responses to environmental changes (Bohrer et al., 2013).

GPS tracking plays a vital role in wildlife conservation and management efforts. It aids in identifying critical habitats, monitoring endangered species, assessing the effectiveness of protected areas, and mitigating human-wildlife conflicts. GPS data can also inform wildlife management decisions, such as establishing wildlife corridors, designing conservation strategies, and evaluating the impacts of human activities on animal movements (Kays et al., 2021).

E. Acoustic Monitoring: Acoustic monitoring is a valuable technique used in wildlife management to study and monitor animal populations, particularly those that communicate through vocalizations or produce distinctive sounds. It involves the use of specialized acoustic recording equipment to capture and analyze animal sounds in their natural habitats (Digby et al., 2018). Acoustic monitoring provides insights into species presence, behavior, distribution, and habitat use (Sueur et al., 2019).

Passive Acoustic Monitoring (PAM) involves deploying recording devices, such as microphones or hydrophones, in strategic locations to capture sounds produced by animals. These devices continuously record sound over extended periods, enabling researchers to study animal vocalizations, communication networks, and acoustic behavior. PAM is particularly useful for studying elusive or nocturnal species that are difficult to observe directly (Marques et al., 2013).

The recorded acoustic data is analyzed using bioacoustics techniques. Spectrograms and sound analyses are employed to identify and classify different animal vocalizations, such as bird songs, insect calls, amphibian choruses, and marine mammal vocalizations. By comparing recorded sounds with known species vocalizations, researchers can determine species presence, estimate abundance, and assess changes in vocal behavior over time (Pieretti et al., 2017).

Acoustic monitoring plays a vital role in wildlife conservation and management. It helps in assessing the status and distribution of endangered species, monitoring the impacts of habitat loss or fragmentation, and evaluating the effectiveness of conservation efforts. Acoustic data can also inform land-use planning, species conservation plans, and the mitigation of human-wildlife conflicts (Linchant, et al. 2015).

F. DNA Analysis and Genetic Monitoring: DNA analysis and genetic monitoring are powerful tools in wildlife management that help researchers understand the genetic diversity, population structure, and relatedness of species (Funk et al., 2012). These techniques involve extracting DNA from individuals or environmental samples and analyzing specific genetic markers to gain insights into population dynamics, gene flow, and conservation strategies (Schwartz et al., 2017).

Genetic sampling involves collecting biological samples such as blood, tissue, feathers, or feces from individuals or the environment. From these samples, DNA is extracted and analyzed using various molecular techniques such as polymerase chain reaction (PCR), DNA sequencing, or genotyping. Specific genetic markers, such as microsatellites or mitochondrial DNA, are targeted to assess genetic variation and population structure (Allendorf et al., 2010).

DNA analysis provides information about population genetics, including measures of genetic diversity, effective population size, and gene flow. It helps in identifying genetically distinct populations, determining their connectivity, and understanding the patterns of migration and dispersal. Genetic relatedness analysis allows for the estimation of kinship and familial relationships among individuals, aiding in studies of social structure and mating systems (Morin et al., 2019).

Genetic monitoring plays a crucial role in wildlife conservation and management. It helps in assessing the impacts of habitat fragmentation, identifying vulnerable populations, and designing effective conservation strategies. Genetic data can guide captive breeding programs, reintroduction efforts, and the establishment of protected areas. It also aids in the detection of wildlife trafficking and the identification of illegal trade routes (Funk et al., 2019).

4. Community-Based Conservation:

Community-based conservation (CBC) has gained recognition as an effective approach to wildlife management that emphasizes the involvement and engagement of local communities in the conservation and sustainable use of natural resources (Berkes, 2004). It recognizes the importance of the knowledge, skills, and perspectives of local people in protecting and managing wildlife and their habitats (Brosius et al., 2005). By involving communities, this approach aims to achieve both conservation goals and socio-economic development in the area (Mehta et al., 2018). The key principles and strategies commonly associated with community-based conservation, are summarized in the Table:

Table: The principles and strategies of Community-based Conservation

Principles	**Strategies**	**References**
Community Engagement and Participation	Local communities are actively involved in decision-making processes, planning, and implementation of conservation initiatives.	Agrawal et al. (1999)

Traditional Ecological Knowledge	Traditional knowledge held by local communities is recognized and integrated into conservation efforts.	Berkes et al. (1999)
Rights and Access	Local communities' rights to land, resources, and benefits derived from conservation activities are recognized and respected.	Ostrom, (1990)
Sustainable Livelihoods	Conservation initiatives are designed to support the sustainable livelihoods of local communities, providing alternative income-generating activities.	Ashley et al. (2002)
Collaborative Partnerships	Collaboration between communities, NGOs, government agencies, and other stakeholders is fostered to achieve common conservation goals.	Brosius et al. (1998)
Adaptive Management	Conservation strategies are flexible and adaptive, incorporating learning from local experiences and adjusting interventions accordingly.	Armitage et al. (2009)

Community-based conservation involves engaging local communities in decision-making processes related to wildlife management. It recognizes the importance of involving community members in discussions, planning, and implementation of conservation strategies (Berkes, 2004). CBC aims to empower local communities by building their capacity in conservation practices, providing training opportunities, and enhancing their understanding of the importance of wildlife and biodiversity conservation (Agrawal et al., 1999). CBC incorporates a sustainable livelihoods approach, which recognizes the importance of addressing socio-economic needs of local communities while promoting conservation. It involves identifying and supporting alternative livelihood options that are compatible with wildlife conservation (Wells et al., 2004). CBC acknowledges the cultural and traditional practices of local communities, integrating indigenous knowledge and practices into conservation strategies. This approach respects and values the connection between local cultures and the natural environment (Berkes et al., 2000). CBC often involves establishing co-management structures and partnerships between local communities, government agencies, and conservation organizations. These collaborations promote shared responsibility, enhance local ownership, and foster effective management of wildlife and their habitats (McNeely et al., 2003).

Human-Wildlife Conflict Mitigation:

Human-wildlife conflict mitigation refers to the strategies and techniques employed to minimize conflicts and negative interactions between humans and wildlife. As human populations expand and encroach upon natural habitats, conflicts with wildlife arise due to competition for resources, damage to property, and threats to human safety (Graham, et al., 2005). Wildlife management aims to address these conflicts while ensuring the conservation and well-being of both humans and wildlife. Further insights into the concept of human-wildlife conflict mitigation and various strategies employed in wildlife management are discuss as follow:

A. Understanding the Nature of Conflicts: Effective mitigation begins with a comprehensive understanding of the underlying causes and context of human-wildlife conflicts. This involves studying factors such as changes in land use patterns, habitat fragmentation, wildlife behavior, and human activities that contribute to conflicts (Dickman et al., 2011). Human-wildlife conflicts can take various forms, including crop raiding, livestock predation, property damage, and human injuries or fatalities. It is crucial to comprehensively assess the underlying causes, such as habitat loss, food scarcity, or human behavior, to develop effective mitigation strategies (Redpath et al., 2015).

B. Habitat Management: Protecting and managing wildlife habitats can help minimize conflicts by maintaining suitable spaces for wildlife. This can involve maintaining or restoring natural corridors, establishing buffer zones between human settlements and wildlife areas, and implementing sustainable land-use practices (Woodroffe, et al., 1998). By providing suitable habitats and adequate food sources for wildlife, their reliance on human-dominated landscapes decreases.

C. Land-Use Planning and Zoning: Effective land-use planning can help reduce conflicts by separating human settlements, agricultural areas, and critical wildlife habitats. Zoning regulations can restrict certain activities near wildlife areas, minimizing the potential for conflicts and ensuring human safety. This approach ensures that development activities consider the needs of wildlife and their movement patterns (Naughton-Treves et al., 2003).

D. Physical barriers and Deterrents: Physical barriers, such as fences, electric fencing, can be used to separate human settlements and agricultural areas from wildlife habitats, reducing direct contact and damage. Additionally, deterrents such as scare devices, noise-making devices, and visual stimuli can be employed to discourage wildlife from approaching human-inhabited areas (Woodroffe et al., 2005; Nyhus et al., 2005).

E. Compensation and Insurance Schemes: Compensation schemes and economic incentives can help alleviate the economic losses experienced by individuals affected by wildlife damage. This can reduce negative attitudes towards wildlife and enhance tolerance, promoting coexistence between humans and wildlife (Madden, 2004). Insurance schemes can also be implemented to mitigate financial risks and compensate for wildlife-related losses (Nyhus et al., 2005).

F. Community-Based Conservation: Engaging local communities in conservation efforts is crucial for successful conflict mitigation. Involving communities in decision-making, providing education and awareness programs, and incentivizing conservation practices can promote coexistence between humans and wildlife. Collaborative initiatives that include local knowledge and perspectives can lead to effective and sustainable conflict mitigation outcomes (Redpath et al., 2015). Raising awareness about the importance of wildlife conservation, promoting understanding of wildlife behavior, and providing guidance on conflict prevention and mitigation can help foster positive attitudes towards wildlife and reduce conflicts (Hill, 2004).

G. Wildlife Corridors and Connectivity: Establishing wildlife corridors and maintaining ecological connectivity between fragmented habitats allow animals to move safely across landscapes, reducing their reliance on human-inhabited areas and minimizing conflicts (Dickman, 2010).

H. Early Warning Systems and Rapid Response: Implementing early warning systems, such as camera traps or acoustic devices, can help detect wildlife presence near human settlements. Rapid response teams can be deployed to deter or relocate wildlife before conflicts escalate (Treves et al., 2003).

I. Research and Monitoring: Continuous research and monitoring of wildlife populations, behavior, and movement patterns are essential for understanding the dynamics of human-wildlife conflicts. This information can inform the development of targeted mitigation strategies (Treves et al. 2009).

J. International Collaboration and Policy Development: Collaborative efforts between governments, conservation organizations, and local communities are crucial for effective human-wildlife conflict mitigation. Developing policies and regulations at regional and national levels can provide a framework for addressing conflicts and promoting sustainable wildlife management (Redpath et al., 2015).

Conservation And Sustainable Development:

This approach recognizes the interdependence of ecosystems, biodiversity, and human well-being. Conservation initiatives are being integrated with sustainable development practices, aiming to achieve a balance between conservation goals and the well-being of communities living in and around wildlife habitats.

Conservation involves the protection, preservation, and sustainable use of natural resources, including wildlife and their habitats. It aims to maintain biodiversity, prevent species extinction, and preserve ecological balance. Conservation strategies in wildlife management encompass a range of approaches, such as establishing protected areas, implementing species-specific conservation programs, managing habitats, controlling invasive species, and combating illegal wildlife trade. These efforts are essential to safeguard the integrity and resilience of ecosystems and ensure the survival of endangered species (Chandrakar et al., 2016).

Sustainable development integrates conservation goals with social, economic, and cultural considerations to achieve a balance between environmental protection and human well-being. In wildlife management, sustainable development recognizes the interdependence between ecosystems and society. It involves managing wildlife resources in a manner that meets present needs while preserving them for future generations. Sustainable development strategies in wildlife management include promoting sustainable hunting and fishing practices, implementing wildlife tourism initiatives, engaging local communities in conservation activities, and considering the socio-economic impacts of conservation efforts.

The recent approaches for conservation and sustainable development in the context of wildlife management are explained as follow:

A. Integrated Conservation and Development : Integrated conservation and development approaches (ICD) seek to combine conservation objectives with socio-economic development goals. ICD recognizes the importance of involving local communities and stakeholders in wildlife management initiatives to achieve sustainable outcomes. This approach emphasizes the integration of conservation actions with community development projects, livelihood diversification, and sustainable resource management. By providing incentives and benefits to local communities, ICD aims to reduce negative human-wildlife interactions and promote the coexistence of people and wildlife (Wells et al., 2004).

B. Ecotourism: Ecotourism promotes wildlife conservation and sustainable development by providing economic incentives for local communities to protect natural areas. It involves responsible travel practices that minimize negative impacts on the environment while generating income and raising awareness about conservation (Honey, 2008).

C. Payment for Ecosystem Services (PES): PES is a mechanism where communities receive financial incentives for the conservation and sustainable management of ecosystems. This approach recognizes and rewards the value of ecosystem services, including those provided by wildlife habitats (Wunder, 2008).

D. Sustainable Livelihoods Approach: This approach focuses on improving the well-being of local communities by promoting diverse and sustainable livelihood options that are compatible with wildlife conservation. It emphasizes the importance of local participation, capacity building, and access to resources (Scoones, 2009).

E. Participatory Conservation: Participatory conservation involves engaging local communities in decision-making processes, resource management, and conservation activities. This approach recognizes the importance of local knowledge, empowers communities, and fosters a sense of ownership and responsibility towards wildlife and their habitats (Salafsky et al., 2000).

F. Ecosystem-based management (EBM): EBM is an approach that focuses on the ecological processes and functions of ecosystems as a basis for decision-making in wildlife management. EBM recognizes the interconnectedness of species, habitats, and ecological processes and emphasizes the need to manage wildlife resources within the context of larger ecosystems. It involves considering the ecological requirements of target species, maintaining ecological processes, and preserving habitat connectivity to promote biodiversity conservation and ecosystem resilience (Noss, 1999; Link et al., 2014).

Invasive Species Management:

Invasive species management is a critical component of wildlife management that focuses on preventing, controlling, and mitigating the impacts of non-native species that pose threats to native wildlife and ecosystems. Wildlife management strategies are increasingly addressing the issue of invasive species through prevention, early detection, and control measures. Efforts are being made to raise awareness, implement monitoring systems, and develop rapid response protocols to effectively manage and mitigate the impacts of invasive species (Simberloff et al., 2011). The recent approaches for invasive species management in the context of wildlife management are explained as follow:

A. Understanding Invasive Species: Invasive species are non-native organisms that, when introduced into a new environment, have the potential to cause ecological, economic, or social harm. They can outcompete native species, disrupt ecosystem processes, and alter habitat structure. Effective invasive species management requires understanding the biology, ecology, and impacts of invasive species on native wildlife and ecosystems (Simberloff et al., 2011).

B. Prevention and Early Detection: Preventing the introduction and establishment of invasive species is a crucial component of management. This includes measures such as regulating the trade and transport of potentially invasive species, implementing biosecurity protocols, and increasing public awareness. Early detection and rapid response efforts involve monitoring for new invasive species arrivals and taking immediate action to eradicate or contain them before they become established (Lodge et al., 2006).

C. Control and Eradication: When invasive species are identified, active control and eradication measures are necessary to reduce their populations and minimize their impacts. Control methods include physical removal, chemical treatments, biological control using natural enemies of the invasive species, and innovative techniques such as gene editing. The choice of control method depends on the species, its specific impacts, and the feasibility of the approach (Simberloff et al., 2013).

D. Restoration and Rehabilitation: Invasive species management often involves restoration and rehabilitation efforts to recover and restore native wildlife and ecosystems affected by invasions. This may include habitat restoration, reintroduction of native species, and promoting native biodiversity. Restoration activities help rebuild ecological resilience and improve the long-term health and functionality of the ecosystem (Palmer et al., 1997).

E. Public Education and Outreach: Raising public awareness about the impacts of invasive species and promoting responsible behavior is crucial for preventing their spread. Education and outreach programs inform communities, landowners, and recreational users about the risks associated with invasive species and the importance of early detection and reporting (McKinney, 2002).

F. Collaboration and Partnerships: Successful invasive species management requires collaboration and partnerships among stakeholders, including wildlife managers, scientists, government agencies, non-governmental organizations, and local communities. Collaborative efforts enhance knowledge sharing, resource allocation, and coordination of invasive species management activities (Ricciardi et al., 2017). Collaborative partnerships enable the development and implementation of policies, regulations, and management strategies to address invasive species at regional, national, and international levels (Pyšek et al., 2010).

Climate Change Adaptation:

Climate change has significant impacts on wildlife populations and ecosystems, necessitating adaptations in wildlife management strategies. Climate change adaptation in wildlife management refers to the strategies and actions taken to help wildlife populations and ecosystems cope with the impacts of climate change. It involves understanding the vulnerabilities of species and habitats to changing climatic conditions and implementing measures to enhance their resilience.

Adaptation strategies are being developed to help wildlife populations cope with changing conditions, including habitat restoration, creating wildlife corridors, and establishing protected areas that account for climate change projections:

A. Assessing Climate Change Vulnerability: Climate change adaptation in wildlife management begins with assessing the potential impacts of climate change on species, habitats, and ecosystems. This includes studying changes in temperature, precipitation patterns, sea-level rise, and extreme weather events and understanding how these changes might affect wildlife populations and their habitats (Parmesan, 2006). These assessments involve evaluating the sensitivity of wildlife species and habitats to climate change impacts, as well as their adaptive capacity. These assessments help identify priority species and areas for conservation action (Heller et al., 2009).

B. Habitat Conservation and Restoration: Protecting and restoring habitats is crucial for supporting wildlife adaptation to climate change. Conservation efforts focus on maintaining intact habitats, creating wildlife corridors, and restoring degraded areas to ensure suitable habitat conditions for wildlife under changing climatic conditions. This involves identifying and conserving areas that provide suitable conditions for species to adapt to changing climates and restoring degraded habitats to enhance their resilience (Hannah et al., 2002).

C. Connectivity Conservation: Establishing and maintaining ecological corridors or connectivity networks is important for facilitating the movement of wildlife as they adapt to shifting climate conditions (Beier et al., 2010).. By enabling species to migrate or disperse to more suitable habitats, connectivity conservation helps reduce the risk of isolation and genetic fragmentation (Carroll et al., 2017).

D. Assisted Migration and Translocation: In some cases, assisted migration or translocation of species may be necessary to help them move to more suitable habitats under changing climates. Assisted migration involves facilitating migration of species to areas where suitable habitat conditions are likely to persist in the future (McLachlan et al., 2007). Species translocation involves relocating individuals or populations to areas where they are expected to have a higher chance of survival and reproduction (Hoegh-Guldberg et al. 2008).

E. Monitoring and Adaptive Management: Monitoring wildlife populations and their responses to climate change is essential for adaptive management (Williams et al., 2007). By continuously monitoring species' distributions, abundance, phenology, and genetic diversity, wildlife managers can adjust conservation strategies and management actions based on the observed impacts of climate change (Stein et al., 2013).

F. Climate-informed Conservation Planning: Integrating climate change projections into conservation planning helps identify priority areas for protection and management. By considering future climate scenarios and species' adaptive capacities, conservation plans can be designed to promote long-term resilience and enable wildlife to persist in the face of changing environmental conditions (Groves et al., 2012).

G. Collaboration and Policy Integration: Effective climate change adaptation in wildlife management requires collaboration among stakeholders, including government agencies, conservation organizations, and local communities. Integrating climate change considerations into policies and management plans ensures that adaptation actions are prioritized and implemented (Heller et al., 2009).

Conclusion

In conclusion, recent trends in wildlife management reflect a growing recognition of the need to address the impacts of climate change and other environmental challenges on wildlife populations. Wildlife management strategies are increasingly integrating climate change considerations, such as habitat conservation, connectivity conservation, and climate-informed planning, to enhance the resilience of wildlife populations

(Millspaugh, 2018). The use of advanced technologies like remote sensing, GPS tracking, and data analytics is revolutionizing wildlife management. These tools provide precise and real-time data on species distribution, movement patterns, and population dynamics, enabling more effective decision-making (LaPoint et al., 2013). Community Engagement and Collaborative Conservation: Recognizing the importance of involving local communities, indigenous peoples, and stakeholders in wildlife management, there is a growing emphasis on participatory approaches. Collaborative efforts foster a sense of ownership, increase awareness, and leverage local knowledge for effective conservation (Maciejewski 2015). Wildlife management is shifting towards a more holistic and landscape-scale approach. This involves considering the entire ecosystem, focusing on large-scale conservation corridors, and promoting connectivity among protected areas to enable species movement and adaptation (Carroll et al., 2004). Rather than solely focusing on individual species, there is a growing recognition of the importance of managing entire ecosystems. This approach emphasizes maintaining ecological processes, biodiversity, and habitat integrity to support the resilience of wildlife communities (Link et al., 2014). These recent trends reflect an evolving understanding of the complexities of wildlife management and the need for adaptive, collaborative, and science-based approaches to conserve biodiversity in the face of changing environmental conditions.

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■■■

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SOCIO-ECONOMIC IMPLICATIONS OF HUMAN-ELEPHANT CONFLICT: A CASE STUDY IN THE DHARAMJAIGARH FOREST DIVISION

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Abstract:

This study investigated the socio-economic profiles of villagers, the extent of crop depredation by elephants, villagers' changing perspectives towards elephants, suggested mitigation measures, and the response of the forest department to human-elephant conflict (HEC). Surveys and interviews were conducted with 240 respondents to gather data. The socio-economic profiles of the villagers showed a diverse distribution across different age groups. The largest percentage of respondents fell within the 41-50 years age range (27.1%), followed by 31-40 years (23.8%) and 21-30 years (17.5%). The majority of villagers possessed small landholdings, with 61% owning between 1-5 bighas of agricultural land. Agriculture was the primary occupation, engaging 85% of the villagers, while 9.6% worked as daily waged laborers and 4.6% were involved in small businesses. Crop depredation by elephants was a significant issue in the study area, with the majority of respondents (58.8%) reporting over 50% crop damage. The highest percentage of respondents (28.3%) experienced crop damage ranging from 61-70%, followed by 17.9% with 51-60% damage. Moreover, 93.3% of farmers cultivated crops for subsistence purposes, suggesting minimal contribution to the economic well-being of the villagers. The study revealed that most villagers (94.6%) relied solely on crop cultivation for income and lacked alternative livelihood sources. This heavy reliance on agriculture made them highly vulnerable to crop damage caused by elephants. Despite the economic losses incurred, 45% of respondents still considered elephants as a form of Lord Ganesha, while 41.7% expressed annoyance and 24.2% even considered elephants as enemies. Concerning the response of the forest department, 42.9% of the villagers reported not receiving any response during emergency calls, while 37.1% experienced occasional responses, and only 20% received a rapid response. This inadequate response from the forest department further frustrated the affected villagers. The study also captured the villagers' suggestions for mitigating HEC. Approximately 26.3% of respondents supported the installation of electric fences, 20.4% suggested constructing trenches, and 42.9% favored a combination of both measures, depending on the landscape features. Additionally, 10.4% of respondents emphasized the construction of rubble walls to prevent elephants from entering agricultural fields and human habitation areas. The findings highlight the significant economic impact of HEC on the local population's livelihoods and emphasize the need for effective conservation strategies. The study's results can provide valuable insights to policymakers and conservationists in formulating targeted measures to address HEC and improve response mechanisms, ultimately fostering the coexistence of humans and elephants in the study area.

Keywords: Elephant, HEC (Human Elephant Conflict), Crop Damage, livelihood, Socio-economic

Introduction

The presence of elephants, in parts of India both historically and presently reflects a complex relationship between these majestic animals and the changing human landscape. The widespread distribution of elephants across the peninsula has been affected by habitat degradation, deforestation, and human encroachment. Although historical records indicate their existence in regions like Chhattisgarh, their extinction during the early 20th century followed by their return, in the late 20th century demonstrates the intricate dynamics of human-elephant interactions. This chapter delves into the distribution explores how human activities have impacted elephant habitats and examines the evolving patterns of elephant movement – all to shed light on the balance needed for humans and elephants to coexist in present day.

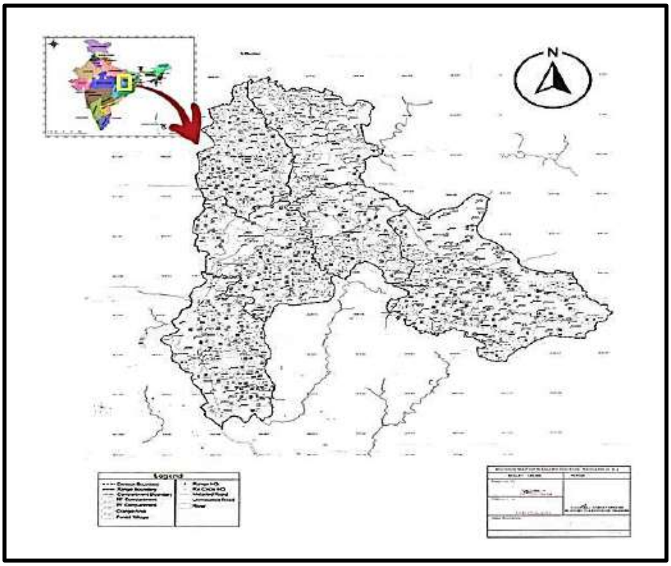
In the expanse of eastern India, around 2,500 elephants thrive (Anon, 2001). Among them, a select few groups have ventured into Chhattisgarh, setting the stage for a poignant human-elephant conflict. The narrative of this region's ecosystem reveals a somber transformation: once-vibrant habitats in Jharkhand and Odisha have succumbed to illegal logging, encroachment, industrial encroachment, and mining (Singh and Chowdhury, 1999; Singh, 2000). This degradation has coerced the local elephant populations to undertake extensive, disjointed migrations. The elephants, accustomed to traversing uninterrupted verdant stretches, now maneuver through fragmented forest patches, seeking larger havens. As a result of these environmental shifts, elephants have ventured into Chhattisgarh, as well as neighboring territories like Madhya Pradesh and Maharashtra, underscoring the complex interplay between habitat loss and their migratory movements.

Since 1988, the migration of elephants from various states to Chhattisgarh has been steadily rising. Presently, these majestic creatures inhabit the Surguja, Bilaspur, and Raipur forest circles. The period between 1993 and 2000 saw a temporary halt in migration due to elephant capture and training for forest patrolling in Achanakmar. However, in 2002, a herd of around 32 tuskers was sighted, now numbering 247-254 in northern Chhattisgarh, organized into 19 herds. Notably, Bilaspur Circle hosts 121 elephants, Surguja houses 110, and Raipur Circle is home to 23.

The latest census reveals that the Korba region boasts the highest elephant population, with 69 individuals, closely trailed by Dharamjaigarh at 49, and Sarguja at 37. Notably, a significant portion of these elephants frequently engage in migratory patterns, traversing the vicinity of neighboring states such as Odisha and Jharkhand.

Since 2000, rising cases of Human-Elephant Conflict (HEC) have plagued Chhattisgarh due to increasing migratory elephants. Unfamiliar with such encounters, local residents attempt unguided elephant deterrence, leading to disoriented elephants causing substantial harm. The regions of Korba, Raigarh, Dharamjaigarh, Jashpur, and Sarguja in Chhattisgarh currently grapple with HEC. Notably, the Dharamjaigarh and Korba Forest Divisions have hosted a consistent elephant herd since 2000, potentially migrating from Jharkhand and Odisha. Tragically, Chhattisgarh recorded an annual average of 18.09 human deaths and 13.91 injuries due to HEC from 2006-07 to 2016-17, underscoring the urgency of addressing this crisis.

Study Area



Dharamjaigarh forest division is primarily flat, with a small northern mountainous section (200m to 1100m elevation), transitioning to a central plateau. Southern-eastern hills form Kaapu and Lailunga plateau at 575m elevation. The Dharamjaigarh Forest Division connects with Sarguja, Jashpur, Odisha, Raigarh, and Korba. With abundant forest cover and connectivity, it serves as a significant elephant habitat. Chhal, despite being small, boasts dense forest preferred by elephants. Dharamjaigarh forest range is their second-choice habitat in the division.

The existing Dharamjaigarh forest division comprises primarily Sal Forest and Mixed Forest with Teak plantations. The area also features a range of climbers, herbs, shrubs, epiphytes, and parasites. Prominent tree species include Sal, Saja, Teak, Tendu, Mahua, Aamla, and Galgala. Bamboo species are also prevalent in the forest area.

Elephant Ranging

The complex interplay between habitat availability, anthropogenic activities, and the survival of Asian elephants (Elephas maximus) in certain regions. The pervasive impact of human activities, primarily large-scale mining operations and human disturbances. These factors have inflicted significant damage on the habitat, leading to forest destruction and disruptions in elephant movements throughout the year. Consequently, the once-established ranging patterns of these elephants have been compromised, hindering their ability to establish permanent range areas. This underscores the precarious existence of Asian elephants in this landscape.

The importance of vast, intact habitats becomes evident when considering the dietary needs of these elephants. Requiring more than 300 kg of fodder per day, Asian elephants necessitate extensive home ranges. These ranges, influenced by various factors such as nutrient availability, vegetation type, and human presence, change with the shifting seasons. As the landscape transitions between wet and dry seasons, elephant habitat preferences shift accordingly, emphasizing the significance of providing diverse and suitable habitats for their survival.

Tragically, the very habitats on which these elephants depend are increasingly under threat due to human-induced changes. Deforestation resulting from illegal logging, encroachments, and open-cast mining has forced elephants to seek refuge in neighboring regions, leading to a notable movement of elephants from Jharkhand into Chhattisgarh. This migration underscores the profound consequences of habitat loss, and the fact that these immense creatures are compelled to adapt to changing landscapes in order to secure their existence.

The intricate factors influencing elephant habitat utilization. Availability of water and nutritional quality of forage emerge as key drivers shaping their movement patterns. Elephants' attraction to lowlands, particularly cultivated ones, is evident. Even within protected reserves, elephants have been known to venture into cultivated lands, possibly as a foraging strategy. These lowlands offer accessibility, relatively flat terrains, and a consistent habitat in terms of vegetation, appealing to elephants' preferences.

The broader implications of habitat destruction and fragmentation are clear. Natural habitats, rich in biodiversity, are being replaced by profitable agricultural landscapes and plantations. Such conversions not only threaten the forest cover but also exacerbate human-elephant conflicts due to increased human settlements, agriculture, livestock grazing, and encroachments. As these landscapes evolve, so must the strategies for managing elephant populations. Understanding how these altered environments affect elephant distribution is imperative, especially as Asian elephants venture beyond protected areas into regions of higher human density.

In conclusion, the intricate balance required for the survival of Asian elephants. Their extensive habitat needs, coupled with dependence on diverse and intact landscapes, make them vulnerable to habitat loss and human-induced disturbances. As human activities continue to transform natural habitats, conservation efforts must prioritize the preservation of expansive, interconnected habitats to ensure the continued existence of these magnificent creatures. Moreover, understanding the dynamic interplay between elephants, their habitat, and human activities is essential for implementing effective strategies to manage and protect these iconic animals in an ever-changing world. In Dharamjaigarh elephants are staying and ranging throughout the year also they found the place suitable.

Feeding Behavior

The feeding ecology of elephants, particularly Asian elephants, offers a fascinating insight into their adaptable dietary habits across various habitats and seasons. These majestic creatures are known as generalist feeders, consuming a diverse array of plant species including leaves, twigs, and grasses.

Their diet composition fluctuates in response to environmental factors, with a preference for browsing during dry seasons and grazing when grasses are abundant in wet seasons. Several studies conducted across different regions have shed light on the plant families and genera that constitute a substantial portion of their diet. Species such as Acacia, Bambusa, Ficus, Musa, and more emerge as important dietary components.

Remarkably, elephants exhibit selective preferences for certain plants, indicating a complex interplay between nutritional needs and available food sources. Additionally, the phenomenon of elephants raiding crops underscores the challenges they face in meeting their nutritional requirements. This behavior is driven by the nutrient-deficient nature of their wild diet, which compels them to venture into agricultural areas. Ultimately, the dietary strategies of elephants highlight their remarkable adaptability and the intricate balance between their ecological role and interactions with human landscapes.

The Dharamjaigarh carry dense forest and these are the tree species: Sal, Saja, Char, Tendu, Dhawara, Mahuwa, Senha, Kekar, Jamun, Teak/Sagon, Shisham, Harra, Khair, Haldu, Amaltas, Kusum, Palas, Aam, Semal, Bargad, Arjun, Bel, Peppal, Beer, Emli, Kullu, Chirol, Anjan, Dhaman, Gamari, Dimaru, Kathjamun on which elephants are feeding. They are using different part of plant like bark, leaves, steam & Fruits.

Conflicts

In the context of Dharamjaigarh, the issue of large-scale forest degradation has led to a complex and multifaceted conflict between wildlife and farming activities, resulting in significant challenges for both humans and animals. As highlighted in the cited text, this conflict stems from the need of a diverse range of wildlife to seek resources from human-affected areas due to the degradation of their natural habitats. This interaction has far-reaching consequences, particularly evident in the form of crop damage and potential threats to human lives.

The conflict is characterized by the intrusion of wildlife, notably elephants, into farming areas, leading to substantial crop damage and occasional human casualties. While the overall crop damage due to human-elephant conflict (HEC) in Dharamjaigarh may be comparatively less than in some other parts of India, the local impact remains significant. Previous studies have reported similar trends in different regions of India, with around 10% crop loss being a common figure irrespective of the location and time.

Notably, the variation in individual-level crop damage, ranging from 0.4% to a staggering 60.6%, underscores the disproportionate economic burden on marginalized farmers who rely heavily on subsistence agriculture. The limited cultivated area and the high dependence of these farmers on their crops exacerbate the negative impact of even a modest percentage of damage. This economic setback has broader implications, including annoyance among the affected population towards wildlife, particularly elephants. The loss of structural property, granaries, and livestock further compounds the economic strain on local communities.

Beyond the economic implications, human-elephant conflict has broader consequences for the overall well-being of rural inhabitants. The loss of earning members or their permanent disability due to such conflicts can have a profound impact, divesting families of their economic stability and livelihoods. These consequences, as documented in previous research, not only affect the psychology and behavior of local people but also reshape their attitudes toward wildlife and forest conservation. The increasingly prevalent instances of human-elephant conflict in Dharamjaigarh have contributed to a significant shift in the relationship between communities and their natural environment.

Ultimately, the conflict in Dharamjaigarh encapsulates the intricate interplay between human activities, wildlife behavior, economic vulnerabilities, and psychological well-being. The struggle for resources driven by large-scale forest degradation has led to a situation where both wildlife and humans are affected negatively, calling for comprehensive strategies that balance conservation efforts with the socio-economic needs of the local population.

Public Attitudes towards Human-Elephant Conflict

The intricate relationship between India's economy and its agricultural sector forms the cornerstone of its rural communities. With agriculture as the backbone of the nation, the rural economy becomes intricately tied to the fortunes of seasonal harvests. This delicate balance, however, is under constant threat from Human-

Elephant Conflict (HEC), which poses substantial economic risks. Farmers, heavily reliant on the bounty of each harvest, face significant losses when their crops fall victim to marauding elephants. The repercussions of such losses are not confined solely to crops; property and livestock also fall prey to the devastating consequences of HEC, further exacerbating the economic toll on rural dwellers. Beyond its economic ramifications, HEC sends shockwaves through the very fabric of rural life, affecting overall well-being.

The repercussions extend even more dramatically when the primary breadwinner of a family succumbs to HEC or is permanently disabled. This catastrophic event leaves the family not only emotionally shattered but also economically vulnerable. Such a misfortune dismantles the economic stability painstakingly built over time, pushing the family into financial distress. These grim consequences reverberate deeply in the lives of the victims, a fact extensively documented in studies by Karanth et al. (2013) and Madhusudan (2003). The psychological and behavioral shifts in the affected communities are palpable, especially in areas with significant proximity to forests. The looming specter of food insecurity and danger to life ushers in a transformation in the locals' perception of elephants and their environment.

An additional factor exacerbating the economic fallout is the absence of viable alternative income sources. The majority of rural inhabitants depend heavily on seasonal agriculture for their livelihoods. Consequently, any disruption, such as damage from HEC, upends their economic stability, triggering a perceptual shift that casts the elephant from a revered entity to a symbol of adversity. This shift is consistent with earlier observations made in diverse regions of India, as highlighted by Sarkar et al. (2008a, 2013). As beliefs evolve, so too does the threshold of tolerance. The villagers' attitudes shift negatively with extended exposure to the forest, as evidenced by Sarker and Roskaft (2011). The escalating instances of HEC across the elephant's range countries inflict profound implications on conservation efforts, a point emphasized by Nsonsi et al. (2017), Patil and Patil (2017), Mumby and Plotnik (2018), Abdullah et al. (2019), and Sampson et al. (2019).

In the studied region, local sentiments took a downturn with the handling of ex-gratia payments. Delays and irregularities in compensating victim families for human casualties, injuries, and crop damage tarnished perceptions of elephant conservation. This phenomenon resonates beyond the study area, as demonstrated by Chakraborty (2018) in other parts of India and Ravenelle and Nyhus (2017) in various nations. To mend this fracture and build bridges toward effective conservation, forest departments must implement strategies to ensure timely compensation, fostering goodwill and cooperation among rural communities. In the face of these multifaceted challenges, a comprehensive conservation approach that takes into account the complexities of HEC and its impact on elephant preservation becomes an imperative task for government bodies.

Conclusion

In conclusion, the situation surrounding human-elephant conflict (HEC) in Chhattisgarh is characterized by a complex interplay of factors that makes predicting the nature and extent of conflicts challenging. With the ongoing mining and developmental activities in neighboring states, elephants have found a refuge in Chhattisgarh, while some continue to migrate between states within the region. The level of conflict has not yet escalated to extreme proportions within the study area, providing an opportunity for proactive intervention. The local communities' ability to coexist with elephants is a crucial aspect that requires time and support to develop. This presents a critical juncture for policy makers to step in, utilizing a combination of modern technologies and traditional methods to mitigate conflicts.

Recognizing the significance of community engagement, ensuring alternative livelihoods, and prompt ex-gratia payments are essential for building a symbiotic relationship between fringe villagers and conservation efforts.

Furthermore, the establishment of a comprehensive policy framework is advocated to streamline ex-gratia payments for all types of damages and casualties resulting from human-elephant encounters. The implementation of community-level initiatives, such as the Grain for Grain Programme and the Watcher Scheme, forms a part of the holistic conservation strategy. However, it is imperative for communities to cultivate a sense of coexistence without impeding each other's progress. To foster effective coordination and knowledge-sharing among the states affected by elephant migration, the proposal for an interstate committee is a promising step forward. Inclusion of experienced individuals from Jharkhand and Odisha in the committee would infuse valuable insights, aiding in the formulation and execution of scientifically sound management plans. Ultimately, this collaborative approach stands to benefit both elephant conservation and the safety of human populations, underscoring the significance of harmonious cohabitation between people and wildlife.

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■■■

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Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

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Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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TREE HABITAT HETEROGENEITY AND ITS UTILIZATION PATTERN BY BIRD COMMUNITY AT PAKKE TIGER RESERVE, ARUNACHAL PRADESH

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Abstract:

In the pursuit of comprehending the ecology of the tropical avian community and enhancing conservation endeavors, it becomes imperative to delve into the functional transformations occurring across diverse habitats, including lowland forests, bamboo enclaves, and riverine ecosystems. These modifications assume paramount importance in elucidating the adjustments within the ecosystem services provided by avian species. Indeed, habitats stand as quintessential ecosystems that cater to a wide spectrum of bird species, accommodating their varied feeding behaviors, whether terrestrial or aerial.

Nestled within the intricate tapestry of landscapes lies the Pakke Tiger Reserve, an entity stratified by the convergence of myriad elements: diminutive river catchment regions, bamboo-rich habitats, and enclaves characterized as classified forests. Situated within the geographical coordinates of 92^0 7.5' to 92^0 22' E longitude and 26^0 3.7' E to 27^0 16.2' N latitude, this reserve spans a substantial expanse, encompassing 861.95 square kilometres within the Pakke Kessang district of Arunachal Pradesh. The principal aim of this endeavour was to meticulously monitor and

ascertain the density, diversity, and abundance of avian species residing within the stratified habitat of the Pakke Tiger Reserve. To achieve this, the point count distance sampling method was judiciously employed to estimate the avian population across selected habitats, namely riverine, bamboo, and forested regions. Through a meticulous assessment at pre-designated point counts, it became evident that the forested habitat reigned supreme in dominance, followed by the riverine and bamboo environs. The forested habitat emerged as a repository of botanical richness, boasting a profusion of tree species, numbering an impressive 53. By contrast, the riverine habitat harbored 35 tree species, while the bamboo habitat exhibited a more modest assortment with a mere ten species. When it came to avian biodiversity, it was the forested expanse that claimed pre-eminence, hosting a total of 169 distinct bird species. Following closely, the bamboo habitat accommodated 123 avian species, while the riverine habitat provided a home to 120 such species.

Further investigation involved the scrutiny of seven key tree variables to fathom the intricate interplay between tree species and the richness of bird species. The findings unequivocally pointed towards a positive correlation between these variables. The dependent variable displayed significant sensitivity to the overall independent variables, as evidenced by the statistical analysis ($F_{6,14}=2.89$, $p=0.05$). This substantiated the assertion that all independent variables under consideration held the potential to significantly augment the richness of bird species. The prevalence of forests as the preferred habitat for avian inhabitants can be attributed to the multifarious ways in which various bird species exploit the verticality of trees for activities ranging from foraging to courtship, mating, and nesting. This intricate relationship between avifauna and their arboreal abodes underscores the profound significance of the forested landscapes within the Pakke Tiger Reserve.

Keywords: Avifauna, habitat heterogeneity, Pakke Tiger Reserve

Introduction

The diversity of avian species serves as a pivotal biological indicator, affording a comprehensive assessment of the overall quality of terrestrial and aquatic habitats (Chamberlain *et al.,* 2005; Rotenberry & Wiens, 2009; Mistry & Mukherjee, 2015). Primarily, forests emerge as the most vital sanctuaries for avian life, accommodating approximately 75% of all avifauna species, while only 45% have successfully adapted to human-altered environments (Birdlife International, 2018). Avifauna manifests a predilection for specific habitats, though some demonstrate adaptability to multiple habitat types. Nonetheless, relentless alterations in land use have compelled the displacement of many avian species from their native abodes (Burgess *et al.,* 2002).

The ability to take flight proves invaluable to avian survival, permitting them to migrate between habitats during adverse environmental conditions or unfavorable seasons. Birds constitute a prominent and integral component of ecosystems, occupying various trophic levels within the intricate web of food chains, ranging from consumers to predators (Bideberi, 2013). Their susceptibility to human-induced habitat changes and modifications (Raman *et al*., 1998; Lohr *et al.,* 2002) renders them valuable indicators of biodiversity and environmental health. Birds play multifaceted roles in ecosystems, including plant pollination, seed dispersal, and pest control (Hadley *et al*., 2012; Ramchandra, 2013).

In most instances, plant communities within habitats exert significant influence over the distribution, abundance, and diversity of birds. The configuration of a forest community is closely intertwined with various functional aspects of the forest, such as the creation of distinct microclimates, tree growth patterns, and the promotion of community stability (O'Hara *et al.,* 1996; Chen *et al*., 1997). For instance, Tews *et al.* (2004) observed that the composition and structure of plant communities significantly impacted bird species diversity. Spatially heterogeneous forests can accommodate a greater array of species, including those with specialized microhabitat requirements (Atwell *et al.,* 2008), providing essential conditions for breeding, roosting, and foraging. The complexity of vertical vegetation structure correlates with the abundance of both insect and avian species inhabiting a specific forested area (Berg & Part, 1994). Consequently, structurally intricate forests offer a richer diversity of conditions compared to less diverse counterparts, owing to the wider range of microhabitats and vegetation they encompass

The astute discernment exhibited by these avian communities underscores their potential as surrogate indicators for the assessment of habitat conditions across various structural, regional, and landscape scales, as expounded by Canterbury et al. (2000), Lindenmayer et al. (2000), and O'Connell et al. (2000). To illustrate, nectarivorous avian species assume a pivotal role in the pollination of dependent plant species, thus facilitating the exchange of genetic material across disparate regions. Likewise, frugivorous avian species engage in the consumption and dissemination of seeds, enhancing germination rates and fostering genetic interchanges between distinct geographical areas. Furthermore, their contribution extends to the repopulation and restoration of disrupted ecosystems. Insectivorous avian species, conversely, function as natural regulators of insect populations, offering a viable alternative to chemical pesticides by mitigating plant damage, a factor of substantial economic import, as elucidated by Sekercioğlu et al. (2004). The degradation of habitat caused by non-essential and unfavourable practices pressed upon anthropogenically is a significant factor in eliminating bird community populations (Palmer *et al.,* 2004; Sidra *et al.,* 2013). Fragmentation in the habitats is one of the results of anthropogenic factors causing the loss of species and, further unchecked, leading to species extinction (Subramanya, 1996).

Numerous preceding inquiries have endeavoured to discern the connections between avian species diversity and attributes intrinsic to their habitats, notably encompassing aspects of vegetation structure and heterogeneity (MacArthur & MacArthur, 1961; Wilson, 1974; Roth, 1976; James & Wamer, 1982). Avian fauna, considered steadfast indicators of habitat quality, have been observed to react to modifications in their respective habitats in multifarious ways (Raman *et al.,* 1998; Chettri *et al.,* 2001). Their responsiveness is underpinned by their acute sensitivity to habitat structure, as expounded by MacArthur and MacArthur (1961), and their representation of diverse trophic groups, as elucidated by Steele *et al.* (1984). The distribution patterns of numerous avian communities are intricately intertwined with factors such as habitat fragmentation and other habitat-related parameters, serving as mirrors reflecting inter-specific dynamics and population trends associated with the habitat itself (O'Connell *et al.,* 2000).

Study area and methods

a. Study area

Arunachal Pradesh, positioned within the geographical coordinates of 26º28' to 29º30' N and 91º30' to 97º30' E, covering an extensive 83,743 square kilometers in the northeastern part of India, lies within the Eastern Himalayan biodiversity hotspot. To the east, it converges with the Indo-Malayan biodiversity hotspot, creating a unique juncture of ecological significance. Within the boundaries of this state, one encounters 13 Wildlife Sanctuaries, 1 Orchid Sanctuary, and 2 National Parks, collectively spanning an area of 9,488.48 square kilometers. This region assumes paramount importance in the realm of biology, given its abundant flora and fauna, situated within the Oriental and Indo-Malayan Realms. It has earned recognition as a biodiversity hotspot, a distinction accorded to it by Myers in 1990. The climatic conditions in this area exhibit a subtropical character, marked by cold temperatures from November to March. Rainfall graces the region during the southwest monsoon season from May to September, as well as during the northeast monsoon season from November to April. During the summer months, temperatures can climb to 30°C, while in winter, they plummet to a chilly 2°C. The topography of the Pakke Tiger Reserve (PTR) undulates with hills, creating a picturesque landscape. Altitudinal variations extend from 150 to 2040 meters above mean sea level. As a result, PTR finds itself embraced by contiguous forests, undulating terrain, and hills that encircle most of its perimeter, with higher elevations adorning its northern confines. In terms of vegetation, PTR boasts the Assam Valley type (2B/C1); it houses tropical semi-evergreen forests that flourish with a profusion of trees, woody lianas, and climbers, meticulously categorized by Champion and Seth in 1968. These lush, semi-evergreen forests dominate the lower plains and foothills, while subtropical, broadleaved, evergreen forests, dense and luxuriant, thrive at elevations ranging from 900 to 1,800 meters above sea level.

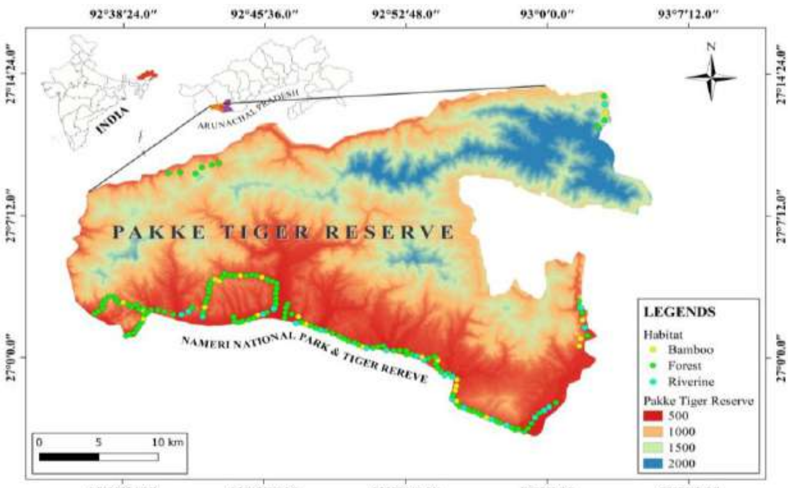

Figure 1. Study area map with sampling points in selected habitats.

b. Methodology

The present study was carried out for two consecutive years from 2020 to 2021 on two major seasonal bases: pre-monsoon and post-monsoon season. *The study locale was partitioned into three primary habitat classifications, contingent upon the presence of avian species.*

A systematic field survey was carried out using the point count distance sampling method (Bibby *et al.,* 1992) to estimate the species diversity and population attributes of avifauna found across different selected habitat types. The point count distance sampling method is widely used to estimate biological populations' diversity, density and abundance. A total of 164 sampling points were laid in the entire landscape in selected habitat types (Forest; 109 points, Bamboo; 25 points, and Riverine; 30 points)

The quadrate sampling method as described by (Schemnitz, 1980) was used to assess the habitat structure and community characteristics of the trees found in the selected habitats of study site.

Quadrates were placed in each point station or sampling points by considering the species-area richness curve in relatively leveled areas in selected habitats (*viz.* Forest, Riverine, bamboo dominated forest) (Photo plate 1) comprising the entire representative avian census area of PTR. Quadrate size of 10m X 10m was used the study of tree layer. In each quadrate, number of tree species and their individual, tree height, tree canopy cover using vertical-point intercept (Jennings *et al.,* 1999) and Girth at Breast Height (GBH) in 1.37 m above from the ground was recorded.

Photo plate 1. Selected habitat types for estimating avian speices and their population

FOREST HABITAT

RIVERINE HABITAT

BAMBOO HABITAT

Result

Overall 67 species of trees from 34 families were recorded during the study periods. The highest number of trees species with individuals was recorded in forest habitat (53 species, 426 individuals (4.35±0.84)), followed by riverine (35 species, 117 individual (1.6±0.34)) and least in bamboo habitat (10 species, 65 individual (0.23±0.07)). Family Malvaceae (9.5%, n=6) was recorded as the dominating family, followed by Meliaceae, Moraceae (7.9%, n=5 each), Burseraceae, Elaeocarpaceae, Fabaceae, Lauraceae, Magnoliaceae (6.3%, n=4 each), Achariaceae, Lythraceae, Phyllanthaceae, (3.2%, n=2 each), and rest of the family comprises only one individual of the species (1.49%, n=1 each). The result reveals that the species richness of bird was found dominant in the forest habitat (169 species), followed by bamboo (123 species) and riverine (120), while 72 species shared all three habitats. However, when compared with two different habitats, it was found that forest and bamboo habitat had 98 common species, and forest and riverine habitat had 97 common species riverine and bamboo habitats had 80 common species (Fig. 2).

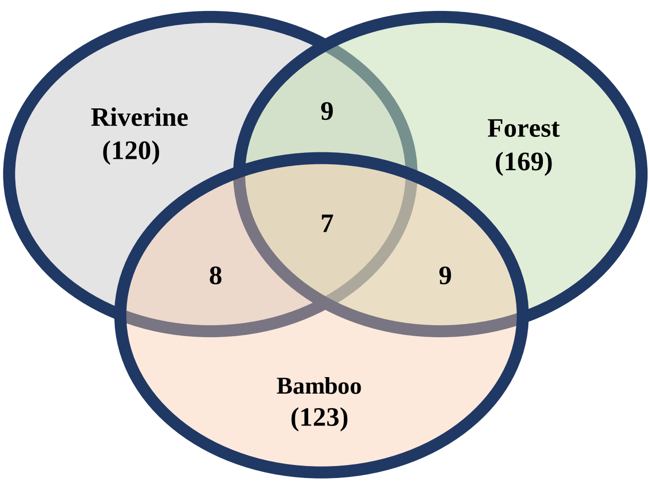

Figure 2. Vein diagram showing the common bird species shared two different habitats.

a. Seasonal variation in diversity indices of avifauna in selected habitats

Based on the selected habitats, species richness was recorded highest during post-monsoon season of the second year in forest habitats and lowest during pre-monsoon season of first year in riverine habitats because during post-monsoon many migratory bird species coming to the Pakke Tiger Reserve as many bird species follow the Pakke river for migration such as Black-necked Stork, Ibis Bill, Common Merganser etc. Shannon diversity index (H) was highest during post-monsoon season of second year in forest habitat (3.93), whereas it was lowest during post-monsoon season of the first year in riverine habitat (3.32). Simpson diversity index results revealed that the highest diversity during post-monsoon season of second year in bamboo habitats (0.97) and lowest during pre-monsoon season of first year in forest habitats (0.92). Dominance was highest (0.078) during pre-monsoon season of first year in forest habitats and lowest (0.031) during post-monsoon season of the second year in the bamboo habitat. The species evenness was recorded the highest (0.65) during post-monsoon season in the second year and lowest (0.24) during pre-monsoon in the first year (Table 1).

Table 1. Variation in diversity indices in different habitats

	Habitat	Dominance	Simpson	Shannon	Evenness
Pre-monsoon 2020	Bamboo	0.063	0.94	3.56	0.42
	Forest	0.078	0.92	3.39	0.24
	Riverine	0.053	0.95	3.47	0.50
Post-monsoon 2020	Bamboo	0.040	0.96	3.64	0.57
	Forest	0.075	0.93	3.55	0.27
	Riverine	0.073	0.93	3.32	0.40
Pre-monsoon 2021	Bamboo	0.054	0.95	3.43	0.45

	Forest	0.066	0.93	3.61	0.28
	Riverine	0.057	0.94	3.52	0.48
Post-monsoon 2021	Bamboo	0.031	0.97	3.80	0.65
	Forest	0.042	0.96	3.93	0.39
	Riverine	0.044	0.96	3.68	0.53

b. Seasonal variation in density of birds in selected habitat

The highest group density recorded during pre-monsoon season of first year in the bamboo habitat (71.47±10.89/km^2) and the lowest during pre-monsoon season of the second year in the riverine habitat (27.065±3.42/km^2).

Whereas the highest individual density was recorded in the pre-monsoon season of first year in bamboo habitat (516.78±78.83/km^2) and the lowest in the pre-monsoon of second year in riverine habitat (274.25±34.81/km^2) (Table 2). Overall, detection probability was a maximum (85.3%) in the second year of pre-monsoon season in riverine habitat and minimum (38.7%) in the first year of pre-monsoon in Bamboo.

In bamboo habitat, detection probability was lowest in pre-monsoon season of the first year and highest in post-monsoon season of first year (Table 2), whereas in the forest habitat lowest detection probability was recorded in pre-monsoon season of the first year and highest in the post-monsoon season of the second year with respect to radial distance (Table 2).

In case of riverine habitat bird detection probability was the highest in the pre-monsoon season of second year and lowest in post-monsoon season of first year with respect to radial distance (Table 2).

Table 2. Seasonal variation of bird species detection probability, density of cluster, density, effective density radius, and encounter rate in selected habitats

Season	Habitat	DP	ER	DS	D	EDR
Pre-Monsoon 2020	Bamboo	38.7	61.2	71.47±10.89	516.78±78.83	21.18±1.0
	Forest	52.2	47.4	57.72±4.05	413.77±29.05	21.66±0.54
	Riverine	65.9	33.8	42.28±5.56	337.83±44.55	23.49±1.25
Post-Monsoon 2020	Bamboo	77.2	21.6	60.79±7.06	424.16±49.58	21.24±1.09
	Forest	61.0	38.6	55.43±3.49	430.81±27.26	23.22±0.57
	Riverine	65.0	34.4	46.61±5.95	363±46.54	22.98±1.18
Pre-Monsoon 2021	Bamboo	65.1	34.6	54.69±6.97	429.24±54.8	23.54±1.22
	Forest	65.7	33.8	55.61± 3.31	432.81±25.88	23.73±0.57
	Riverine	85.3	14.0	27.06±3.42	274.25±34.81	31.31±1.83
Post-Monsoon 2021	Bamboo	73.6	24.8	55.79±6.69	394.99±47.77	22.91±1.18
	Forest	68.1	31.2	56.69±3.27	448.66±26.01	23.87±0.57
	Riverine	81.0	18.2	35.9±4.22	332.51±39.25	28.04±1.49

DP= Detection probability, DS= Density of cluster (Number/km^2), D= Density of individual (Number/km^2), EDR= Effective density radius (m), ER= Encounter rate (individual/km)

Correlation analysis was carried out between seven habitat variables and bird species richness. Findings of the present study revealed a strong positive correlation between the number of tree individuals with the number of bird species and a number of bird individuals. Whereas GBH and height showed a negative correlation with the number of bird species and number of bird species individuals (Table 3).

Table 3. Correlation matrix between habitat variables and bird species and individuals

Variable	Tree_ Species	Tree_Ind	GBH	Height	Crown_ cover	Bird_ species	Bird_Ind
Tree_Species	1						
Tree_Ind	0.885	1					
GBH	-0.792	-0.417	1				
Height	-0.641	-0.211	0.976	1			
Crown_cover	0.892	**1.00****	-0.430	-0.224	1		
Bird_species	0.855	**0.998***	-0.360	-0.150	**0.997***	1	
Bird_Ind	0.820	0.992	-0.300	-0.087	0.990	0.998*	1

** Correlation 0.01 level (2-tailed)

* Correlation 0.05 level (2-tailed)

Principal component analysis (PCA) was carried out on seven standardized habitat variables (Fig. 3) and resulted in the extraction of principal components (Eigenvalues greater than 1) that collectively explained 74.23% of the total variation in the habitat variables.

The study reveals that the relationship between avifauna species richness and habitat patterns/structure addresses the effects of habitat variables on avian species richness and distribution patterns (Fig. 3).

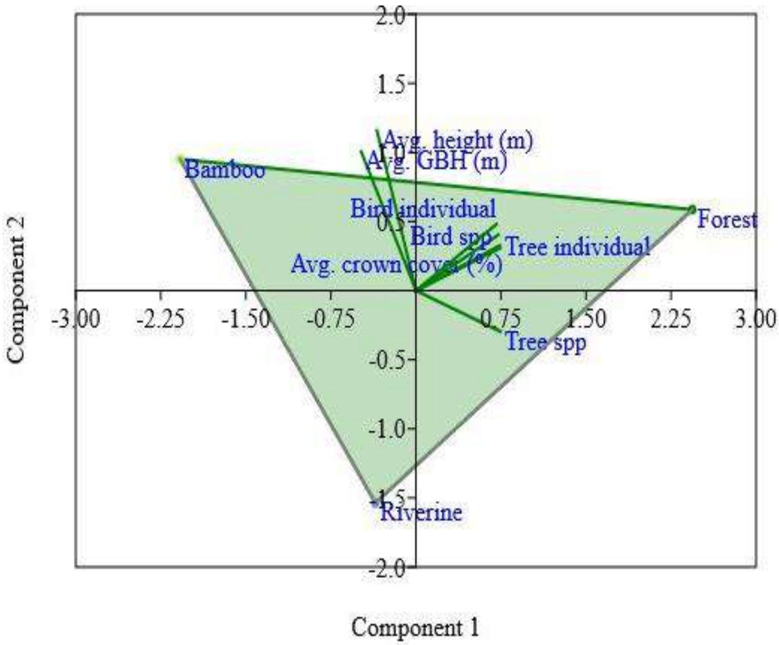

Figure 3. Principle component analysis showing interaction between all the dependent and independent variables.

Birds are dependent on trees for various activity such as nesting, feeding, roosting and foraging. So five variables of trees were taken to understand bird dependency on tree species. The hypothesis tested tree species, tree individual, tree crown cover, GBH and height carries a significant impact on bird species richness. These results clearly direct the positive effect of the overall independent variables.

The dependant variable (bird species richness) was showing significant impact with overall independent variables, $F_{6,14}$=2.89, p=0.05, which indicates that the all-independent variables can play a significant role in increasing bird species richness (Table 4). The hypothesis tested proves that with low numbers of tree bird population will decrease because they are fully dependent on tree species.

Table 4. Descriptive results of one-way ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	31142362.59	6	5190393.76	2.88698	0.047884	2.847726
Within Groups	25170075.16	14	1797862.51			
Total	**56312437.74**	**20**				
*SS- sum of square, *df*- degree of freedom, MS- mean square, *F* crit - *F* critical						

Discussion

Bird species mainly depend on trees for nesting, feeding and foraging. The present study maximized sampling points in the forest habitat because of the low detection of species in the dense forest compared to the bamboo and riverine habitat. Consequently, maximum bird species were recorded in the forest habitat, followed by the riverine and bamboo habitat. In the present study, *Tetrameles nudiflora* was the dominant tree species in the forest habitat, which is used by hornbills and many other birds for nesting, such as woodpeckers, mynas, barbet, roller birds & parakeets. *Tetrameles Nudiflora* is flowering and fruiting from March to May (Page *et al.,* 2022) and provides a foraging place for many seasonal birds.

On the other hand, *Duabanga grandiflora* is dominated in riverine and bamboo habitats. This tree is used as camaflouge hide by green colour birds and birds of prey and used for nesting and foraging activities by small bird species. The presence of avian species in specific trees is contingent upon the particular attributes of these trees, including their height, canopy surface, crown density, and the presence of flowers and berries (Zwarts *et al.,* 2015). Forest-dwelling birds typically make their habitat selection for breeding based on the overarching vegetational characteristics (Hilden, 1965; Klopfer & Hailman, 1965; James, 1971; Robinson

& Holmes, 1982; Smith & Shugart, 1987). James (1971) coined the term "niche gestalt" to describe the characteristic vegetational profile associated with the breeding territories of individual species. The concept of the niche gestalt has proven to be invaluable in the field of avian ecology, as it can be easily quantified using straightforward measures of vegetation structure and synthesized through the application of multivariate statistical techniques (James, 1971; Capen, 1981).

In the current scholarly investigation, it is worth noting that the preeminent assemblage of avian species was documented within the forested habitats. This occurrence may be attributed to the characteristic conduct of avian denizens of the forest, who diligently safeguard their breeding territories, thus ensuring the availability of propitious nesting sites (Martin, 1971; Zimmerman, 1971; Calder, 1973), bountiful foraging grounds (Partridge, 1976), and an abundance of prey (Miller, 1931; Howell, 1952; Stenger & Falls, 1959; Cody, 1968). Consequently, it becomes apparent that the term "habitat" encompasses a broader spectrum of niche dimensions, including trophic relationships, and can be construed as a foundational wellspring of resources for avian species dwelling in forested environs, aligning with the principles elucidated by Grinnell (1917) and Hutchinson (1957).

It is noteworthy that avian creatures' reliance on their surroundings extends beyond the realm of mere survival necessities, encompassing a psychological affinity for specific landscapes (Von Haartman, 1948; Bergman, 1946; Fabricius, 1951). Furthermore, it is imperative to acknowledge that each plant species exhibits distinct phenological patterns, intricately influenced by climatic factors and evolutionary processes (Silva *et al.,* 2011). These phenological events, in turn, wield a pivotal influence in determining the reproductive success of flora (Carvalho & Sartori, 2015). The drastic change in the phonological condition of the particular region could be attributed to climate change or periodic drought, flood, or genetic factors affecting the avifauna species.

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Appendix 1. Checklist of Tree species of Pakke Tiger Reserve with their abundance in selected habitat

S. N.	Tree species	Family	Forest	Riverine	Bamboo
1.	*Gynocardia odorata* R. Br.	Achariaceae	0	1	0
2.	*Saurauia roxburghii* Wall.	Actinidiaceae	0	1	0
3.	*Liquidambar excelsa* (Noronha) Oken	Altingiaceae	0	3	0
4.	*Litsea glutinosa* (Lour.) C.B. Rob.	Altingiaceae	1	0	0
5.	*Rhus chinensis* Mill.	Anacardiaceae	1	0	0
6.	*Polyalthia simiarum* (Buch. Ham. ex Hook.f. & Thomson) Hook.f. &Thomson	Annonaceae	2	0	0
7.	*Brassaiopsis glomerulata* (Blume) Regel	Araliaceae	2	0	0
8.	*Livistona jenkinsiana* Griff.	Arecaceae	3	1	0
9.	*Stereospermum chelonoides* (L. fil.) DC.	Bignoniaceae	4	4	0
10.	*Ehretia acuminata* R. Br.	Boraginaceae	1	0	0
11.	*Canarium resiniferum* Bruce ex King	Burseraceae	23	2	0
12.	*Canarium strictum* Roxb.	Burseraceae	3	0	0
13.	*Garuga floribunda* Decne.	Burseraceae	0	2	0
14.	*Garuga pinnata* Roxb.	Burseraceae	1	0	0
15.	*Mesua ferrea* L.	Calophyllaceae	2	0	0

16.	*Crateva religiosa* G. Forst.	Capparaceae	5	0	0
17.	*Terminalia myriocarpa* Van Heurck & Mull. Arg.	Combretaceae	7	11	3
18.	*Dillenia indica* L.	Dilleniaceae	14	8	1
19.	*Dipterocapus retusus* Blume	Dipterocarpaceae	0	1	0
20.	*Elaeocarpus aristatus* Roxb.	Elaeocarpaceae	6	4	0
21.	*Elaeocarpus robustus* Roxb.	Elaeocarpaceae	0	1	0
22.	*Sloanea sterculiacea* (Benth.) Rehder & E. H. Wilson	Elaeocarpaceae	2	1	0
23.	*Glochidion assamicum* (Mull. Arg.) Hook.f.	Euphorbiaceae	1	0	0
24.	*Macaranga denticulata* (Blume) Mull. Arg.	Euphorbiaceae	2	3	0
25.	*Albizia procera* (Roxb.)Benth.	Fabaceae	5	1	2
26.	*Bauhinia purpurea* L.	Fabaceae	1	0	0
27.	*Bauhinia racemosa* L.	Fabaceae	5	0	0
28.	*Bauhinia variegata* L.	Fabaceae	3	3	0
29.	*Altingia excelsa* Noronha	Hamamelidaceae	7	6	0
30.	*Gmelina arborea* Roxb.ex Sm.	Lamiaceae	1	0	0
31.	*Beilschmiedia assamica* Meisn.	Lauraceae	1	0	0
32.	*Cinnamomum bejolghota* (Buch. Ham.) Sweet	Lauraceae	1	0	0
33.	*Phoebe attenuata* (Nees) Nees	Lauraceae	3	0	0

34.	*Phoebe cooperiana* P.C. Kanjilal & Das	Lauraceae	2	0	0
35.	*Duabanga grandiflora* (Roxb. Ex DC.) Walp.	Lythraceae	11	15	2
36.	*Lagerstroemia parviflora* Roxb.	Lythraceae	2	3	0
37.	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	2	0	0
38.	*Magnolia hodgsonii* (Hook.f. & Thomson)	Magnoliaceae	30	3	0
39.	*Michelia oblonga* Wall. ex Hook.f. & Thomson	Magnoliaceae	0	1	0
40.	*Bombax Ceiba L.*	Malvaceae	1	0	0
41.	*Pterospermum acerifolium* (L.) Willd.	Malvaceae	20	1	2
42.	*Sterculia lanceolata* Cav.	Malvaceae	0	1	0
43.	*Sterculia villosa* Roxb. ex Sm.	Malvaceae	1	0	0
44.	*Sterculia alata* Roxb.	Malvaceae	4	3	0
45.	*Sterculia hamiltonii* (Kuntze) Adelb.	Malvaceae	2	0	0
46.	*Aglaia spectabilis* (Miq) S.S.Jain & Bennet	Meliaceae	14	4	0
47.	*Amoora wallichi* King	Meliaceae	0	1	0
48.	*Chukrasia tabularis* A. Juss	Meliaceae	1	1	0
49.	*Dysolxylum gotadhora* (Buch. Ham.) Mabb.	Meliaceae	22	2	1
50.	*Aglaia sp. Lour.*	Meliaceae	2	0	0
51.	*Artocarpus chaplasha* Roxb.	Moraceae	4	0	0

52.	*Ficus auriculata* L.	Moraceae	0	1	0
53.	*Ficus Benghalensis* L.	Moraceae	1	0	0
54.	*Ficus religiosa* L.	Moraceae	1	0	0
55.	*Ficus sp*	Moraceae	3	3	0
56.	*Horsfieldia kingii* (Hook. F.) Warb.	Myristicaceae	1	3	0
57.	*Syzygium spp.*	Myrtaceae	2	9	2
58.	*Chionanthus macrophyllus* (Wall. Ex G. Don) Blume	Oleaceae	1	0	0
59.	*Baccaurea ramiflora* Lour.	Phyllanthaceae	2	0	0
60.	*Bridelia retusa*(L.) A. Juss.	Phyllanthaceae	1	0	0
61.	*Micromelum integerrimum* (Roxb. ex DC) Wight & Arn. ex M.Roem.	Rutaceae	1	0	0
62.	*Meliosma pinnata (Roxb.) Walp. ssp. barbulata (Cufod.) Beus.*	Sabiaceae	1	0	0
63.	*Ailanthus grandis* Prain	Simaroubaceae	5	1	0
64.	*Tetrameles nudiflora* R. Br.	Tetramelaceae	33	4	1
65.	*Elaeocarpus obtusifolius* Merr.	Tiliaceae	0	0	1
66.	*Dendrocnide sinuata* (Blume) Chew	Urticaceae	5	0	0
67.	*Laportea crenulata* Gaud.	Urticaceae	1	0	0

■■■

Dr. Ajay Kumar Singh *With over 15 years of research experience in forest watershed management, remote sensing & GIS, landscape dynamics, and forest biodiversity, Dr. Ajay Kumar Singh currently holds the position of Assistant Professor at Guru Ghasidas University in Bilaspur, Chhattisgarh, India. He is the recipient of multiple prestigious awards, including Young Scientist of the Year in 2022, 2019, and Environmental Biologist of the Year in 2017.*

Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

Sudhir Ranjan Choudhury, *an Indian researcher, currently pursuing a Ph.D. in Forestry, Wildlife, and Environmental Sciences from Guru Ghasidas University. With a robust background in Forestry, Biodiversity, GIS, Remote Sensing, and Conservation of Natural Resources, he has actively engaged in various training programs and workshops to enhance his expertise. His scholarly pursuits extend to participation in conferences and seminars dedicated to water resource management, biodiversity, and conservation. The editor, Mr. Choudhury has contributed significantly to the field of environmental science. His research publications, focusing on diversity, taxonomy, and conservation, have found a place in various reputable journals. Notably, his impactful work has been cited in numerous publications, attesting to its relevance and influence in the academic domain. In recognition of his contributions, Mr. Choudhury was honored with the Young Scientist Associate Award-2023, underscoring his dedication and achievements.*

Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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COILING FAITH: INVESTIGATING THE IMPACT OF RELIGIOUS BELIEFS ON SNAKES AND HUMAN CONFLICT IN INDIA

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Abstract:

India, a country known for its diverse cultural landscape, has long been a hub of religious beliefs and practices. Among the various religious beliefs, the significance of snakes holds a unique position in Indian culture and mythology. Snakes are revered as deities and symbols of fertility, protection, and power in several religions, most notably in Hinduism. However, the coexistence of humans and snakes has led to conflicts arising from deeply rooted religious beliefs, presenting intriguing socio-environmental challenges.

This paper explores the multifaceted dynamics of human-snake conflicts in India, focusing specifically on conflicts stemming from religious beliefs. The relationship between humans and snakes has been shaped by centuries-old traditions, rituals, and mythologies, which have assigned both divine reverence and fear to these reptiles. Snakes are often associated with deities like Lord Shiva and Nag Devta (Snake God), and their worship is an integral part of many religious festivals and ceremonies.

Despite the religious significance accorded to snakes, the encounters between humans and snakes can result in conflicts, particularly in rural areas where snakebite incidents are more prevalent. Religious beliefs sometimes discourage individuals from taking necessary precautions or seeking medical treatment promptly, which can exacerbate the consequences of snakebite incidents. These interactions often generate fear and panic among communities, further complicating the efforts to strike a harmonious balance between religious beliefs and human well-being.

This paper aims to provide a comprehensive overview of the complexities surrounding human-snake conflicts in India, particularly with respect to religious beliefs. It explores the case studies, research findings, and relevant literature to examine the social, cultural, and ecological dimensions of these conflicts. By understanding the underlying factors and the interplay between religious beliefs, conservation efforts, and public health concerns, and seeks to shed light on potential strategies for mitigating conflicts and promoting coexistence between humans and snakes in the Indian context.

Keywords: snakes, human conflict, religious beliefs, India, coexistence, conservation, mythology, rituals, snakebite incidents.

Introduction:

In the diverse tapestry of human societies, the intricate interplay between cultural practices, religious beliefs, and ecological relationships has shaped the course of history and continues to influence contemporary interactions with wild animals (Castillo, 2020). India, a country in South East Asia where cultural and spiritual tapestry is woven with a rich array of religious beliefs and practices, each contributing to the nation's unique identity (Satpathy, 2015). India, renowned for its rich religious diversity and deep-rooted traditions, has long been a stage where humanity's reverence for the divine and its coexistence with the natural world converge. At the heart of this convergence lies the veneration of snakes, which holds a central position in various religious frameworks across the country (Allocco, 2009). From the cosmic serpent in Hindu mythology to the Naga cults of north eastern India, snakes have garnered veneration that transcends the boundaries of belief systems (Lange, 2019; Pathak, 2022). This veneration often stems from their symbolic significance as well as their perceived role in ecological balance, intertwining the spiritual and ecological realms in a unique manner. However, the coexistence of humans and snakes is not devoid of conflict. India's diverse ecosystems harbour numerous snake species, some of which are venomous and pose potential threats to human populations (Sulabh & Pushp, 2008; Bawaskar et. al., 2017; Chakma et. al., 2020; Suraweera et. al., 2020; Malhotra et. al., 2021; Pandya et. al., 2022). The conflict between human interests and snake presence has led to a complex web of interactions, varying from religious rituals and snake handling practices to incidents of snakebite and even snake killings (Vaiyapuri, 2013). This intricate interplay between religious beliefs, cultural practices, and ecological dynamics shapes perceptions, responses, and actions concerning snakes and their habitats. In some instances, deeply ingrained religious beliefs may hinder individuals from taking essential precautions or seeking immediate medical intervention following snakebites, exacerbating the repercussions of such incidents (Nann, 2021). These interactions, fraught with complexity, have the potential to induce fear and panic within communities, thus augmenting the challenge of balancing religious beliefs with human well-being. This paper seeks to provide an exhaustive overview of the intricate tapestry of human-snake conflicts in India, focusing particularly on the intricate interplay of religious beliefs. Employing a multidisciplinary approach that draws upon case studies, research findings, and pertinent literature, the paper endeavours to unravel the multifaceted dimensions of these conflicts. By discerning the underlying factors and deciphering the intricate interactions between religious convictions, conservation initiatives, and public health concerns, the paper aims to shed light on potential strategies for mitigating conflicts and fostering harmonious coexistence between humans and snakes in the unique and vibrant context of India.

A. Religious Significance of Snakes:

Snakes, throughout history and across cultures, have evoked fascination and symbolized diverse concepts, from life and death to regeneration and rebirth. In India's spiritual landscape, the veneration of snakes assumes an extraordinary significance, interwoven with the beliefs and practices of various religions (Das & Balasubramanian, 2017).

Hinduism:

In the intricate tapestry of Hinduism, one of India's predominant religions, the veneration of snakes emerges as a profound and intricate facet. Far from being mere creatures, snakes in Hinduism embody a rich symbolism that traverses the boundaries of the material world to touch the realms of cosmic energy, power, and profound transformation (Das & Balasubramanian, 2017).

Cosmic Energy and Transcendence:

Within Hindu thought, snakes symbolize an embodiment of cosmic energy, an elemental force that courses through the universe (Jayram, V). This symbolism finds its vivid expression in the portrayal of Lord Shiva, the deity renowned for his dance of creation and destruction. In his divine dance, Nataraja, Lord Shiva adorns serpents as ornaments, emphasizing the convergence of opposing forces—life and death, creation and destruction—within his divine dance (Indian culture, GOI). This portrayal encapsulates the dualistic nature of existence, where opposing forces coalesce to create a harmonious cosmic dance.

Cycle of Life and Transformation:

The shedding of a snake's skin, a process known as molting (Rutland et. al., 2019), mirrors the cyclical nature of life and existence. Just as a snake discards its old skin to emerge a new, humanity too experiences cycles of birth, growth, death, and rebirth. This transformational process serves as a potent metaphor for the continuous renewal of life, a cycle embedded within the very fabric of existence.

Serpent Ananta and Eternity:

The symbolism of snakes extends further to the divine realm, where the serpent Ananta, also known as Adi Sesha, plays a pivotal role. Ananta's coils serve as the resting place for Lord Vishnu, the preserver in the Hindu trinity (Bala, 1946). In this depiction, the serpent embodies eternity itself, its endless coils evoking the timeless nature of the universe and the divine. Ananta's presence beneath Lord Vishnu underscores the symbiotic relationship between cosmic forces and the divine.

Protection and Fertility:

In addition to their cosmic significance, snakes are often considered protectors against malevolent forces. Snakes are believed to guard sacred spaces, temples, and shrines, a role that exemplifies their dual nature as both protectors and divine beings. Snakes' association with fertility and prosperity is also profound (Fergusson, 1868). In certain regions, snake worship is intertwined with agricultural practices, where snakes are invoked to bless the land and ensure bountiful harvests.

Jainism:

Jainism emerges as a unique and contemplative religion, distinguished by its emphasis on non-violence (ahimsa), compassion, and respect for all forms of life (Howard, 2023). Within this philosophical framework, the relationship with snakes is imbued with a distinct perspective that underscores harmony and coexistence.

Non-Violence and Compassion:

Central to Jainism is the principle of non-violence, a foundational tenet that extends beyond human interactions to encompass all living beings, no matter their form. This ethical stance resonates deeply with the reverence for snakes, where they are perceived as fellow sentient beings deserving of compassion and respect. Jain teachings emphasize the interconnectedness of all life, urging adherents to treat every living being with kindness and consideration.

Tirthankara Parshvanatha and the Serpent Canopy:

In Jain tradition, the Tirthankaras are revered spiritual teachers who have attained enlightenment and guide others on the path to liberation (national geographic society). The 23rd Tirthankara, Parshvanatha, is often depicted with a unique emblem—a serpent canopy that arches over his head.

This distinctive representation symbolizes the harmony between humans and serpents within the Jain philosophical framework. It is a visual embodiment of the principle of non-violence, where even potentially fearsome creatures are treated with reverence and care.

Harmony and Balance:

The serpent canopy encapsulates a profound message: the coexistence of diverse beings is possible through mutual respect and understanding. This imagery reflects the Jain ideal of living in harmony with all life forms, exemplifying the compassionate ethos that guides Jain practice.

B. Snakebite Incidents and Religious Beliefs

Snakebite incidents, a pressing public health concern in India, offer a lens through which the interplay between deeply ingrained religious beliefs and practical realities becomes starkly apparent. While religious convictions hold significant sway in guiding human behavior, they can also hinder prompt medical intervention and exacerbate the consequences of snakebite incidents (Vaiyapuri, 2013).

Beliefs and Delayed Medical Intervention:

Religious beliefs often shape individuals' responses to snakebite incidents. For instance, in some communities, the perception that snakes hold divine protection may dissuade individuals from seeking immediate medical attention. This delay can prove detrimental, as timely administration of anti-venom and medical treatment is crucial to mitigate the effects of venomous snakebites.

Cultural Practices and Treatment:

Certain cultural practices surrounding snakebites may also intertwine with religious beliefs (Nann, 2021). Traditional healers, who may incorporate spiritual rituals into their treatments, can influence individuals' choices regarding seeking medical assistance. This complex amalgamation of religious and cultural factors can contribute to a delay in accessing appropriate medical care.

Fear and Panic Amplification:

Religious beliefs can also influence emotional responses to snakebite incidents, often amplifying fear and panic within affected communities. The perceived spiritual significance of snakes can intensify the emotional impact of such encounters, further complicating the efforts to manage the aftermath of snakebites.

C. Balancing Religious Beliefs and Mitigation:

The challenge of mitigating snakebite incidents while respecting deeply ingrained religious beliefs is a nuanced endeavour that requires a multi-faceted approach. Striking a balance between cultural heritage and public health imperatives demands collaborative efforts, cultural sensitivity, and innovative strategies.

Educational Initiatives:

Integrating religious teachings with ecological knowledge in educational initiatives can indeed be a powerful approach to promote snake conservation and responsible coexistence. This strategy recognizes the cultural and spiritual value that snakes hold in various societies while also emphasizing their ecological importance.

1. Cultural and Religious Significance of Snakes: In many cultures, snakes are associated with symbolism, myths, and religious narratives. They can represent various qualities such as wisdom, transformation, and balance. Incorporating these narratives into educational programs can help raise awareness about the positive aspects of snakes and dispel negative stereotypes.
2. Ecological Roles of Snakes: Snakes play crucial roles in ecosystems as both predators and prey. They help control populations of rodents and other pests, maintaining a balance in the food chain. Educating people about these roles helps them understand that snakes are valuable components of their environment.
3. Interconnectedness of Nature: Many religious teachings emphasize the interconnectedness of all living beings and the environment. By incorporating ecological knowledge into these teachings, educators can highlight the importance

of preserving biodiversity and respecting all forms of life, including snakes.

4. Promoting Coexistence: When religious teachings emphasize compassion, empathy, and respect for all creatures, including snakes, individuals are more likely to adopt attitudes and behaviors that promote coexistence. This can reduce incidents of unnecessary harm or killing of snakes out of fear.
5. Community Engagement: Educational initiatives can involve local religious leaders and communities in discussions about the ecological and religious aspects of snake conservation. This engagement fosters a sense of ownership and responsibility among community members to protect snakes and their habitats.
6. Incorporating Science and Spirituality: These initiatives encourage individuals to appreciate both scientific understanding and spiritual beliefs. This integration can lead to a more holistic view of the environment and the role that different species, like snakes, play in it.
7. Youth Engagement: Integrating ecological and religious knowledge can be particularly impactful among young people. Children and adolescents are more likely to absorb and internalize such teachings, which can shape their attitudes and behaviors as they grow up.
8. Art and Culture: Artistic expressions like paintings, sculptures, music, and stories can be used to convey the message of snake conservation through the lens of religious teachings. This creative approach can make the learning experience more engaging and memorable.
9. Case Studies and Success Stories: Sharing success stories of snake conservation efforts that were influenced by religious teachings can inspire others to take similar actions. Highlighting instances where communities have

successfully protected snakes can serve as a model for replication.

10. Long-Term Impact: Over time, such educational initiatives can lead to a shift in societal attitudes and behaviors toward snakes and their conservation. This can contribute to healthier ecosystems and a more harmonious relationship between humans and snakes.

Religious Leaders as Advocates:

Engaging religious leaders as advocates can bridge the gap between faith and practical concerns. Their influence can extend beyond spiritual matters to encompass health and well-being. Religious leaders can be instrumental in conveying accurate information about snakebite prevention, dispelling myths, and encouraging timely medical intervention.

Cultural Sensitivity in Messaging:

Addressing cultural sensitivities in messaging is vital, particularly when tailoring public health communication to religious beliefs. By creating messages that resonate with cultural values and underscore the common objective of preserving life, it becomes possible to successfully connect faith with practical measures. This approach serves as a bridge between religious convictions and the implementation of necessary precautions.

Conclusion:

In conclusion, the interplay between religious beliefs, cultural practices, and ecological relationships has woven a complex tapestry that shapes human interactions with snakes in India. The veneration of snakes in various religious frameworks highlights their profound significance, from Hinduism's cosmic symbolism to Jainism's ethos of non-violence and harmony. This reverence, however, is not without its challenges, particularly in the context of snakebite incidents. Religious convictions, while deeply ingrained and culturally significant, can sometimes hinder timely medical intervention and exacerbate the consequences of snakebites. Balancing these deeply rooted beliefs with public health imperatives necessitates a multi-faceted approach. Educational initiatives that integrate religious teachings with ecological knowledge can foster a deeper understanding of the value of snakes in ecosystems while promoting responsible coexistence. Engaging religious leaders as advocates and crafting culturally sensitive messaging can bridge the gap between faith and practical considerations. The diverse cultural and spiritual tapestry of India provides a unique opportunity to cultivate a harmonious relationship between humans and snakes. By recognizing the interconnectedness of all life and promoting a holistic view that encompasses both religious significance and ecological roles, it is possible to mitigate conflicts and promote the well-being of both communities and the natural world. Through collaborative efforts, empathy, and innovative strategies, the intricate interactions between religious beliefs, cultural practices, and ecological dynamics can be unraveled, fostering a future where humans and snakes coexist in balance and harmony

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ASSESSMENT OF FISH DIVERSITY AND ANTHROPOGENIC PRESSURE ON KOPRA WETLAND OF BILASPUR DISTRICT OF CHHATTISGARH

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Introduction

Wetlands have a significant role in groundwater recharging, recreation, the retention of pollutants, and the survival of several aquatic plant and animal species (Crisman 2001). A number of variables, including food availability, risks from poaching and hunting, the size of the wetland (Paracuellos, 2006), and abiotic changes in the wetlands (Jaksic 2004), have an impact on the water-dependent avifauna and their habitat. These biotic elements are dependent on the hydrology and seasons of a wetland habitat. A number of organisms have their natural habitat in the freshwater ecosystem. According to Simon and Lyons (1995), fishes are highly sensitive to environmental changes. Fishes are essential to the survival and maintenance of the aquatic ecosystem. As a result of their long existence and Septo-temporal influence, fish serve as a bio-monitoring instrument. IUCN estimates that there are 868 species of fish in India's freshwater ecosystem, of which 192 are endemic and 327 are threatened (Lakra et al., 2010).

Reservoirs often provide new habitats for fish species that were not present in the original river or stream. They can support a diverse range of aquatic plants, insects, and other organisms, which in turn attract various fish species. Reservoirs typically have abundant food resources, such as plankton, algae, and aquatic invertebrates. This can lead to increased productivity and provide a food source for a wide variety of fish species. Reservoirs can facilitate the expansion of fish species' ranges by creating new water bodies connected to existing river systems. This can enhance fish diversity by allowing species to colonize previously inaccessible areas. Reservoirs often provide new habitats for fish species that were not present in the original river or stream. They can support a diverse range of aquatic plants, insects, and other organisms, which in turn attract various fish species. Reservoirs typically have abundant food resources, such as plankton, algae, and aquatic invertebrates. This can lead to increased productivity and provide a food source for a wide variety of fish species. Reservoirs can facilitate the expansion of fish species' ranges by creating new water bodies connected to existing river systems. This can enhance fish diversity by allowing species to colonize previously inaccessible areas. The water quality of a reservoir can vary depending on various factors, including its location, surrounding land use, water sources, and management practices.

The habitat of freshwater fishes may be destroyed or altered by natural disasters, anthropogenic activity, and pollution (Sarkar, 2021). According to Cowx (2002), these pose the biggest challenges to aquatic ecosystems. Mass fish species mortality and significant population size reduction are brought on by overfishing or indiscriminate fishing (including the use of mosquito net, dynamite, and electrofishing) (Sarkar et al., 2008). Exotic fish introductions could result in the spread of new parasites and diseases into previously uninhabited areas. Finally, the introduction of exotic fishes may cause the population size of native fish species to decline. They can enhance conflict between exotic and indigenous fishes. The feeding river system, weathering and geochemical processes taking place in the catchments, as well as anthropogenic sources, all contribute to the composition of reservoir water. The disintegration of the rock matrix in response to reactive rains containing dissolved carbon dioxide largely controls the composition of reservoir waters naturally; nevertheless, human intervention could induce aberrations in natural water chemistry at any point or location in the drainage basin. The primary resources exploited for inland fisheries may be reservoirs and lakes. For the use of freshwater reservoirs and sustainable as well as economical management, an important component is understanding the variety of the fish fauna (Battul et al. 2007). India's lakes are home to a wide range of fish species, which in turn encourages the commercial use of fishery resources.

A reservoir is a body of water that is created by either pumping water into an artificial impoundment that is completely surrounded by man-made embankments to form a fully bunded dam (a river reservoir) or, less frequently, by the accumulation of flowing water behind a built dam. Despite the debate and criticism they spark, more reservoirs must be built as the need for water increases globally.

Anthropogenic pressure refers to the impact or influence that human activities have on the environment. Reservoirs, which are artificial bodies of water created by the construction of dams, can be subject to various anthropogenic pressures. Reservoirs are often built to provide a reliable water supply for human consumption, agriculture, and industrial use. The extraction of water from reservoirs can put pressure on their water levels, leading to reduced storage capacity and potential water scarcity. Human activities near or within the catchment area of a reservoir can result in the introduction of pollutants. Industrial discharges, agricultural runoff, and improper waste disposal can contaminate the water in reservoirs, affecting their quality and making them less suitable for various purpose. The construction of dams and reservoirs can interrupt the natural flow of rivers, causing sediment to accumulate in the reservoirs. Over time, this sedimentation reduces the storage capacity of the reservoir, affecting its efficiency and lifespan. It is important to note that the specific anthropogenic pressures on reservoirs can vary depending on the region, local regulations, and the nature of human activities in the vicinity of the reservoir. The fresh water reservoirs made with this purpose are underutilized and except water utility management no further use of such water sheets is done.

In India, there are 3.15 million acres are covered by 19,370 reservoirs in 15 states. In 25 years, it's anticipated that the area would increase in size to 6 million acres. 1.707 million hectares of the state of Chhattisgarh are covered by water. In Chhattisgarh, 54% of the total water distributed area is in the form of reservoirs. There are 1,690 reservoirs (85,188 ha) total in the state, of which 1,657 (37,432 ha) are small, 21 (25,610 ha) are medium, and 12 (22,146 ha) are large, covering 56.72 percent, 20.83 percent, and 22.45 percent of the total land area, respectively. (Annon, 2008). In comparison to their potential, fish production from these resources in India is now relatively low (on average about 20 kg/ha/yr). This is a result of improper management and exploitation practises, as well as a lack of knowledge of reservoir ecology.

The state of Chhattisgarh contains 27,823 wetlands (including those smaller than 2.25 ha), covering 337,966 ha, or about 2.5% of the state's overall land area. According to http://chtenvis.nic.in/Forest.html, the three main forms of wetlands are reservoirs (90,389 ha), tanks/ponds (40,226 ha), and rivers/streams, which account for around 53% of all wetlands (179,088 ha). The Kopra Wetland is a special habitat matrix that varies seasonally.

Kopra reservoir is one of the suitable habitats for water-birds and fishes near Bilaspur city, Chhattisgarh and it was established in the year 1993 in the Mahanadi basin for the purpose of irrigation.

The main purpose of establishing this dam was to provide irrigation facilities to surrounding villages for the purpose of agriculture. These reservoir play a crucial role in the overall development of the region by providing water resources for agriculture, drinking water supply, and supporting the local ecology. Reservoir contribute significantly to the socio-economic growth of Bilaspur district in Chhattisgarh (India-WRIS 2014).

The present study is based on the documentation and estimation of fish diversity, water quality of Kopra wetland and how the diversity changes throughout the year with a focus on the pre-monsoon season. By performing the community interaction, fisherman community interaction and socio-economic survey in kopra and khairadhih villages. Kopra village is located in south west of the kopra reservoir and khairadhih village located in north east of the kopra reservoir.

Objective :-

1. Survey of pre-monsoon Fish diversity of Kopra reservoir of Bilaspur district.

2. To evaluate the water quality of the Kopra reservoir.

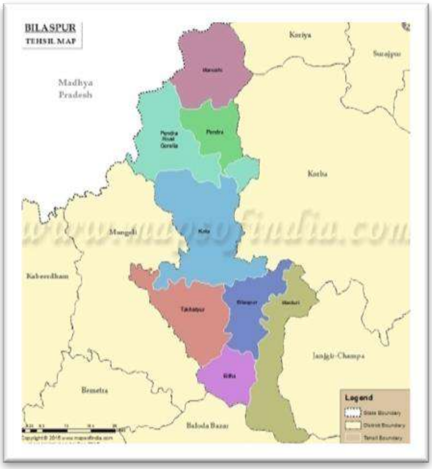
3. To study the anthropogenic pressure on the reservoir.

Material and Methodology

Description of study area :- Bilaspur district is located in the state of Chhattisgarh, India. The district is known for its rich natural resources, including several reservoirs that serve as important water sources and provide irrigation and drinking water to the region. In the Mahanadi basin, the Kopra reservoir was built in the years 2000–2001 for irrigation purposes. This wetland is seasonal, and its GPS coordinates are 22°304000 N to 22°401500 N latitude and 82°203000 E to 82°303100 E longitude. The Kopra wetland is located in the Sakri Village of the Bilaspur district of Chhattisgarh, India, on the Raipur-Bilaspur bypass. The distance to

Bilaspur city is about 10 kilometres. The wetland has a length of 1680 metres and a total volume content of 113 TCM (India-WRIS 2012).

Sampling sites as a map:-



Map.1 : kopra reservoir map of Bilaspur.

Method:

Survey of Kopra dam and nearby area was carried out from April 2023 to July 2023. The survey was done based on a general interview of fisherman and local peoples. Primary data was collected through personal interviews of fisher community families. Samples were collected at regular intervals with fishermen community interaction and local village peoples. Evening 5pm fishermen lay the fishing nets in water. After overnight, in the early morning fishermen take out the fishing nets. Collected fishes all identified by its colour patterns, Spots, size, shape, position of fins or the number of scales in a specific series and designs have been noted when they are in fresh condition. And took some pictures for identification and confirmation of species. than prepared a list of fishes in field diary with its local names. The length and depth of the head, the position and diameter of the eyes, the length of the snout, the maximum and minimum breadth and girth, and the lengths of the pre dorsal fin, pre pectoral fin, pre anal fin, and pre caudal fin are among the morphological characteristics. Characteristics that can be described include the body's profile and shape, the skin's texture and colour, the position and shape of the mouth, the lips, the snout, and the jaws, as well as scales and the lateral line system. median fins' form, size, and kind; paired and caudal fins' fin rays and formula; tail; and distinctive markings. A field kit with measurement tools like rope, preserver and a digital camera.

Water samples are collected from different points on kopra reservoir. The water quality Parameters such as water pH, oxygen reduction potential-ORP, Dissolved Oxygen-DO, Total Dissolved Solids-TDS, temperature, Conductivity are measured by multi-parameter instrument. During general interviews with village people observations have been noted and observed how they depend on reservoir and asked some question for relate the anthropogenic presser on Kopra reservoir. And also collected samples of ground water from near villages; Kopra village and Khairadhih village.

Result

Data analysis:-

Survey of pre-monsoon Fish diversity of Kopra reservoir of Bilaspur district.

The collected data show different types fish species are present in Kopra reservoir. Total 27 species, 11 family and 6 order of fishes are present. In this species 14 species are LR-nt (lower risk near threatened), 8 species are VU (Vulnerable), 1 species are LR-Ic (lower risk least concern and 3 species are EN (endangered species).

To evaluate the water quality of the Kopra reservoir.

Reservoir water quality refers to the chemical, physical, and biological characteristics of water in a reservoir. The quality of reservoir water is important because it directly impacts the ecosystem within and around the reservoir, as well as the suitability of the water for various uses such as drinking water supply, irrigation, industrial processes, and recreation.

Here are some key factors that affect reservoir water quality:

- Temperature: Reservoir water temperature can influence the growth and survival of aquatic organisms. Higher temperatures can lead to reduced oxygen levels, increased algal growth, and changes in species composition. A average temperature in kopra reservoir water is 32˚C in summer season and in rainy season temperature is 26˚C. and ground water temperature are 26.58 kopra and 26.79 is khairadhih village.

- Dissolved Oxygen (DO): DO is essential for the survival of aquatic organisms. It enters the water through atmospheric diffusion and photosynthesis by aquatic plants. Factors such as temperature, organic matter decomposition, and algal blooms can affect DO levels. Low DO concentrations can lead to fish kills and other negative impacts on aquatic life.DO is essential for the survival of aquatic organisms. It is the amount of oxygen dissolved in the water, and it is necessary for fish and other aquatic organisms to respire. Low DO levels can result from pollution, high temperatures, or excessive algal growth. Average DO in kopra reservoir water 7.32 in ppm. Kopra village water DO is and 5.81 ppm DO , is kharadhih water DO and 5.01ppm DO.
- pH: pH is a measure of the acidity or alkalinity of water. It can influence the availability of nutrients and the toxicity of certain substances to aquatic organisms. Most aquatic species thrive within a specific pH range, and significant deviations from that range can harm them. The pH level indicates the acidity or alkalinity of water. It is an important factor that affects the survival and growth of aquatic organisms. Some species are more sensitive to changes in pH than others. in kopra reservoir water pH is 9.2 water is slightly basic or alkaline. In terms of water quality, a pH of 9.2 is generally considered acceptable and safe for most purposes. Kopra village ground water pH is 7.68 and khairadhih village ground pH is 7.28. However, the ideal pH for drinking water is typically in the neutral range of 6.5 to 8.5. Water with a pH slightly above or below this range is still generally safe to drink.

- ORP: stands for Oxidation-Reduction Potential, which is a measure of the ability of a substance to oxidize or reduce another substance. In the context of water, ORP refers to the water's potential to either gain or lose electrons during a chemical reaction. It is typically measured in millivolts (mV). In kopra reservoir -24. ORP. And kopra village ground water -9.3, khairadhih village ground water -2.9. A positive ORP value indicates that the water has the potential to oxidize substances, while a negative ORP value suggests that the water has the potential to reduce substance effect the taste and could potentially indicate other water quality issues.
- Water conductivity: also known as electrical conductivity (EC), is a measure of the ability of water to conduct an electrical current. It is a fundamental parameter used to assess the overall quality and purity of water. Conductivity is typically measured in units of Siemens per meter (S/m) or micro siemens per centimeter (µS/cm). kopra reservoir water EC is 240µS/cm and kopra village ground water 809µS/cm and khairadhih village ground water 2403µS/cm . The electrical conductivity of water is influenced by the presence of dissolved ions, such as salts and minerals. When these ions are dissolved in water, they become charged particles called ions. These ions facilitate the flow of electrical current through the water. According parameter khairadhih groung water conductivity is very high, Water conductivity of 2403 µS/cm (microsiemens per centimeter) indicates that the water has a relatively high level of dissolved salts or ions. Conductivity is a measure of how well water can conduct an electrical current, and it is influenced by the presence of dissolved substances.
- TDS: stands for Total Dissolved Solids, and it is a measure of the total concentration of all dissolved substances in water. These substances can include minerals, salts, metals, organic compounds, and other dissolved solids. TDS is typically

measured in units of milligrams per liter (mg/L) or parts per million (ppm). In kopra reservoir water TDS is 104.74ppm, kopra village ground water TDS is 404 ppm, khairadhih village ground water is 1202ppm. The measurement of TDS provides important information about the overall quality of water, as it reflects the total amount of dissolved substances present. Generally, higher TDS levels can indicate a higher concentration of dissolved solids in the water.1204 ppm (parts per million) indicates the presence of various dissolved substances in the water, such as salts, minerals, metals, and other ions. The TDS level can have several implications,

- Biological Contaminants: Reservoirs may be affected by pathogens, such as bacteria, viruses, and parasites, which can be introduced through sewage discharge, animal waste, or other sources. Proper disinfection and water treatment are necessary to ensure safe drinking water. Bacterial and Pathogen Contamination: Reservoirs can be susceptible to bacterial contamination, such as from fecal coliform bacteria, which can indicate the presence of harmful pathogens. This can occur due to inadequate wastewater treatment or the runoff of animal waste from agricultural activities. Reservoirs can be susceptible to bacterial contamination, such as from fecal coliform bacteria, which can indicate the presence of harmful pathogens. This can occur due to inadequate wastewater treatment or the runoff of animal waste from agricultural activities.

Monitoring and managing reservoir water quality is crucial to maintain a healthy ecosystem and to ensure the safety of water supplies. Water resource management agencies often conduct regular water quality testing, implement pollution control measures, and enforce regulations to protect reservoirs and the surrounding environment. To ensure and maintain good reservoir water quality, regular monitoring, testing, and appropriate management practices are necessary. This includes implementing water treatment processes, regulating pollutant discharges, and implementing conservation measures to protect the watershed and prevent pollution sources from entering the reservoir.

3. To study the anthropogenic pressure on the reservoir:-

Anthropogenic pressure refers to the impact and influence of human activities on the environment. These pressures can have various forms and can affect different aspects of the environment, including air, water, land, and ecosystems. Here are some examples of anthropogenic pressures

- Pollution: Human activities such as industrial processes, transportation, agriculture, and waste disposal can release pollutants into the environment. This includes air pollution from vehicle emissions and industrial smokestacks, water pollution from chemical runoff and wastewater discharge, and soil contamination from improper waste disposal. Kopra reservoir is free from pollution like industrial processes or other activities, it's very peaceful place and human interaptions is very less. That's why in kopra reservoir is one of the highly bird diversity wetland.
- Deforestation: Clearing forests for agricultural purposes, urban development, or logging contributes to deforestation. This results in the loss of habitats for numerous plant and animal species, disrupts ecosystems and contributes to climate change by reducing the capacity of forests to absorb carbon dioxide. In kopra reservoir deforestation activity is less.
- Overfishing: Overfishing occurs when fishing practices exceed sustainable levels, depleting fish populations and disrupting marine ecosystems. It can result in the collapse of fish stocks, affecting the livelihoods of communities

dependent on fishing and the overall health of marine ecosystems. There on overfishing done in Kopra reservoir.

- Habitat Destruction: Human activities, such as urbanization, agriculture, and infrastructure development, can lead to the destruction and fragmentation of natural habitats. This results in the loss of biodiversity, as many species depend on specific habitats for their survival.
- Land Use Changes: Conversion of natural landscapes, such as forests or grasslands, into agricultural fields, urban areas, or industrial zones, alters the natural balance of ecosystems. This can lead to habitat loss, soil erosion, and changes in water availability. Addressing anthropogenic pressures requires sustainable practices, environmental regulations, conservation efforts, and the adoption of cleaner technologies. It involves promoting resource efficiency, reducing pollution, protecting natural habitats, and mitigating climate change through measures such as renewable energy adoption and carbon sequestration. part of the Kopra reservoir has been excluded due to construction of the NH130 highway. For such reason pollution increases at high rate, ecosystem has been disturbed and feeding habits of fauna shifted. And main component disturbed by this were aquatic vertebrates.

Fig no.4 kopra reservoir

Tables and graph :-

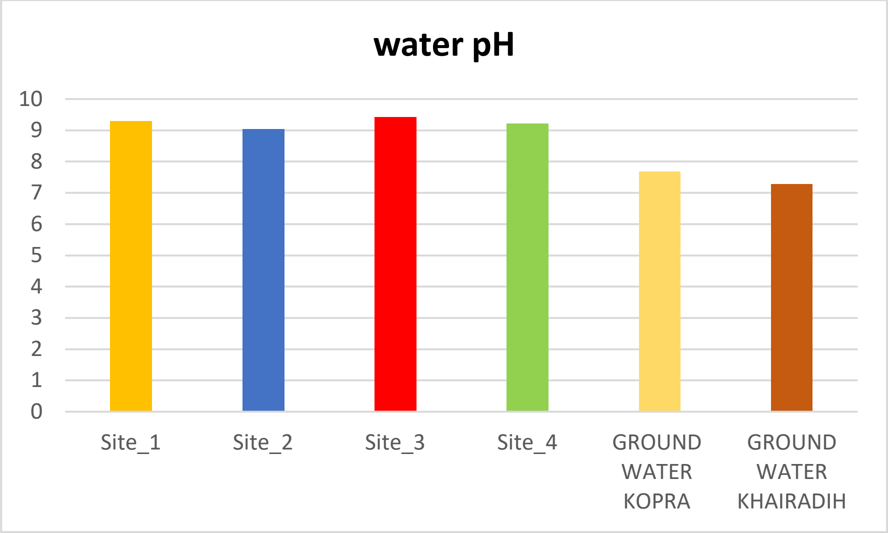
Table no. 1:-List of fish diversity of kopra reservoir-

S.N	**Common/ local name**	**zoological name**	**Family**	**order**	**IUCN status**
1	Tilapia	*Oreochromis mossambicus*	cichlidae	cichliformes	LR-nt
2	Catla	*Catla catla*	cyprinidae	cyriniformes	LR-nt
3	Mrigal	*Cirrhinus mrigala*			LR-nt
4	Borai/Reba	*Cirrhinus reba*			VU
5	Komal carp	*Cyprinus carpio*			VU
6	Bata	*Labeo bata*			LR-nt
7	Kamach/Kariya	*Labeo calbasu*			LR-nt
8	Rohu	*Labea rohita*			LR-ic
9	Bata	*Labeo boggut*			LR-nt
10	Amachaini	*Labeo dyocheilus*			
11	Kotri	*Puntius chola*			LR-nt
12	Puthia/Kotra	*Puntius saranasarana*			VU
13	JarhiKotra	*Puntius sophore*			LR-nt
14	Sanwal/Sol	*Channa marulius*	channidae	ophiecephaliformes	VU
15	Khoksi	*Channa punctatus*			LR-nt
16	Bhunda	*Channa striatus*			LR-nt
17	Kevai	*Anabus testudineus*	anabantidae		LR-nt
18	Chital	*Chitala chitala*	notopteridae	osteoglossiformes	EN
19	Patola	*Notopterus notopterus*			EN
20	Mongri/Mangur	*Clarias batrachus*	claridae		VU
21	Singhi	*Heteropneustes*	saccobranc		VU

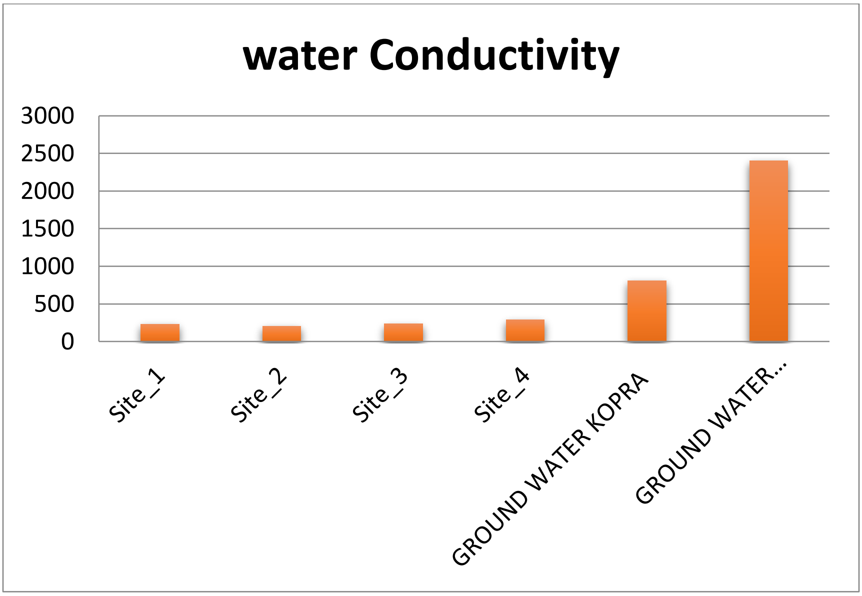
		fossilis	hidae	siluriformes	
22	Tengna	*Mystus gulio*	bagridae		LR-nt
23	Botia	*Ompok bimaculatus*			EN
24	Padhan/lonch	*Wallago attu*	siluridae		LR-nt
25	Kewai	*Heteropneustes fossilis*	heteropneustidae		VU
26	Bami	*Mastacembelus armatus*	mastacembelidae	synbranchiforms	VU
27	Choti Bami	*Mastacembelus pancalus*			LR-nt
Abbreviation-EN=endangered; LR-ic=Lower risk least concern; LR-nt=Lower risk near threatened; VU-vulnerable					

Table no.2 water quality parameters:-

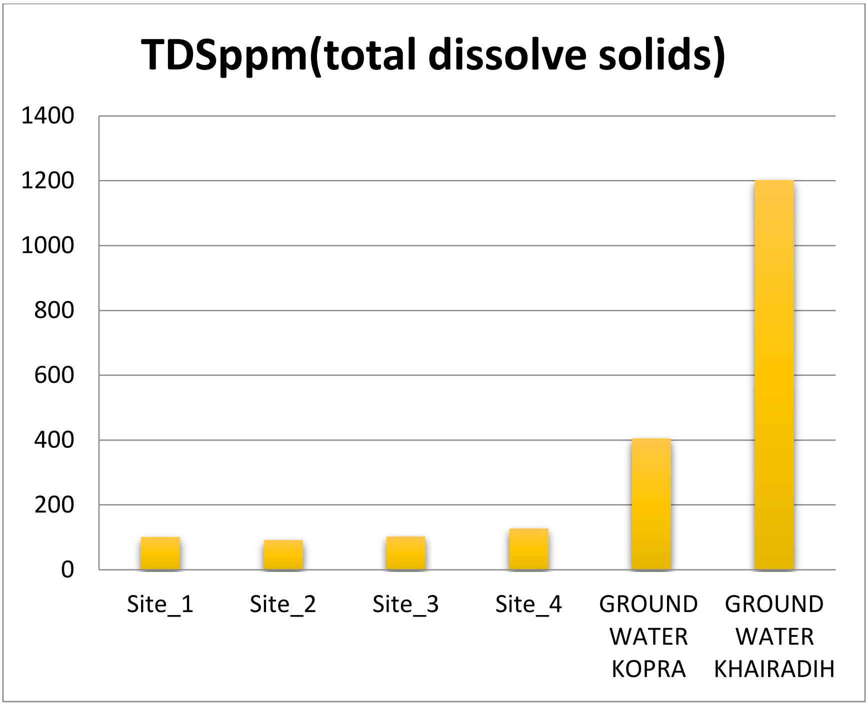
Name sites	Temperature	pH	DO ppm	conductivity	ORP(oxygen reduction potential)	TDS ppm (total dissolve solids)
Site_1	33.11	9.3	7.08	231	-17.7	100
Site_2	31.7	9.04	7.45	205	-20.7	91
Site_3	32.24	9.42	7.37	235	-32.2	102
Site_4	32.6	9.22	7.28	289	-25.8	126
Ground water kopra	26.58	7.68	5.81	809	-9.3	404
Ground water khairadih	26.79	7.28	5.01	2403	-2.9	1202



Ghaph no.2 showing the kopra reservoir and both villages groung water pH



Graph no.5 showing the kopra reservoir and villages ground water conductivity



Graph no. 7 showing the kopra reservoir water and villages ground water TDS

Reservoirs play a crucial role in maintaining healthy aquatic ecosystems, supporting biodiversity, and providing recreational opportunities for anglers and nature enthusiasts. High water quality is vital for supporting diverse fish populations. Clean and well-oxygenated water is essential for the survival of various fish species.kopra reservoir is contains high number of fish diversity and Consideration of water level fluctuations, as some fish species rely on specific water depths and seasonal variations for breeding and feeding. Without anthropogenic inputs such as pollution, industrial runoff, or agricultural discharges, the water quality remains high and free from harmful contaminants. This leads to better oxygen levels, clear water, and suitable conditions for aquatic life. Reservoirs without anthropogenic activity would likely have unobstructed migration routes for fish, facilitating natural movements between different habitats and contributing to gene flow among populations. Implementing responsible and sustainable fishing practices helps maintain fish populations at healthy levels. Fishing regulations, such as catch limits and size restrictions, can prevent overfishing and ensure the sustainability of fish populations. Overall, kopra reservoir well-managed fish diversity reservoir, balance the needs of human use, conservation, and ecological health. Reservoir is essential to work towards preserving the natural balance and diversity of fish species to ensure the reservoir's long-term sustainability and the well-being of the surrounding ecosystem.

Discussion:- A total of 27 species representing 11 family and 6 order (table 1). Were recorded; of 14 species are LR-nt(lower risk near threatened), 8 species are VU (Vulnerable), 1 species are LR-Ic (lower risk least concern and 3 species are EN (endangered species). some following fish species found in kopra reservoir. *Labeo rohita, Labeo gonius*, and *Ompok bimaculatus* are the principal shallow-water fishes, whereas *Catla catla*, *Chita lachitala*, and *Notopterus notopterus* are the principal deep-water fishes, respectively. The collected fish have been divided into three groups based on their eating habits: bottom feeders *Labeo calbasu, L. bata, Labeo gonius*, and *Cirhinnus mrigala*; medium feeders *Labe orohita*, *Wallego attu*, and *Mystes* sps.

Water parameters are collected from different sites representing on (table 2), reservoir water Temperature is 32.4˚C, pH is 9.24, DO is 7.32ppm, conductivity-240, ORP -24.1µS/cm, TDS 104.75ppm. kopra village ground water parameters are 26.58˚C, pH is 7.68 , DO is 5.81ppm , conductivity 809, ORP -9.31µS/cm, TDS 404ppm. Khairadih village ground water is very hard water temperature is 26.79˚C, pH 7.28, DO 5.01ppm, conductivity of water is 2403, ORP is-2.91µS/cm, TDS of water is 1202ppm. TDS includes a wide range of dissolved substances, such as minerals (e.g., calcium, magnesium, potassium), salts (e.g., sodium chloride), metals (e.g., iron, manganese), and other organic and inorganic compounds. In some cases, elevated TDS levels may be naturally occurring and might not necessarily be harmful to health. For example, certain minerals in water can contribute to its taste and have some health benefits. khairadhih village peoples for drinking water and cooking purpose use kopra reservoir , they only use for bathing and washing purposes of ground water. Mostly khairadhih village peoples are directly and indirectly depended on kopra reservoir.

Sakara, Sarseni, Amsena, and Medpara village inhabitants use reservoir water for irrigation. A few villages use kopra reservoir water for irrigation during the kharif crop season. Not a lot of anthropogenic pressure on reservoirs is observed. The kopra reservoir is a pressure-free, pollution-free reservoir. The reservoir lies away from populated areas and is only partially shielded from the state highway's and an agricultural field's heavy traffic. The reservoir is used for both household and agricultural purposes.

Kopra reservoir is rich in fish diversity but the conversation of it very important,from last 1 year fishermens suffering with aquatic plants high amount of aquatic plants spread across the areas in reservoir. Due to aquatic plants fish net does not disperse in water properly. Some days fisher man get less fish.

Conclution:-

There are a total of 27 species in the kopra reservoir, representing 11 families and 6 orders (table 1). 14 species were identified; of those, LR-nt (lower risk near threatened) species, VU (vulnerable) species, LR-Ic (lower risk least concern) species, and EN (endangered species) species were documented. In the kopra reservoir, the following fish species can be found. Deepwater fish include *Catla catla, Chitala chitala*, and *Notopterus notopterus* among others, whereas the principal shallow water fish are *Labeo rohita, Labeo gonius*, and *Ombok bimaculatus*. The collected fish have been divided into three groups based on their eating habits:

surface feeders *Catla catla*, middle feeders *Labeo rohita*, *Wallego attu,* and Mystessps, and bottom feeders *Labeo calbasu, L.bata, Labeogonius, and Cirhinnus mrigala*. Regarding fish diversity in other natural waters, more research is required. It must be aware of the threats facing our inland waters' biodiversity as well as the factors contributing to their deterioration. It must continue to develop and use techniques for estimating the ecosystems' environmental, social, and economic values and the effects these values have on inland waterways' biodiversity. In order to define biodiversity in operational terms and to create and test robust inventory, evaluation, and monitoring techniques across a variety of geographical scales, researchers and managers must collaborate. After assessment of water quality of Kopra Reservoir there are many different parameters found water pH, DO, TDS, ORP and temperature of reservoir water and ground water of kopra and khairadhih villages. Khairadhih water parameters are highly increased parameters, water contains TDS and ORP is more. the water from this village is very unsafe and must be used only after suitable treatment process.

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■■■

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Dr. Singh has actively contributed to international conferences through presentations and has undertaken various research projects. Additionally, he has shared his expertise by delivering lectures at both national and international conferences and workshops. Dr. Singh's commitment to environmental conservation is evident through his organization of workshops and training programs, such as "Jal Shakti: Catch the Rain" and "Snake Bite Awareness," aimed at promoting forest biodiversity. Furthermore, Dr. Singh's significant contributions extend to the realm of academia, as evidenced by his publication of numerous research articles in international journals. Overall, his comprehensive engagement in research, conferences, workshops, and publications reflects a dedicated pursuit of advancing knowledge and practices in the field of environmental science.

Sudhir Ranjan Choudhury, *an Indian researcher, currently pursuing a Ph.D. in Forestry, Wildlife, and Environmental Sciences from Guru Ghasidas University. With a robust background in Forestry, Biodiversity, GIS, Remote Sensing, and Conservation of Natural Resources, he has actively engaged in various training programs and workshops to enhance his expertise. His scholarly pursuits extend to participation in conferences and seminars dedicated to water resource management, biodiversity, and conservation. The editor, Mr. Choudhury has contributed significantly to the field of environmental science. His research publications, focusing on diversity, taxonomy, and conservation, have found a place in various reputable journals. Notably, his impactful work has been cited in numerous publications, attesting to its relevance and influence in the academic domain. In recognition of his contributions, Mr. Choudhury was honored with the Young Scientist Associate Award-2023, underscoring his dedication and achievements.*

Ashutosh Anand *is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.*

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STUDY ON THE ETHNOBOTANICAL PRACTICE PERFORMED BY TRIBAL COMMUNITIES IN SURAJPUR FOREST AREA, CHHATTISGARH

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Abstract:

The study of local (indigenous) plant uses by humans in a particular culture and region is known as ethnobotany. A pre-scientific medical system with bodies of medical knowledge that are passed down from one Vaidya to another through generations is referred to as traditional medicine. The practices for treating illnesses and ailments are related to the tribal people's beliefs, justifications, and ways of making herbal medicine. This paper presents the ethnomedical wealth of the Surajpur district. In various villages throughout Surajpur district, an ethnobotanical study was conducted. In order to treat a variety of illnesses among the various tribes, the paper focuses on the traditional phytotherapy practiced by the current investigations in the Surajpur district of Chhattisgarh, 62 species of plant or plant part have been identified which are used for ethnobotanical purpose by tribal groups. In the list of plant, there were 29 species of trees, 21 Species of herbs, 8 species of shrubs, and 4 species climber. The current study objective was to emphasize the crucial role that local knowledge and culture can play in resource management, to concentrate on the variety of ethnobotanical plants for future use, and to provide a

framework for teaching people how to use plants to solve various types of problems.

Keywords: Ethnobotany, Medicinal plant, Traditional knowledge, Ethnomedicine, Ethnic group, Tribal community.

Introduction

Chhattisgarh (C.G) is referred to as the “Herbal State” due to its abundant biodiversity and the reliance of its native tribal population on traditional medical practices. Ethno-botany accounts for the study of relationship between people and plants for their use as medicines, food, shelter, clothing, fuel, fodder, and other household Purposes (Jangdey et. al 2016). It deals with the Interaction of indigenous plants and the local Inhabitants of the area.

The main aim of the present study is to collect information on plants used for ethnobotanical practices by some selected local tribes of the Surajpur Forest area, Chhattisgarh. Various plants have been used in traditional Medicine for several thousand years. India is a repository of medicinal plants. The herbal treasure of the nation is rich in its floristic wealth. Ethnobotany is a fascinating field that explores the intricate relationship between plants and human cultures. It focuses on the traditional knowledge and practices of different ethnic groups, particularly those by living in forest areas (Painkara et. al, 2015). Tribal communities, in particular, have a deep understanding of the local flora and have developed unique ethnobotanical practices over generations. In forest areas, tribal people have a profound connection with their natural surroundings. They have acquired a wealth of knowledge about the diverse plant species found in their environment and have learned to utilize them for various purposes. These practices are deeply rooted in their cultural traditions and play a significant role in their daily lives (Kala, 2009).

The study of ethnobotany not only provides valuable Insights into the traditional knowledge of tribal communities but also offers potential contributions to modern science. Many plant species used by indigenous people have been found to possess medicinal properties or other valuable attributes. Ethnobotanical research can help identify new compounds, uncover unique uses for plants, and contribute to the development of sustainable practices for resource management (Kujur and Ahirwar, 2015). Ethnobotany practices by tribal people offer a unique perspective on the intricate relationships between humans and plants. They provide valuable insights into the sustainable use of natural resources and hold the potential for discovering new medicinal compounds (Kujur and Ahirwar,2015). Furthermore, these practices underscore the importance of cultural diversity and the need to protect indigenous knowledge systems for the benefit of future generations and the well-being of our planet. Ethnobotanical practices have been carried out by societies throughout history and across different geographical regions. They are deeply rooted in the cultural and ecological

Objective

1. Data collection on ethnobotanical usage of floral species, by tribal community in the Surajpur forest area, in Chhattisgarh.
2. To document the traditional knowledge of plants used in ethnobotanical practices.
3. To document the method of drug preparation used by the tribal community in the Surajpur forest area of Chhattisgarh.

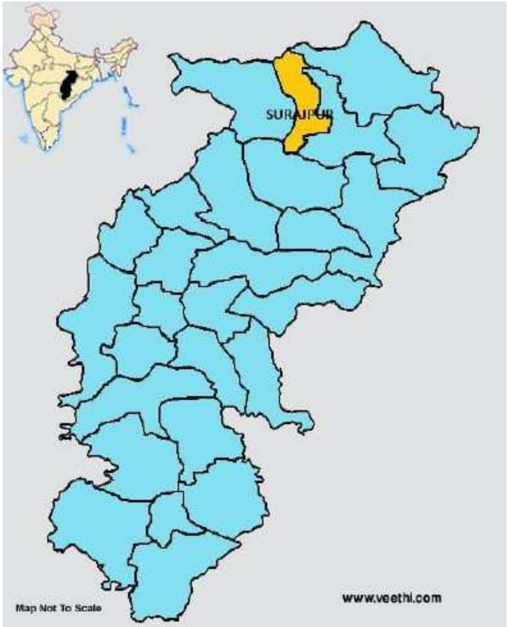
Material And Method:

Study Area

Chhattisgarh is situated in the central region of India. It is surrounded by states like Orissa, Maharashtra, Madhya Pradesh, Jharkhand, Uttar Pradesh, Telangana and Andhra Pradesh. Also, there are 5 different river basins that lie in the states which are

Brahmani, Mahanadi, Ganga, Godavari, and Narmada. Furthermore, the soils found here are Black Soil, Laterite, Red Soil, Loamy Soil, Black Soil, and others. The southern and northern part of the state is covered with hilly areas, and the central area is plain land.

The current study was conducted in the selected site of Surajpur Forest Area of Chhattisgarh (Lat: 23.2136011°N , Long: 82.8679549°E). Around 2,787 km2 area of the Surajpur District is under forest cover. Surajpur has a humid subtropical, dry winter climate and at 553.09 metres (1814.6 feet) above sea level. Tribes in the Surajpur district eat a variety of wild fruits as part of their diet, particularly during times of food scarcity, due to the area's dense forests and rich flora. Surajpur generally experiences 35.81 rainy days (9.81%) per year and averages about 51.59 millimeters (2.03 inches) of precipitation yearly. The Gond, Oraon, Kanwar, and other hill tribes and indigenous people of the Surajpur district.



Map 1: study area map Source: internet

Map 2: Study area Village (Source – Google Earth)

Ethnobotanical exploration

According to literature review on the ethnobotanical investigations, there have not been any research done in the Surajpur region, although there have been a few research done in neighboring districts. As a result, from April to July 2023, field surveys were conducted in the tribal villages of Surajpur district, including Aamgao, Jobaga, Ketka, Kot Lachaa, and Lanchhi Pendrakhi, to collect information on the uses of various plant species. Semi-structured questionnaires on plant components used for food, medicine, vegetables, fibres, colours, gums, agricultural instruments, and other types of illnesses were also utilised to collect data during the survey period. Group conversations among tribal villagers of various ages, representing both genders in the community, were used to cross-check the data.He participant observation method was also used to comprehend the approaches and procedures used by tribe members when using plants and plant components. With the help of informed elders and local youth, the surrounding forested region and agricultural land of the villages were also surveyed for the identification of several ethnobotanical species and their traditional applications.

Method used:

Ethno-botanical survey is conduct in different tribal inhibited areas of Surajpur Forest Area, District- Surajpur Chhattisgarh during (April-July). Extensive field Trips were organized for collecting the plant Species and data. The method adopted for the Collection of data is based on medicinal uses of plants in the treatment of various diseases. Several visits has been done with these resource persons who helped to identify the plants, local/tribal names of the Plants, and the medicinal uses which need to confirm through many resource person as far as possible in other localities of the State. Information like medicinal use of Plant, plant parts used, diseases treated, modes of drug Preparation and administration has been recorded.

Participant Selection: Indentation of members of the community who are having knowledgeable about plants, such as traditional healers, elders, herbalists, and community leaders. Seeked permission and built trust within the community before initiating data collection activities.

Plant Identification References: Various field guide used for floras, or botanical keys specific to the study area. These references aid in plant identification based on botanical features such as leaves, flowers, fruits, and other characteristics.

Identification- Species were identified on the basis of morphology and taxonomic characters. The identities of several plants were confirmed by experts from various institutions. Anatomical sections were also taken to confirm species identity.

Ethnomedicinal practices documentation: An essential method of preserving traditional knowledge about the medicinal plants and cures utilised by many cultures is by documenting ethnomedical practises. It includes keeping a record of the plants' characteristics, cooking techniques, and uses in curing particular diseases.

Result and Discussions:

During the current investigations in the Surajpur district of Chhattisgarh,62 species of plant or plant part have been identified which are used for ethnobotanical purpose by tribal groups. In the list of plant, there were 29 species of trees, 21 Species of herbs, 8 species of shrubs, 4 species climber. Although 62 plant families are represented in the research region, Fabaceae was the most prevalent family in terms of the number of ethnobotanical species. These ethnobotanical plants were used for a variety of things, including food, medicine, drinks, vegetables, tonics, fish poison, insect repellent, and clothing dye.

Medicinal Plants: The 34 families that make up the overall number of known medicinal plant that are used in ethnobotanical practices in Surajpur forest area. For ethnomedicinal usage whole plant or various parts, including the root, tuber, leaf, fruit, bark, resin, seed, and latex, were all employed as medicines. The most common plant part used to make medicine was the root (12 species), which was then followed by fruit (6 species), bark (7 species), leaves (18 species), and seeds (8 species). One species of tuber and three species of stem whole plant (5 species). These plant species have been used to treat a variety of conditions, including indigestion, a cough, body aches, diarrhea, cut wounds, scorpion bites, snake bites, and muscular pain.

The specific results obtained from such a survey can vary depending on the objectives and scope of the study. However, here are some potential outcomes that may arise from an ethno botanical survey: after grinding the stem of *Curcuma* in ball shaped *romatic.*

Fig 1- This figure shows the paste made

Fig 2- Showing prepared mixture that is turned

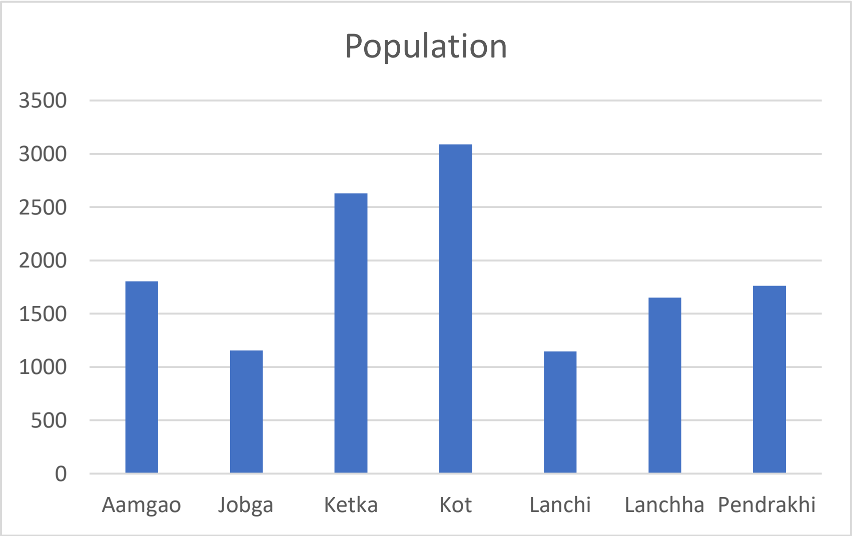


Figure 3- Variation in Population of Study Area

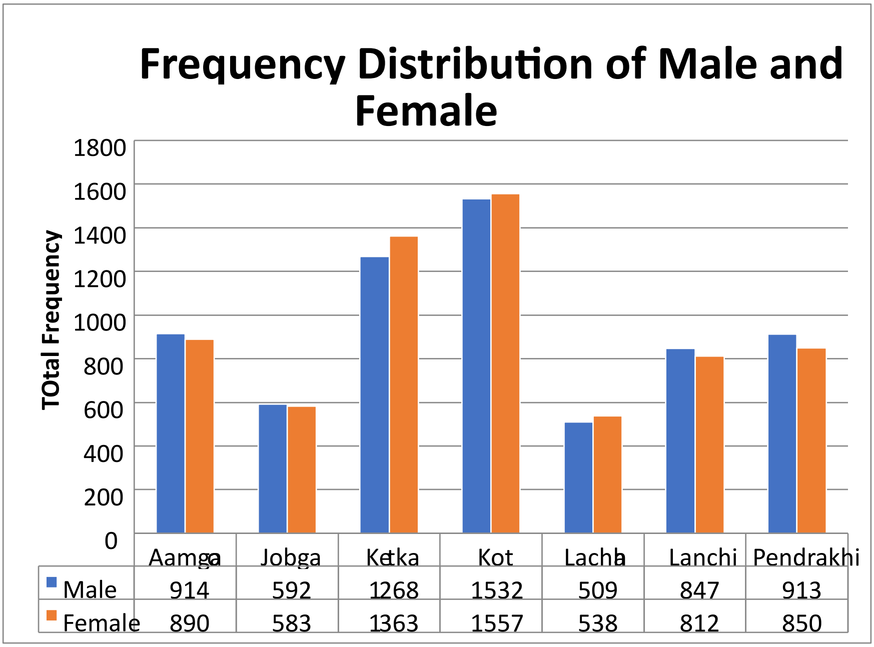


Fig 4- Frequency Distribution of Male and Female in different villages

Medicinal Plant Uses:

The performed survey provides detailed information about the traditional medicinal uses of plants in the treatment of various diseases. This includes information about specific plant parts used, modes of drug preparation, and administration methods. Here are the list: -

Table 1: Drug preparation procedure documented from the tribal community

S. N.	Common Name	Scientific Name	Family	Parts use	Disease Uses	Method of preparation	Dose
1	Dabi	*Cadaba fruticosa*	Capparaceae	Seed	Heart disease	seed is processed into paste and then drink it with water.	3-6 Dose

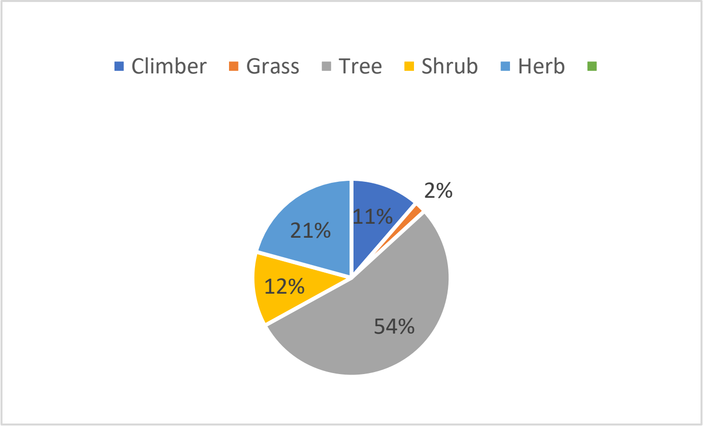
2	Jangli haldi	*Curcuma aromatica*	Zingiberaceae	Stem	Pain	blackgram is soaked in water overninght or for 6hrs, then the prepared mixture is turned in ball shaped	20-25 Dose
3	Doob	*Cynodon dactylon*	Poaceae	Leaves	Small injury	grinds with grinding stone, apply the paste to injuries	4-5 Dose
4	Mahua	*Madhuca longifolia*	Sapotaceae	Bark	Helps in reducing gum pain	twig is used to brush teeth.	4-5 Dose
5	Aam	*Mangifera indica*	Myrtaceae	Bark	Fever	Collection of bark, then grinding with help of grinding stone, then ready todrink.	5-7 Dose
6	Charota	*Senna tora*	Caesalpiniaceae	Seed	Itching.	processed into paste and applied into exposed area.	4-5 Dose
7	Sal	*Shorea robusta*	Dipterocarpaceae	Seed	Dysentery	seed is used in powered form through grinding boil the seed	4-5 Dose
8	Kateli	*Solanum virginianum*	Solanaceae	Seed	Teeth pain	tranform it into paste form, then applied to hairs directlt	3-5 Dose

9	Rohina	*Soymida febrifuga*	Meliaceae	Bark	Body pain	bark is boiled and the remains liquid is drinked	4-6 Dose
10	Baheda	*Terminalia bellirica*	Combretaceae	Fruit	Cough	roasted in pan, some people turns it into small pieces which further ready to eat directly	3-5 Dose
11	Saja	*Terminalia elliptica*	Combretaceae	Bark	Diarrhea	processed into powered, consumable with water	

Conservation and Sustainable Use: The survey may highlight plant species of conservation concern or those that are at risk due to over-harvesting or habitat loss. This information can contribute to the development of conservation strategies and sustainable use practices.

Comparative Ethnobotanical Study by Tribal Community

As per this study, the indigenous communities living within the forest of Sarjapur have long been a source of admiration as they



possess a unique understanding of, and ability to utilize, the plants around them. The four largest tribal communities (Gond, Pando, Kanwar, Raon) were investigated and data on their use of plants were obtained by discussion with tribal informants. Data on ethnobotanical practices which are mostly used to cure body pain, dysentery, gum pain, blood pressure, itching, fractures, etc. The study reveals too little commonality in usage of herbal remedies for the selected villages. The difference in usage of plants by same tribes occupying different localities and different tribes of the same or nearby localities was observed.

Fig 26: Distribution of Ethnobotanical species across life forms in the Study area

S. No.	Local Name	Scientific Name	Family	Plant parts	Disease Uses	Use by community	Area
1	Koilar	Bauhinia variegata	Caesalpinia ceae	Leaves	vegitable	Gond	Kot
2	Bach	Acorus calamus	Araceae	Tuber	Asthma	Gond	Pendra khi
3	Arusa	Adhatoda vasica	Acanthacea e	Root and leaves	Asthma and cough	Pando	Ketka
4	Bael	Aegle marmelos	Rutaceae	Fruit	Dysenter y, Fever	Gond	Lanchi
5	Ghritkum ari	Aloe vera	Asphodelac eae	Leaves	Asthma	Pando	Aamga o
6	Kalmegh	Andrographis paniculata	Acanthacea e	Whole plant	Fever	Gond	Pendra khi
7	Sitaphal	Annona squamosa	Annonaceae	Leaves	prevents hair lice	Oraon	Kot
8	Satavar	Asparagus racemosus	Asparagace ae	Tuber	Immunity booster	Gond	Jobga
9	Leem	Azadirachta indica	Meliaceae	Bark	Fever	Gond	Lanchi
10	Brahmi	Bacopa monnieri	Plantaginac eae	Whole plant	Increase memory power	Gond	Pendra khi
11	Char	Buchanania lanzan	Anacardiace ae	Leaves	Small injury	Gond	Kot
12	Parsa	Butea monosperma	Fabaceae	Root	Paralysis	Gond	Kot
13	Katkarej	Cadaba	Capparacea	Seed	Heart	Oraon	Jobga

		fruticosa	e		disease		
14	Mandar	Calotropis gigantea	Apocynaceae	Root	Asthma	Gond	Kot
15	Aak	Calotropis procera	Apocynaceae	Root	Asthma	Gond	Ketka
16	Bhalmushree	Cassia fistula	Fabaceae	Whole plant	Body swelling	Gond	Lanchi
17	Safed musli	Chlorophytum tuberrosum	Asparagaceae	Root	Weekness	Gond	Ketka
18	Harajora	Cissus quadrangularis	Vitaceae	Whole plant	Bone fracture	Gond	Jobga
19	Aparajita	Clitoria ternatea	Fabaceae	Root	Asthma	Pando	Ketka
20	Jangli haldi	Curcuma aromatica	Zingiberaceae	Stem	Pain	Gond	Ketka
21	Doobi Ghash	Cynodon dactylon	Poaceae	Leaves	Small injury	Kanwar	Jobga
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28	Gudmar	Gymnema sylvestre	Apocynaceae	Root and leaves	Fever, Cough and Diabetes	Gond	Ketka
29	Gurhal	Hibiscus rosa sinensis	Malvaceae	Leaves	Swelling	Gond	Ketka
30	Kutuj	Holorrhena antidysenterica	Apocynaceae	Seed	Pain	Gond	Ketka
31	Arusa	Justicia adhatoda	Acanthaceae	Leaves	Asthma	Gond	Pendrakhi
32	Bhui Champa	Kaemperia rotunda	Zingiberaceae	Bark	Injury	Kanwar	Jobga
33	Patharbhaji	Kalanchoe pinnata	Crassulaceae	Leaves	Kidney stones	Gond	Pendrakhi
34	Mahua	Madhuca longifolia	Sapotaceae	Bark	Helps in reducing gum pain	Gond	Lanchi
35	Aam	Mangifera	Myrtaceae	Bark	Fever	Gond	Kot

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36	Pudina	Mentha piperita	Lamiaceae	Leaves	Cough	Gond	Ketka
37	Baukla	Mimusops elengi	Sapotaceae	Stem	Helps in reducing gum pain	Pando	Aamgao
38	Senjana	Moringa oleifera	Moringaceae	Leaves	Stomachache problem	Gond	Aamgao
39	Kevanch	Mucuna pruriens	Fabaceae	Leaves	Asthma	Pando	Aamgao
40	Kalijiri	Nigella sativa	Ranunculaceae	Seed	Immunity booster Respiration system	Oraon	Kot
41	Tulsi	Ocimum sanctum	Lamiaceae	Leaves	Cold cough and fever	Gond	Pendrakhi
42	Bhui aonla	Phyllanthus amarus	Phyllanthaceae	Whole plant	Diarrhoea, Dysentery	Gond	Aamgao
43	Aonla	Phyllanthus embelica	Phyllanthaceae	Fruit	Immunity booster	Gond	Ketka
44	Karanj	Pongamia pinnata	Fabaceae	Seed	Itching	Gond	Pendrakhi
45	Anar	Punica granatum	Lythraceae	Leaves	Diarrhoea	Gond	Aamgao
46	Sarpgandha	Rauvolfia serpentina	Apocynaceae	Root	Blood pressure	Gond	Ketka
47	Kattha	Senegalia catechu	Mimosaceae	Latex	Mouths ulcer	Pando	Aamgao
48	Charota	Senna tora	Caesalpiniaceae	Seed	Itching.	Kanwar	Jobga
49	Sarai	Shorea robusta	Dipterocarpaceae	Seed	Dysentery	Gond	Lanchi
50	Kateri	Solanum virginianum	Solanaceae	Seed	Teeth pain	Oraon	Jobga
51	Rohina	Soymida febrifuga	Meliaceae	Bark	Body pain	Gond	Kot
52	Sugarleaf	Stevia rebaudiana	Asteraceae	Leaves	Diabetes	Gond	Ketka
53	Jaam	Syzygium cumini	Myrtaceae	Fruit	Body swelling	Gond	Kot
54	Amli	Tamarindus indica	Fabaceae	Seed	Skin problems	Gond	Lanchi
55	Kauha	Terminalia arjuna	Combretaceae	Root	Teeth pain	Gond	Lanchi
56	Bahera	Terminalia bellirica	Combretaceae	Fruit	Cough	Oraon	Kot

57	Harra	Terminalia chebula	Combretaceae	Fruit	Fever, Heart disease	Oraon	Kot
58	Saja	Terminalia elliptica	Combretaceae	Bark	Diarrhea	Gond	Ketka
59	Giloy	Tinospora cordifolia	Menispermaceae	Stem	Immunity booster	Gond	Pendrakhi
60	Sindvar	Vitex negudo	Verbenaceae	Leaves	Fever	Oraon	Kot
61	Ashwagandha	Withania Somnifera	Solanaceae	Root	Blood pressure	Gond	Ketka
62	Dhawai	Woodfordia fruticosa	Lythraceae	Bark	Stop bleeding	Gond	Ketka

Conclusion:

These ethnobotanical practices and knowledge of plants, their use and associated rituals, ceremonies were passed done from generation to generation contributing in preservation of tribal identity, culture and wisdom. Tribal also possess deep knowledge and understanding about plant and its properties and their practices help in development of herbal remedies and also in new medicinal plants. The understanding of growth pattern, way of harvesting and utilization of plant resources ensures the availability of important plant species for future generations promoting the sustainable management of resources. Also, the rituals, beliefs and taboos include in tribal practices promotes a sence of responsibility towards environmental conservation.

The traditional medical system in India is crucial for providing rural people with comprehensive healthcare for a variety of illnesses. The study, in the forest area of Surajpur, Chhattisgarh, India, to learn more about the customs and traditional remedies of the residents of the surrounding villages. This ethnomedical research aimed to properly document the significant plants for ethnomedicinal that were flourishing in the village. In the village, 106 different species of medicinal plants from 49 different families were counted. The research concluded that this location is home to the medicinal plants with the greatest therapeutic utility, and further documentation is required. This study is the first to list and collect medicinal plants in the Surajpur forest area, and it offers the first analysis of the species' ethnomedical and cultural significance.

The ethnobotanical practices of tribal people in forest areas provide a rich tapestry of knowledge, culture, and sustainability. These practices represent an intricate relationship between humans and plants, encompassing medicinal uses, spiritual and ritual significance, food and nutrition, economic sustainability, and cultural preservation**.** By studying and understanding ethnobotanical practices, we gain valuable insights into traditional knowledge systems and the sustainable use of natural resources. Indigenous communities have developed a deep understanding of the diverse plant species in their environment and have honed their practices over generations, ensuring the preservation of valuable resources for future generations.

Moreover, ethnobotanical research holds significant potential for modern science. Many plant species used by indigenous people have been found to possess medicinal properties or offer unique attributes. By exploring these traditional practices, we can identify new compounds, uncover novel uses for plants, and contribute to the development of sustainable resource management strategies Furthermore, ethnobotanical practices underscore the importance of cultural diversity and the need to protect indigenous knowledge systems. Preserving and respecting ethnobotanical practices not only benefits indigenous communities but also contributes to the well-being of our planet. These practices offer lessons in sustainable harvesting, conservation, and the importance of cultural heritage. By integrating traditional wisdom with modern approaches, we can foster a more sustainable and holistic relationship with nature. In essence, the ethnobotanical practices of tribal people in forest areas serve as a reminder of the profound connection between humans and plants. They offer a wealth of knowledge, cultural richness, and potential contributions to various fields. By valuing and preserving these practices, we can foster a more sustainable future that embraces the intricate relationships between people and plants.

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STUDY ON THE ETHNOBOTANICAL PRACTICE PERFORMED BY TRIBAL COMMUNITIES IN SURAJPUR FOREST AREA, CHHATTISGARH

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Abstract:

The study of local (indigenous) plant uses by humans in a particular culture and region is known as ethnobotany. A pre-scientific medical system with bodies of medical knowledge that are passed down from one Vaidya to another through generations is referred to as traditional medicine. The practices for treating illnesses and ailments are related to the tribal people's beliefs, justifications, and ways of making herbal medicine. This paper presents the ethnomedical wealth of the Surajpur district. In various villages throughout Surajpur district, an ethnobotanical study was conducted. In order to treat a variety of illnesses among the various tribes, the paper focuses on the traditional phytotherapy practiced by the current investigations in the Surajpur district of Chhattisgarh, 62 species of plant or plant part have been identified which are used for ethnobotanical purpose by tribal groups. In the list of plant, there were 29 species of trees, 21 Species of herbs, 8 species of shrubs, and 4 species climber. The current study objective was to emphasize the crucial role that local knowledge and culture can play in resource management, to concentrate on the variety of ethnobotanical plants for future use, and to provide a framework for teaching people how to use plants to solve various types of problems.

Keywords: Ethnobotany, Medicinal plant, Traditional knowledge, Ethnomedicine, Ethnic group, Tribal community.

Introduction

Chhattisgarh (C.G) is referred to as the "Herbal State" due to its abundant biodiversity and the reliance of its native tribal population on traditional medical practices. Ethno-botany accounts for the study of relationship between people and plants for their use as medicines, food, shelter, clothing, fuel, fodder, and other household Purposes (Jangdey et. al 2016). It deals with the Interaction of indigenous plants and the local Inhabitants of the area.

The main aim of the present study is to collect information on plants used for ethnobotanical practices by some selected local tribes of the Surajpur Forest area, Chhattisgarh. Various plants have been used in traditional Medicine for several thousand years. India is a repository of medicinal plants. The herbal treasure of the nation is rich in its floristic wealth. Ethnobotany is a fascinating field that explores the intricate relationship between plants and human cultures. It focuses on the traditional knowledge and practices of different ethnic groups, particularly those by living in forest areas (Painkara et. al, 2015). Tribal communities, in particular, have a deep understanding of the local flora and have developed unique ethnobotanical practices over generations. In forest areas, tribal people have a profound connection with their natural surroundings. They have acquired a wealth of knowledge about the diverse plant species found in their environment and have learned to utilize them for various purposes. These practices are deeply rooted in their cultural traditions and play a significant role in their daily lives (Kala, 2009).

The study of ethnobotany not only provides valuable Insights into the traditional knowledge of tribal communities but also offers potential contributions to modern science. Many plant species used by indigenous people have been found to possess medicinal properties or other valuable attributes. Ethnobotanical research can help identify new compounds, uncover unique uses for plants, and contribute to the development of sustainable practices for resource management (Kujur and Ahirwar, 2015). Ethnobotany practices by tribal people offer a unique perspective on the intricate relationships between humans and plants. They provide valuable insights into the sustainable use of natural resources and hold the potential for discovering new medicinal compounds (Kujur and Ahirwar,2015). Furthermore, these practices underscore the importance of cultural diversity and the need to protect indigenous knowledge systems for the benefit of future generations and the well-being of our planet. Ethnobotanical practices have been carried out by societies throughout history and across different geographical regions. They are deeply rooted in the cultural and ecological

Objective

1. Data collection on ethnobotanical usage of floral species, by tribal community in the Surajpur forest area, in Chhattisgarh.
2. To document the traditional knowledge of plants used in ethnobotanical practices.
3. To document the method of drug preparation used by the tribal community in the Surajpur forest area of Chhattisgarh.

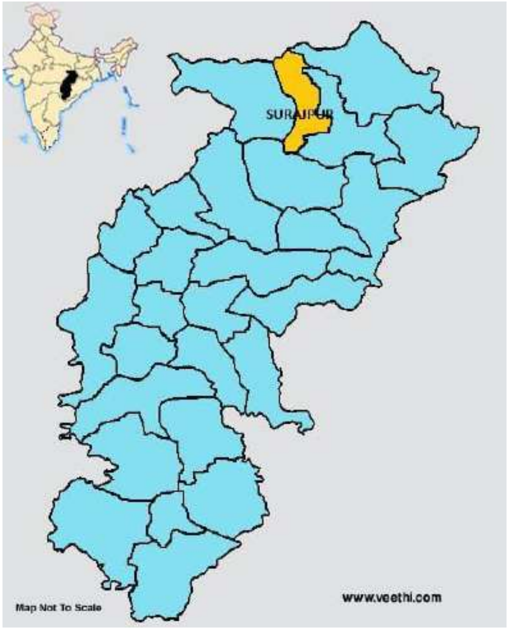
Material And Method:

Study Area

Chhattisgarh is situated in the central region of India. It is surrounded by states like Orissa, Maharashtra, Madhya Pradesh, Jharkhand, Uttar Pradesh, Telangana and Andhra Pradesh. Also, there are 5 different river basins that lie in the states which are

Brahmani, Mahanadi, Ganga, Godavari, and Narmada. Furthermore, the soils found here are Black Soil, Laterite, Red Soil, Loamy Soil, Black Soil, and others. The southern and northern part of the state is covered with hilly areas, and the central area is plain land.

The current study was conducted in the selected site of Surajpur Forest Area of Chhattisgarh (Lat: 23.2136011°N , Long: 82.8679549°E). Around 2,787 km2 area of the Surajpur District is under forest cover. Surajpur has a humid subtropical, dry winter climate and at 553.09 metres (1814.6 feet) above sea level. Tribes in the Surajpur district eat a variety of wild fruits as part of their diet, particularly during times of food scarcity, due to the area's dense forests and rich flora. Surajpur generally experiences 35.81 rainy days (9.81%) per year and averages about 51.59 millimeters (2.03 inches) of precipitation yearly. The Gond, Oraon, Kanwar, and other hill tribes and indigenous people of the Surajpur district.



Map 1: study area map Source: internet

Map 2: Study area Village (Source – Google Earth)

Ethnobotanical exploration

According to literature review on the ethnobotanical investigations, there have not been any research done in the Surajpur region, although there have been a few research done in neighboring districts. As a result, from April to July 2023, field surveys were conducted in the tribal villages of Surajpur district, including Aamgao, Jobaga, Ketka, Kot Lachaa, and Lanchhi Pendrakhi, to collect information on the uses of various plant species. Semi-structured questionnaires on plant components used for food, medicine, vegetables, fibres, colours, gums, agricultural instruments, and other types of illnesses were also utilised to collect data during the survey period. Group conversations among tribal villagers of various ages, representing both genders in the community, were used to cross-check the data.He participant observation method was also used to comprehend the approaches and procedures used by tribe members when using plants and plant components. With the help of informed elders and local youth, the surrounding forested region and agricultural land of the villages were also surveyed for the identification of several ethnobotanical species and their traditional applications.

Method used:

Ethno-botanical survey is conduct in different tribal inhibited areas of Surajpur Forest Area, District- Surajpur Chhattisgarh during (April-July). Extensive field Trips were organized for collecting the plant Species and data. The method adopted for the Collection of data is based on medicinal uses of plants in the treatment of various diseases. Several visits has been done with these resource persons who helped to identify the plants, local/tribal names of the Plants, and the medicinal uses which need to confirm through many resource person as far as possible in other localities of the State. Information like medicinal use of Plant, plant parts used, diseases treated, modes of drug Preparation and administration has been recorded.

Participant Selection: Indentation of members of the community who are having knowledgeable about plants, such as traditional healers, elders, herbalists, and community leaders. Seeked permission and built trust within the community before initiating data collection activities.

Plant Identification References: Various field guide used for floras, or botanical keys specific to the study area. These references aid in plant identification based on botanical features such as leaves, flowers, fruits, and other characteristics.

Identification- Species were identified on the basis of morphology and taxonomic characters. The identities of several plants were confirmed by experts from various institutions. Anatomical sections were also taken to confirm species identity.

Ethnomedicinal practices documentation: An essential method of preserving traditional knowledge about the medicinal plants and cures utilised by many cultures is by documenting ethnomedical practises. It includes keeping a record of the plants' characteristics, cooking techniques, and uses in curing particular diseases.

Result and Discussions:

During the current investigations in the Surajpur district of Chhattisgarh,62 species of plant or plant part have been identified which are used for ethnobotanical purpose by tribal groups. In the list of plant, there were 29 species of trees, 21 Species of herbs, 8 species of shrubs, 4 species climber. Although 62 plant families are represented in the research region, Fabaceae was the most prevalent family in terms of the number of ethnobotanical species. These ethnobotanical plants were used for a variety of things, including food, medicine, drinks, vegetables, tonics, fish poison, insect repellent, and clothing dye.

Medicinal Plants: The 34 families that make up the overall number of known medicinal plant that are used in ethnobotanical practices in Surajpur forest area. For ethnomedicinal usage whole plant or various parts, including the root, tuber, leaf, fruit, bark, resin, seed, and latex, were all employed as medicines. The most common plant part used to make medicine was the root (12 species), which was then followed by fruit (6 species), bark (7 species), leaves (18 species), and seeds (8 species). One species of tuber and three species of stem whole plant (5 species). These plant species have been used to treat a variety of conditions, including indigestion, a cough, body aches, diarrhea, cut wounds, scorpion bites, snake bites, and muscular pain.

The specific results obtained from such a survey can vary depending on the objectives and scope of the study. However, here are some potential outcomes that may arise from an ethno botanical survey: after grinding the stem of *Curcuma* in ball shaped *romatic.*

Fig 1- This figure shows the paste made

Fig 2- Showing prepared mixture that is turned

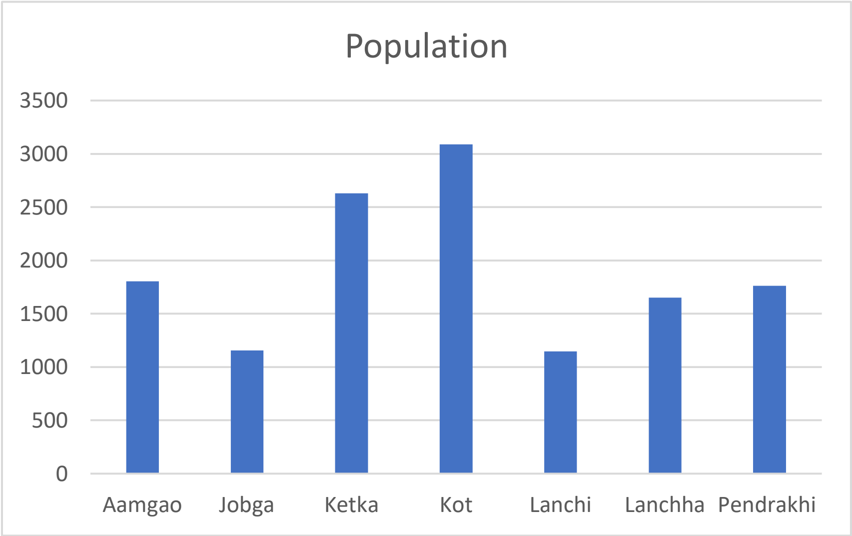


Figure 3- Variation in Population of Study Area

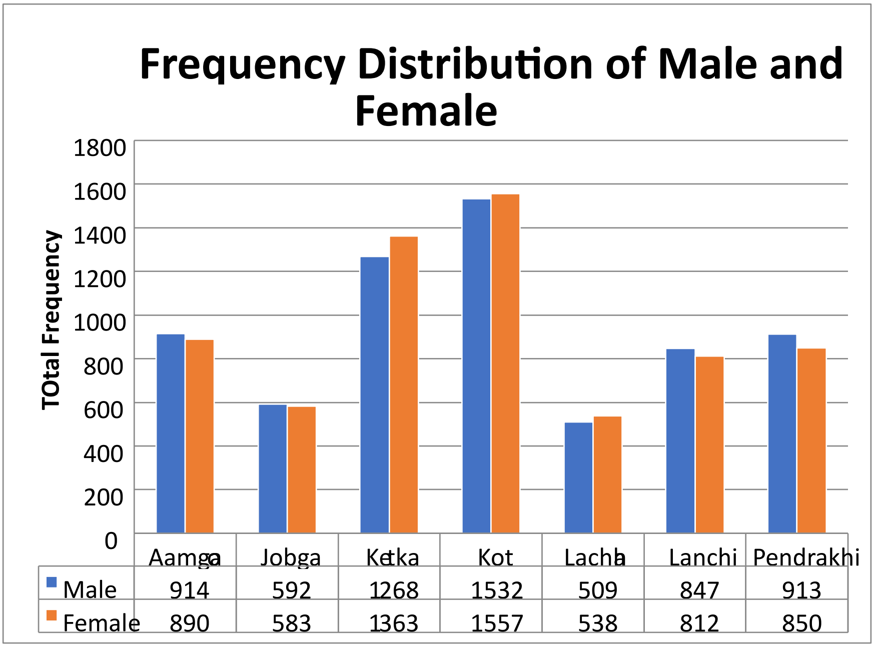


Fig 4- Frequency Distribution of Male and Female in different villages

Medicinal Plant Uses:

The performed survey provides detailed information about the traditional medicinal uses of plants in the treatment of various diseases. This includes information about specific plant parts used, modes of drug preparation, and administration methods**.** Here are the list: -

Table 1: Drug preparation procedure documented from the tribal community

S. N.	Common Name	Scientific Name	Family	Parts use	Disease Uses	Method of preparation	Dose
1	Dabi	*Cadaba fruticosa*	Capparaceae	Seed	Heart disease	seed is processed into paste and then drink it with water.	3-6 Dose

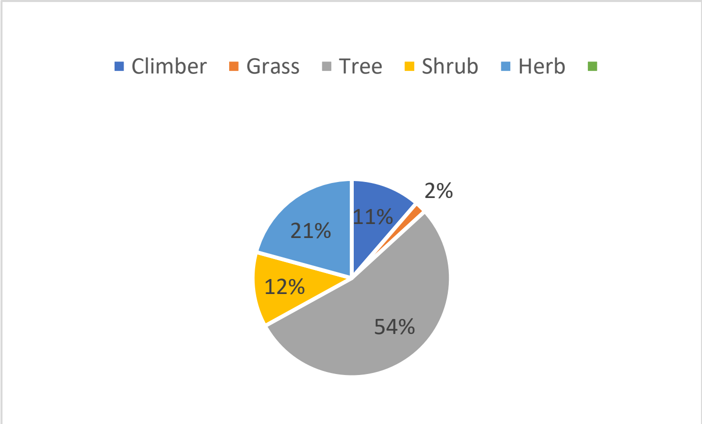
2	Jangli haldi	*Curcuma aromatica*	Zingiberaceae	Stem	Pain	blackgram is soaked in water overninght or for 6hrs, then the prepared mixture is turned in ball shaped	20-25 Dose
3	Doob	*Cynodon dactylon*	Poaceae	Leaves	Small injury	grinds with grinding stone, apply the paste to injuries	4-5 Dose
4	Mahua	*Madhuca longifolia*	Sapotaceae	Bark	Helps in reducing gum pain	twig is used to brush teeth.	4-5 Dose
5	Aam	*Mangifera indica*	Myrtaceae	Bark	Fever	Collection of bark, then grinding with help of grinding stone, then ready todrink.	5-7 Dose
6	Charota	*Senna tora*	Caesalpiniaceae	Seed	Itching.	processed into paste and applied into exposed area.	4-5 Dose
7	Sal	*Shorea robusta*	Dipterocarpaceae	Seed	Dysentery	seed is used in powered form through grinding boil the seed	4-5 Dose
8	Kateli	*Solanum virginianum*	Solanaceae	Seed	Teeth pain	tranform it into paste form, then applied to hairs directlt	3-5 Dose

9	Rohina	*Soymida febrifuga*	Meliaceae	Bark	Body pain	bark is boiled and the remains liquid is drinked	4-6 Dose
10	Baheda	*Terminalia bellirica*	Combretaceae	Fruit	Cough	roasted in pan, some people turns it into small pieces which further ready to eat directly	3-5 Dose
11	Saja	*Terminalia elliptica*	Combretaceae	Bark	Diarrhea	processed into powered, consumable with water	

Conservation and Sustainable Use: The survey may highlight plant species of conservation concern or those that are at risk due to over-harvesting or habitat loss. This information can contribute to the development of conservation strategies and sustainable use practices.

Comparative Ethnobotanical Study by Tribal Community

As per this study, the indigenous communities living within the forest of Sarjapur have long been a source of admiration as they



possess a unique understanding of, and ability to utilize, the plants around them. The four largest tribal communities (Gond, Pando, Kanwar, Raon) were investigated and data on their use of plants were obtained by discussion with tribal informants. Data on ethnobotanical practices which are mostly used to cure body pain, dysentery, gum pain, blood pressure, itching, fractures, etc. The study reveals too little commonality in usage of herbal remedies for the selected villages. The difference in usage of plants by same tribes occupying different localities and different tribes of the same or nearby localities was observed.

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6	Kalmegh	Andrographis paniculata	Acanthaceae	Whole plant	Fever	Gond	Pendrakhi
7	Sitaphal	Annona squamosa	Annonaceae	Leaves	prevents hair lice	Oraon	Kot
8	Satavar	Asparagus racemosus	Asparagaceae	Tuber	Immunity booster	Gond	Jobga
9	Leem	Azadirachta indica	Meliaceae	Bark	Fever	Gond	Lanchi
10	Brahmi	Bacopa monnieri	Plantaginaceae	Whole plant	Increase memory power	Gond	Pendrakhi
11	Char	Buchanania lanzan	Anacardiaceae	Leaves	Small injury	Gond	Kot
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		indica					
36	Pudina	Mentha piperita	Lamiaceae	Leaves	Cough	Gond	Ketka
37	Baukla	Mimusops elengi	Sapotaceae	Stem	Helps in reducing gum pain	Pando	Aamgao
38	Senjana	Moringa oleifera	Moringaceae	Leaves	Stomachache problem	Gond	Aamgao
39	Kevanch	Mucuna pruriens	Fabaceae	Leaves	Asthma	Pando	Aamgao
40	Kalijiri	Nigella sativa	Ranunculaceae	Seed	Immunity booster Respiration system	Oraon	Kot
41	Tulsi	Ocimum sanctum	Lamiaceae	Leaves	Cold cough and fever	Gond	Pendrakhi
42	Bhui aonla	Phyllanthus amarus	Phyllanthaceae	Whole plant	Diarrhoea, Dysentery	Gond	Aamgao
43	Aonla	Phyllanthus embelica	Phyllanthaceae	Fruit	Immunity booster	Gond	Ketka
44	Karanj	Pongamia pinnata	Fabaceae	Seed	Itching	Gond	Pendrakhi
45	Anar	Punica granatum	Lythraceae	Leaves	Diarrhoea	Gond	Aamgao
46	Sarpgandha	Rauvolfia serpentina	Apocynaceae	Root	Blood pressure	Gond	Ketka
47	Kattha	Senegalia catechu	Mimosaceae	Latex	Mouths ulcer	Pando	Aamgao
48	Charota	Senna tora	Caesalpiniaceae	Seed	Itching.	Kanwar	Jobga
49	Sarai	Shorea robusta	Dipterocarpaceae	Seed	Dysentery	Gond	Lanchi
50	Kateri	Solanum virginianum	Solanaceae	Seed	Teeth pain	Oraon	Jobga
51	Rohina	Soymida febrifuga	Meliaceae	Bark	Body pain	Gond	Kot
52	Sugarleaf	Stevia rebaudiana	Asteraceae	Leaves	Diabetes	Gond	Ketka
53	Jaam	Syzygium cumini	Myrtaceae	Fruit	Body swelling	Gond	Kot
54	Amli	Tamarindus indica	Fabaceae	Seed	Skin problems	Gond	Lanchi
55	Kauha	Terminalia arjuna	Combretaceae	Root	Teeth pain	Gond	Lanchi
56	Bahera	Terminalia bellirica	Combretaceae	Fruit	Cough	Oraon	Kot

57	Harra	Terminalia chebula	Combretaceae	Fruit	Fever, Heart disease	Oraon	Kot
58	Saja	Terminalia elliptica	Combretaceae	Bark	Diarrhea	Gond	Ketka
59	Giloy	Tinospora cordifolia	Menispermaceae	Stem	Immunity booster	Gond	Pendrakhi
60	Sindvar	Vitex negudo	Verbenaceae	Leaves	Fever	Oraon	Kot
61	Ashwagandha	Withania Somnifera	Solanaceae	Root	Blood pressure	Gond	Ketka
62	Dhawai	Woodfordia fruticosa	Lythraceae	Bark	Stop bleeding	Gond	Ketka

Conclusion:

These ethnobotanical practices and knowledge of plants, their use and associated rituals, ceremonies were passed done from generation to generation contributing in preservation of tribal identity, culture and wisdom. Tribal also possess deep knowledge and understanding about plant and its properties and their practices help in development of herbal remedies and also in new medicinal plants. The understanding of growth pattern, way of harvesting and utilization of plant resources ensures the availability of important plant species for future generations promoting the sustainable management of resources. Also, the rituals, beliefs and taboos include in tribal practices promotes a sence of responsibility towards environmental conservation.

The traditional medical system in India is crucial for providing rural people with comprehensive healthcare for a variety of illnesses. The study, in the forest area of Surajpur, Chhattisgarh, India, to learn more about the customs and traditional remedies of the residents of the surrounding villages. This ethnomedical research aimed to properly document the significant plants for ethnomedicinal that were flourishing in the village. In the village, 106 different species of medicinal plants from 49 different families were counted. The research concluded that this location is home to the medicinal plants with the greatest therapeutic utility, and further documentation is required. This study is the first to list and collect medicinal plants in the Surajpur forest area, and it offers the first analysis of the species' ethnomedical and cultural significance.

The ethnobotanical practices of tribal people in forest areas provide a rich tapestry of knowledge, culture, and sustainability. These practices represent an intricate relationship between humans and plants, encompassing medicinal uses, spiritual and ritual significance, food and nutrition, economic sustainability, and cultural preservation. By studying and understanding ethnobotanical practices, we gain valuable insights into traditional knowledge systems and the sustainable use of natural resources. Indigenous communities have developed a deep understanding of the diverse plant species in their environment and have honed their practices over generations, ensuring the preservation of valuable resources for future generations.

Moreover, ethnobotanical research holds significant potential for modern science. Many plant species used by indigenous people have been found to possess medicinal properties or offer unique attributes. By exploring these traditional practices, we can identify new compounds, uncover novel uses for plants, and contribute to the development of sustainable resource management strategies Furthermore, ethnobotanical practices underscore the importance of cultural diversity and the need to protect indigenous knowledge systems. Preserving and respecting ethnobotanical practices not only benefits indigenous communities but also contributes to the well-being of our planet. These practices offer lessons in sustainable harvesting, conservation, and the importance of cultural heritage. By integrating traditional wisdom with modern approaches, we can foster a more sustainable and holistic relationship with nature. In essence, the ethnobotanical practices of tribal people in forest areas serve as a reminder of the profound connection between humans and plants. They offer a wealth of knowledge, cultural richness, and potential contributions to various fields. By valuing and preserving these practices, we can foster a more sustainable future that embraces the intricate relationships between people and plants.

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Forest, Water and Wildlife Management

A Futuristic Approach

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A COMPREHENSIVE REVIEW OF TRENDS IN THE EVOLUTION OF FOREST

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Introduction

Forests hold immense significance for the well-being of our planet and all its inhabitants. Forests are crucial for the health of the planet, supporting life in various ways (Turner-Skoff and Cavender, 2019). Preserving and sustainably managing forests is essential for the well-being of current and future generations (Ali, 2023). The phrase "mother of all" is often used metaphorically to emphasize the importance, origin, or fundamental nature of something. When it comes to calling the forest the "mother of all," it might be highlighting the vital role forests play in supporting life on Earth. Forests are incredibly important ecosystems that provide a multitude of benefits (Bhat, 2023). They produce oxygen, store carbon, support biodiversity, and offer resources like wood and various plant-based products. Additionally, forests play a crucial role in regulating the climate, preventing soil erosion, and purifying water. (Brockerhoff, 2017).

In a poetic sense, you could consider the forest as a nurturing and sustaining force, akin to a mother, providing the essentials for life and fostering the well-being of the planet. It's a beautiful way to acknowledge the interconnectedness of nature and our dependence on these ecosystems for our survival and prosperity (Martin et al., 2016). Forests are integral to numerous applied sectors, each playing a crucial role in sustaining life and fostering ecological balance (Brockerhoff, 2017). In the water sector, forests act as natural watersheds, regulating and purifying water. They help maintain consistent water flow, prevent soil erosion, and serve as a source for rivers and streams. Forests are vital for wildlife, providing habitats for countless species. The diverse ecosystems within forests support a wide range of flora and fauna, contributing to global biodiversity (FAO and UNEP, 2020). In agriculture, forests influence climate patterns, impacting rainfall and temperature, which in turn affect crop yields. The timber industry relies on forests for wood and other products, while non-timber forest resources contribute to various sectors, including medicine, food, and traditional practices. Additionally, forests play a pivotal role in carbon sequestration, mitigating climate change effects. Indigenous communities often have cultural ties to forests, relying on them for livelihoods and preserving traditional knowledge (Ogar, et al., 2020). In essence, forests are intertwined with water management, wildlife conservation, agriculture, industry, and cultural heritage, highlighting their multidimensional significance for a sustainable and balanced planet.

Evolutionary trajectory of earth's forests from ancient to beyond

About 420 million years ago, during the Silurian Period, ancient plants and arthropods began to occupy the land (Johnson, 2023). Over the millions of years that followed, these land colonizers developed and adapted to their new habitat. The first forests were dominated by giant horsetails, club mosses, and ferns that stood up to 40 feet tall. Terrestrial vegetation of the Silurian and Early Devonian was typically short and restricted to a narrow band along the water's edge. But by the early Middle Devonian (Eifelian), taller, arborescent forms evolved independently within the cormose lycopsids, cladoxylopsids and progymnosperms. The first known forests on Earth arose in the Late Devonian (approximately 419.2 to 358.9 million years ago), with the evolution of Archaeopteris which was a plant that was both tree-like and fern-like, growing to 10 meters (33 ft) in height. It quickly spread throughout the world, from the equator to subpolar latitudes;(The first forest, 2016) and it formed the first forest by being the first species known to cast shade due to its fronds and by forming soil from its roots. Archaeopteris was deciduous, dropping its fronds onto the forest floor, the shade, soil, and forest duff from the dropped fronds creating the first forest. (The first forest, 2016) The shed organic matter altered the freshwater environment, slowing its flow and providing food. This promoted freshwater fish. (The first forest, 2016)

Life on Earth continued to evolve, and in the late Paleozoic era (538.8 to 251.9 million years ago), gymnosperms appeared (Feng, 2017). By the Triassic Period (245-208 million year ago), gymnosperms dominated the Earth's forests. In the Cretaceous Period (144-65 million year ago), the first flowering plants (angiosperms) appeared. They evolved together with insects, birds, and mammals and radiated rapidly, dominating the landscape by the end of the Period. The landscape changed again during the Pleistocene Ice Ages — the surface of the planet that had been dominated by tropical forests for millions of years changed, and temperate forests spread in the Northern Hemisphere (Ellis and Palmer, 2016). In Paleogene period (66 to 23 million years ago) Ferns were initially abundant following the K-T extinction, but flowering plants and conifers soon took over as they returned to abundance. Deciduous trees dominated swamp forests in North America from middle latitudes to the Arctic Ocean. The onset of the Neogene Period (23 to 2.6 million years ago) marked a pivotal shift as expansive forests yielded to the emergence of widespread grasslands and savannahs. This transformation created novel ecological opportunities and sustenance, propelling the evolutionary trajectory of mammals and birds. The grasslands and savannahs presented new niches and abundant food sources, influencing the development of diverse species. This shift in ecosystems during the Neogene spurred significant adaptations among fauna, fostering the evolution of mammals and birds to thrive in the evolving landscapes. The interplay between changing environments and emerging ecological niches shaped the course of life during this transformative period. - The Neogene Period started with the replacement of vast areas of forest by grasslands and savannahs. New food sources and niches on the grasslands and savannahs fostered further evolution of mammals and birds. During the Quaternary Period (2.6 to 0 million years ago) the forests with which we are familiar seldom maintained a constant species composition for more than 2000 or 3000 years at a time (Davis, 1981). During the Quaternary Period (2.6 million years ago to the present), Earth witnessed significant changes in its forests (Elias, 2013). Ice ages and interglacial periods influenced the distribution and composition of forests globally. Glacial advances led to the contraction of forests, while warmer interglacial periods saw their expansion (Shao, 2022). These climatic shifts shaped the composition of flora and fauna within forests. Additionally, human activities, including the emergence of Homo sapiens, began to impact forests through practices like fire management and eventually deforestation. The Quaternary Period marks a dynamic era for forests, responding to both natural climatic fluctuations and human interventions.

Gilboa forest in eastern New York

One of the more famous Middle Devonian sites is the Gilboa "Forest" in eastern New York State. The arrangement of mudstones, coarse sandstone and tree stumps suggest that this site was a natural levee subject to successive destructive floods interspersed with stable periods in which soils accumulated and the vegetation recovered (Sona, 2023). Plants at Gilboa included ground cover, shrubs and medium-sized trees. One aborescent lycopsid, *Lepidosigillaria*, may have reached 5 m in height. *Eospermatopteris*, a tree of uncertain affinity, may have been 9 m tall. A common cladoxylopsid, *Pseudosporochnus*, was about 3 m tall. The vegetation at Gilboa may have reached considerable heights, but it didn't exhibit some important characteristics of modern forests. For one, the vegetation was apparently still restricted to a narrow band along the water's edge. This narrow band, combined with the absence of webbed leaves, indicate that there was relatively little shade and litter production. In addition, the Gilboa vegetation lacked deeply penetrating root systems that would have stabilized stream banks and enhanced pedogenesis (Lukasz, 2020). Nonetheless, Middle Devonian vegetation such as the Gilboa "Forest" probably moderated the physical environment of freshwater ecosystems and enriched them with organic matter.

The Arrival of *Archaeopteris*

Vegetation resembling modern forests first occurred with the appearance of *Archaeopteris* in the Late Devonian (Stein, et al., 2020). This remarkable genus has been recorded from virtually all known Devonian land masses and ranged from tropical to sub-polar paleolatitudes. These large trees (20 m or more in height) possessed webbed leaves that produced relatively dense shade. In addition, they possessed a deeper and more extensive root system that greatly accelerated pedogenesis and probably allowed them to colonize drier parts of floodplains and coastal lowlands. The advent of shade and the greater spread of trees created an entirely new terrestrial habitat, the forest biome. This new habitat was characterized by leaf canopy that moderated temperature and humidity regimes and shielded microbes and invertebrates from ultraviolet light. The seasonal duration of these moderated conditions, however, is unclear. We know *Archaeopteris* was deciduous, but not whether its leaves were shed once a year or throughout the year (Berthaud, et al., 1999). If they were shed throughout the year then the forest floor would have been continuously moderated. But if they were shed seasonally, then the forest floor would have been exposed for part of the year. In either case, *Archaeopteris* forests produced what must have been an unprecedented amount of organic matter for microbial decomposers and invertebrate detritivores. However, evidence for any increase in the diversity or abundance of terrestrial detritivores is lacking, in large part because Late Devonian terrestrial invertebrates are poorly known. While the impact of terrestrial plant production on invertebrate detritivores remains unclear, other consequences are evident in Late Devonian sediments. One of these is the first appearance of coals. No coal deposits have been found at Red Hill, possibly because of its seasonal climate, but similar age coals have been found elsewhere in the paleocontinent Euramerica (North America and part of Western Europe). Another consequence is wildfire. Red Hill is one of the two earliest localities for which we have direct evidence of wildfires (Liu, et al., 2021). In this case, the primary "victim" appeared to have been *Rhacophyton*, an ancient "fern" that was co-dominant with *Archaeopteris* at Red Hill. These fires appeared to have been low intensity blazes that burned low-lying material (i.e., shrubs), but spared the trees. The first forests probably also had profound influences on aquatic systems. They contributed to the moderation of flow regimes and stabilization of stream habitats (Shah, et al., 2022). They also probably greatly enriched streams with substantial increases of organic matter, primarily in the form of detritus. Some of this would result from plant material falling directly into the water, but most of the organic matter created by the forests would probably enter via flooding (Sao, et al., 2023). The rise in forests is also associated with global changes of marine systems (Perry, 2010). The widespread deposition of black marine shales during the late Middle Devonian (Givetian) and Late Devonian has been attributed to a dramatic increase in the influx of terrestrial organic matter (Dunkel, et al. 2022). In turn, these black shales are associated with the Late Devonian Mass Extinction.

The *Archaeopteris* forests of the Late Devonian probably transformed terrestrial, freshwater and marine ecosystems (The first forest, 2016). But another striking characteristic of these ancient forests is their apparent lack of diversity. Arborescent forms are overwhelmingly dominated by a single genus, *Archaeopteris*. Several leaf species of this climatically and geographically widespread genus are known, but it’s now clear whether they represent biological species or merely leaf-taxa of fewer true species. Arborescent forms are otherwise represented by a group of cormose lycopsids, which were apparently restricted to wetter sites (Stein, et al., 2020).

Rhacophyton is the other dominant plant in most *Archaeopteris* forests as well as several Late Devonian wetlands (Capel, et al., 2022). It’s not known outside of North America and Western Europe, but this may be a result of our ignorance of Gondwana macrofloral assemblages rather than a geographic restriction of this apparently prolific plant. Seed plants make their first appearance in the Famennian (late Late Devonian), but they appear to have been pioneer species that succeeded only in disturbed sites.

Another striking characteristic of the Late Devonian forests is the apparent disappearance of the forest biome following the extinction of *Archaeopteris* near the end of the Devonian. An increasingly diverse assemblage of seed plants, ancient "ferns" (zygopterids), sphenopsids (relatives of horsetails) and arborescent lycopsids occur in the earliest Carboniferous. Arborescent lycopsids (e.g., *Cyclostigma* and *Lepidodendropsis*) dominated many wetland sites, but floodplain and coastal lowland assemblages were characterized primarily by low-growing seed plants and zygopterids. Trees apparently didn’t become dominant again until much later in the Carboniferous.

Evolution and status of present forest

The ongoing evolution of forests represents a complex interplay between natural processes and human influences, and this delicate balance has significant implications for the state of the global environment. Human activities, driven by factors such as population growth and economic development, have become powerful agents of change alongside natural forces. Climate fluctuations, a key driver of forest dynamics, contribute to alterations in temperature and precipitation patterns, impacting the distribution and health of various forest types (Sarah, et al., 2020).

Tropical rainforests, characterized by their unparalleled biodiversity and luxuriant vegetation, face considerable threats stemming from human activities (Morris, 2010). Deforestation, driven by the expansion of agriculture and logging, poses a severe risk to these ecosystems (Ortiz, et al., 2021). The loss of large areas of rainforest not only disrupts intricate ecological balances but also contributes to global carbon emissions (Ometto, et al., 2022). Efforts to address these challenges include conservation initiatives, sustainable land-use practices, and reforestation projects aimed at mitigating the impact of deforestation (Dieng, et al., 2023). Similarly, temperate forests, which experience distinct seasonal changes, find themselves in a state of flux due to climate change. As temperatures rise and weather patterns become less predictable, these forests undergo shifts in species composition and altered migration patterns of animals. These changes have cascading effects on ecosystem dynamics, affecting everything from nutrient cycling to the availability of resources for various species. Boreal forests in northern latitudes, traditionally adapted to cold climates, are witnessing transformations due to global warming. Warming temperatures lead to shifts in vegetation zones, impacting the types of trees that can thrive in these environments. Moreover, the increased frequency and intensity of wildfires in these regions further contribute to the evolution of boreal ecosystems, with potential consequences for carbon storage and the release of greenhouse gases. Coastal ecosystems, particularly mangrove forests, face unique challenges as urbanization encroaches upon these critical habitats (Akram, 2023). Rising sea levels, a consequence of climate change, pose a direct threat to the existence of mangroves, which play a vital role in protecting coastlines, providing nurseries for marine life, and supporting diverse ecosystems. Conservation efforts aimed at preserving mangroves involve a combination of habitat restoration, sustainable coastal development practices, and measures to mitigate the impacts of climate change (Ellison, et al., 2020). The diversity of forest types globally underscores their multifaceted roles in maintaining ecological balance. Deciduous forests, with trees that shed their leaves seasonally, contribute to nutrient cycling and provide habitat for a wide range of wildlife. Coniferous forests, dominated by evergreen trees with needle-like leaves, play a crucial role in carbon sequestration and are often found in colder climates. Montane forests, situated in mountainous regions, showcase adaptations to harsh environmental conditions and are crucial for regulating water flow in watersheds.

Forest report according to FAO and CPF. 2022

Global Forest Resources Assessment led by the Food and Agriculture Organization of the United Nations (FAO) found that forests covered 4.06 billion hectares (10.0 billion acres; 40.6 million square kilometres; 15.7 million square miles), or approximately 31 percent of the world's land area in 2020 (The State of the World's Forests 2020).

"Proportion of Total Land Area Covered by Forests". Globally, the percentage of land covered by forests decreased from 31.9 percent in 2000 to 31.2 percent in 2020. In just 20 years, this amounts to a net loss of about 100 million hectares of global forest cover.

“**Rate of Annual Change in Forest Area”.** The yearly forest-area change rate decreased somewhat between 2000 and 2020, going from -0.13 percent to -0.12 percent. Globally, the yearly loss of forests has decreased as a result, from -5.2 million ha in 2000–2010 to -4.7 million hectares in 2010–2020.

“**Percentage of Forest Area Encompassed by Legally Designated Protected Areas”** Around 18% of the world's forest land (726 million hectares) is found in officially recognised protected areas, including game reserves, national parks, and conservation areas. Globally, the amount of forests in protected areas grew by 191 million hectares between 1990 and 2020; however, from 2010 to 2020, the annual growth rate of this area decreased.

“Primary Forest Area Dynamics”. 1.11 billion hectares, or almost one-third (34%) of the total forest area of the 146 countries and territories that reported to the FAO for its 2020 Global Forest Resources Assessment (FRA), were anticipated to be primary forests worldwide in 2020. Between 1990 and 2020, the primary forest area worldwide shrank by 81.3 million hectares, with an estimated 1.27 million hectares lost annually between 2010 and 2020. Western and Central Africa experienced the greatest rate of loss between 2010 and 2020 (from 97 million hectares to 88 million ha), followed by South America (from 301 million ha to 298 million ha).

“Percentage of Disturbed Forest Area”. The total forest area affected by disturbances in 2015 (the most recent year for which data are available globally) was 30.2 million hectares in 62 countries and territories (1.4 percent of those countries' total forest area) for insects; 6.60 million hectares in 51 countries and territories (0.4 percent of those countries' total forest area) for diseases; 3.83 million hectares in 48 countries and territories (0.3 percent of those countries' total forest area) for severe weather events; and 98 million hectares in 118 countries and territories (3 percent of those countries' total forest area) for forest fires.

"Extent of Degraded Forest Area". FRA 2020 received reports from 58 countries, or 38% of the world's total forest area, indicating that they kept an eye on the area of damaged forest. The inability to establish a globally accepted definition of forest degradation prevents data on the area of degraded forest from being combined on a regional or global scale.

"Aboveground Biomass within Forests". With the highest value found in Latin America and the Caribbean, the aboveground biomass in the world's forests was expected to have increased to approximately 118 tonnes per ha in 2020 from roughly 117 tonnes per ha in 2010.

"Forest Area Dedicated to Protective Functions through Managed Objectives". In 2020, the global area allocated primarily for safeguarding soils and water was approximately 398 million hectares, covering 141 countries and territories that reported to FRA 2020, representing 82 percent of the total forest area. This marked a notable increase of 119 million hectares compared to 1990, encompassing 131 countries and territories with time-series data on this aspect.

Europe holds the largest portion of forested land designated for soil and water protection, accounting for 171 million hectares (18 percent of the region's total forest area). Asia follows closely with 132 million hectares (22 percent of the forest area), the highest proportion among all regions. Simultaneously, the area specifically designated for biodiversity conservation in 2020 was estimated at 424 million hectares, covering 165 countries and representing 91 percent of the world's forest area. Africa boasts the largest area dedicated to this purpose, amounting to 107 million hectares, while Europe has the lowest proportion at 4 percent.

“Employment in the Forest Sector”. Between 2017 and 2019, the global workforce in the forest sector was estimated at approximately 33 million people, with a significant concentration of 80 percent in Asia and Africa. Over the course of the decade leading up to 2019, there was an observable decline in employment within the forest sector, a trend largely driven by a decrease in the number of individuals employed in subsectors related to wood-based manufacturing.

“Number of Individuals in Extreme Poverty Dependent on Forests”. In 2019, an estimated 3.27 billion people globally lived within 1 km of a forest, constituting 75 percent of the total rural population. Additionally, around 4.17 billion people, or 95 percent of the total rural population, were situated within 5 km of a forest. Efforts are currently underway to develop methodologies that integrate poverty data with information on forest proximity, marking the next phase in reporting on this indicator.

“Percentage of Forest Area Covered by Long-Term Management Plans”. As of 2020, the global area of forest covered by management plans has expanded by 233 million hectares since 2000, reaching a total of 2.05 billion hectares. This growth is evident across all regions. Notably, a significant proportion of forests in Europe, specifically 96 percent, have established management plans. In contrast, management plans cover less than 25 percent of forests in Africa and less than 20 percent of forests in South America. This discrepancy highlights regional variations in the adoption of forest management strategies, with Europe demonstrating a higher prevalence of such plans compared to Africa and South America.

“Forest Area Certified under Independent Verification for Forest Management”. In 2021, the combined reported net certified forest area by the two primary certification bodies amounted to 463 million hectares. Notably, nearly 60 percent of this certified forest area is concentrated in three countries: Canada, accounting for 165 million hectares, the Russian Federation with 72.3 million hectares, and the United States of America covering 39.8 million hectares. These figures underscore the significant presence and contribution of these three countries to the certified forest landscape on a global scale.

"Traceability Systems for Wood Products: A Existence Analysis". In 2020, 94 countries and territories reported the implementation of national-level traceability systems for wood products to FRA 2020, while an additional three reported the existence of such systems at the subnational level. Collectively, these 97 countries and territories represent 84 percent of the total global forest area. This data emphasizes a widespread effort to establish traceability mechanisms for wood products, signifying a significant commitment on both national and subnational levels across the reported regions.

A Glimpse into the Future of our Forests

The current scenario of forests worldwide is marked by a complex interplay of various factors that have led to significant changes from ancient times (Abbass, et al., 2022). While forests have always undergone natural evolution, the present era is witnessing unprecedented challenges driven by human activities, climate change, and global socio-economic dynamics. In the near future, the status of forests is likely to be characterized by a mix of both positive and negative trends (Forzieri, et al., 2022). One major driver of change is deforestation, primarily fueled by expanding agriculture, urbanization, and logging activities (Dieng, et al., 2023). The conversion of forests into agricultural land and urban areas has led to the loss of biodiversity, disruption of ecosystems, and alteration of traditional forest types. Climate change further compounds these issues, causing shifts in temperature and precipitation patterns that affect the distribution and composition of forests globally. Another significant factor is the increasing recognition of the importance of forests for mitigating climate change. There is a growing emphasis on afforestation and reforestation efforts to sequester carbon dioxide from the atmosphere (Waring, et al., 2020). However, the types of forests being created may differ from the ancient ones, as they are often designed to maximize carbon capture rather than replicate the intricate ecosystems of the past. Furthermore, invasive species and diseases pose additional threats to forest health. Globalization has facilitated the movement of species beyond their natural habitats, leading to the displacement of native flora and fauna. The resulting changes in species composition can impact the structure and function of forests, potentially giving rise to novel ecosystems. In the future, technological advancements, including the use of remote sensing and artificial intelligence, may play a crucial role in monitoring and managing forests. Conservation efforts are likely to focus on maintaining and restoring biodiversity, preserving crucial ecosystem services, and promoting sustainable land-use practices. However, the success of these initiatives will depend on addressing the root causes of deforestation, such as unsustainable resource exploitation and the socio-economic factors that drive it.

Conclusion

The journey of Earth's forests, from ancient times to the present, reveals a rich tapestry of evolution, interconnectedness, and profound significance for our planet's well-being. The metaphorical expression of forests as the "mother of all" encapsulates their vital role in sustaining life on Earth. As the cradle of biodiversity, regulators of climate, and providers of essential resources, forests have been integral to the evolutionary trajectory of our planet. The historical evolution of forests, marked by the emergence of complex ecosystems and the pivotal role of species like Archaeopteris, highlights the transformative impact these ancient giants had on terrestrial, freshwater, and marine environments. However, the Late Devonian extinction of Archaeopteris marked a significant shift, paving the way for the rise of diverse seed plants in the Carboniferous. This cyclical pattern of forest evolution and transformation continued through geological epochs, responding to climatic fluctuations and human interventions during the Quaternary Period.

In the contemporary context, the status of global forests faces a complex interplay of challenges and opportunities. Human activities, climate change, and socio-economic dynamics are shaping the future of forests. While deforestation poses a significant threat, there is a growing recognition of the crucial role forests play in mitigating climate change. Afforestation and reforestation efforts, coupled with advancements in technology, offer avenues for sustainable forest management and conservation.

The report by the Food and Agriculture Organization of the United Nations (FAO) and the Collaborative Partnership on Forests (CPF) provides a snapshot of the present state of global forests. The data underscores the need for concerted efforts to address issues such as deforestation, loss of biodiversity, and the impact of disturbances on forest ecosystems. Sustainable forest management, conservation initiatives, and the recognition of the socioeconomic ties to forests are crucial elements in securing the well-being of these vital ecosystems.

Looking ahead, the future of our forests hinges on our ability to address the root causes of environmental degradation, promote sustainable practices, and foster a global commitment to forest conservation.

As we navigate the complexities of the Anthropocene, the preservation of forests is not only an ecological imperative but a moral responsibility to safeguard the intricate balance of life on Earth. In the spirit of acknowledging the "mother of all," let us strive to be stewards of our forests, nurturing and sustaining them for the benefit of current and future generations.

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■■■

Dr. Ajay Kumar Singh With over 15 years of research experience in forest watershed management, remote sensing & GIS, landscape dynamics, and forest biodiversity, Dr. Ajay Kumar Singh currently holds the position of Assistant Professor at Guru Ghasidas University in Bilaspur, Chhattisgarh, India. He is the recipient of multiple prestigious awards, including Young Scientist of the Year in 2022, 2019, and Environmental Biologist of the Year in 2017.

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Sudhir Ranjan Choudhury, an Indian researcher, currently pursuing a Ph.D. in Forestry, Wildlife, and Environmental Sciences from Guru Ghasidas University. With a robust background in Forestry, Biodiversity, GIS, Remote Sensing, and Conservation of Natural Resources, he has actively engaged in various training programs and workshops to enhance his expertise. His scholarly pursuits extend to participation in conferences and seminars dedicated to water resource management, biodiversity, and conservation. The editor, Mr. Choudhury has contributed significantly to the field of environmental science. His research publications, focusing on diversity, taxonomy, and conservation, have found a place in various reputable journals. Notably, his impactful work has been cited in numerous publications, attesting to its relevance and influence in the academic domain. In recognition of his contributions, Mr. Choudhury was honored with the Young Scientist Associate Award-2023, underscoring his dedication and achievements.

Ashutosh Anand is a PhD scholar and wildlife biologist with a deep understanding of the intricate relationships between fauna and their habitats. His research focuses on understanding habitat suitability for mammals, assessing the impacts of forest vegetation on animal populations, and developing strategies to minimize wildlife-human conflict. Currently pursuing a PhD in Forestry, Anand brings a wealth of knowledge and experience gained through his B.Sc. and M.Sc. studies in Forestry, Wildife and Environmental Sciences at Guru Ghasidas Central University in Bilaspur, Chhattisgarh, India. Anand's expertise, coupled with his unwavering dedication to conservation, positions him as a valuable asset to the field of wildlife biology. His ongoing research and outreach efforts contribute significantly to our understanding and appreciation of the natural world, ensuring the continued protection of wildlife and its habitats for generations to come.

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FOREST GENETIC TOOLS TO IMPROVE FOREST RESILIENCE TO CLIMATE CHANGE AND FOREST HEALTH

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Abstract:

Forest health parameters respond to climate change having a direct impact on forest resilience. Intensification of human impact on ecosystem within the last decades has led to unexpected disturbances in the resilience of forest ecosystem on a global level as well as the provisions made for ecosystem services. The current Anthropocene era has led us to reconsider the forest management approach and to device new management practices having flexible nature and better dealing with global climate changes. This review aims to focus on the contemporary forest genetic tools, their utility and limitations with respect to improvement of forest resilience, climate change and forest health. Potential implications of genetic tools in forest management, its goals and principles and its response reveal the role of genetically diverse and adapted seeds and stock to be the foundation of forest health and ecosystem in addition to major contribution of gene conservation in vulnerable species and population preservation for future generations. Adaptive implementation owing to climate change require new tools, methodologies, skilled workforce, better infrastructure, re – focused investments as well as refined and reliable research and management.

Keywords: Forest Resilience, Forest Health, Climate change, Genetic tools, gene conservation.

Introduction

Forest health has been the prime concern of forest pathologists including the symptom and causes as well as preventive measures to maintain forest health. There has been a shift in perspective pertaining to forest health towards tree disease and their important role in forest ecosystem mechanisms as well as the ecological health (Franklin et al., (1987), Teale and Castello, 2011). In lieu of this, it can be observed that the effect of native fungal diseases has been evident in maintenance of diversity in the forest as they facilitate the species to be more resilient towards other types of disturbances (Hansen 1999, Hansen and Goheen 2000). Exotic trees have high biodiversity and aesthetics but low commercial value due to their controlled and uniform plantation owing to native and exotic tree diseases, maintaining a controlled biodiversity (Carnuset al.,2006), Lombardero et al., 2012). On the contrary, the whole ecosystem can be threatened as a result of some tree species extinction owing to the act of some invasive exotic pathogens (Roberge et al., 2011, Cobb et al., 2013, Cahill et al., 2008, Davis et al., 2014).

Forest health risks

Major contributors in forest change are lack of management, over exploitation, degradation, habitat fragmentation, species distribution shifts and ecological succession. In addition, there has been also a shift in forest development from traditionally sustainable timber production to its multipurpose role in recreation and as a source of clean air and water (MacDonald, 2003, Hepting and Cowling 1977, Petrokofsky et al., 2010). Along with that an increase in the trade of plant commodities to remote and faraway places globally and the effect of change in climate has further impacted retrogressively on the condition of forest health (Wingfield, 1990, Holdenrieder, 2000). Excessive trade and climate change can lead to greater risks of establishment, spread and influence of newer and dangerous pests and pathogens. Lack of taxonomical morphologic expertise recently due to retirement without replacement along with rapid updation of new molecular methodological advances are one of the major concerns in forest ecosystem disturbances (Gadoury et al., 2009, MacDonald et al., 2009, Hamelin, 2012, Wood and Gebhardt, 2013). Regional outbreak of exotic tree fungal pathogens can be better understood using landscape ecology tools and forest pathology perspectives (Holdenrieder et al., 2004, Hatala et al., 2011). Diversity studies of endophytes of tree species provide insights of tree health (Sieber, 2007, Witzell et al., 2014) in addition to implementation of conservational biology tools pertaining to tree disease (Orwig 2002; Holzmueller et al., 2010; Pautasso et al., 2013 ;Shearer et al., 2013). In this rapidly evolving ecological aspect, the major aim of the present study lies in the selective evaluation of forest health, climate change and its effects on forest resilience. Secondarily, this study attempts to map out bridges between forest health, climate change and forest resilience with other aspects. Keeping in mind the time and space constrains, the focus has been mainly concentrated on the different genetical tools used in these three regions and their overall effect.

Human forced global climate change superimposed many different anthropogenic impacts on forest ecosystem. Rate of photosynthesis and respiration are readily influenced by climate change (Friberg et al., 2011, Jiao et al 2015, Kueppers et al., 2004). Other factors include forest temperature, radiation, and moisture in addition to medium and long climate periods. Short term process like frequency of storm and wild fires, herbivory and species migration are also influenced by climate and weather conditions. Biophysical forest process rate along with species' physiological tolerance are altered causing change in forest ecosystem owing to global climate changes (Olesen et al., 2007, Kellomaki et al., 2008, Malhi et al., 2008).

Forest is a self-organised and complex system which is equipped with multiple natural occurrences responding to the intrinsic and extrinsic factors. As in the height and density of tree canopy are dependent on the water availability revealing the echo physiological relationship between environmental controls and plant growth (Berry and Roderick, 2002). There will be evident change in the forest ecosystem and species composition in response to climate change and specifically reduction in water availability. Upon reaching a threshold the vegetation beyond this limit will be lacking the characteristic taxonomic composition like in extreme arid conditions forest may reduce to savannas or grasslands while in case of rainforest, the high temperature may show closed boreal canopy having sufficient moisture for an extended growing season (Price and Scott, 2006; Kellomaki et al., 2008).

Regional climates are also affected by the availability of forest as evident from the Amazon forests (Betts et al., 2008; Phillips et al., 2009). Large number of literatures is available with respect to climate change and forests (Bonan et al., 2003; Callaghan et al., 2004). Climatic changes like moisture change (Bonan et al., 2003), energy fluxes (Wilson and Agnew, 1992), forest fire and herbivory (Ayres and Lomardero, 2000), carbon cycle systems (Phillips et al., 2009) emphasize the importance of maintaining forest resilience in order to cope up with the climatic changes and to survive under such conditions.

Forest resilience or the ability of the ecosystem to regain its original state after perturbation and the maintenance of its characteristic composition, structure, function, and process rates (Holling, 1973). In other words, ability of the forest system to tackle with the disturbance and not being affected, retaining its own basic structure and function, is termed as forest resilience (Walker and Salt, 2012). Forest give different responses to different types of disturbances and climatic changes, and depending upon its capability to cope up, the forest may show variation in its characteristic taxonomy and ecological processes and may also be altered in certain conditions. The state of a forest ecosystem represents its most dominant species assemblage at that location in the ecosystem, their functional roles, characteristic morphology and features like height, layers etc. and these define the state of forest in a mature forest type. Many researchers have worked and differentiated engineering resilience and ecological resilience (Holling, 1973; Peterson et al., 1998; Gunderson, 2000; Walker et al., 2004). The former refers to the ability of the ecosystem to return to its exact state after a disturbance. It is characterised by only one steady state and is also known as equilibrium dynamics. On the contrary, ecological resilience is the ability to face the disturbance and bear with the adverse conditions before reaching a threshold after which the forest ecosystem changes completely to another state and is also known as the non-equilibrium dynamics.

Resilience is eminent property of ecosystem being conferred at different levels like genes, species, functional groups, and processes (Gunderson 2000; Drever et al., 2006) and is maintained as an important characteristic feature owing to societal adaptation to climate change as suggested by various researchers (Millar et al., 2007; Chapin et al., 2010). Forest shows the property of resistance towards little changes within bounds owing to non-catastrophic variations like chronic and dynamic insect herbivory, minor blowdown, or canopy gaps due to tree deaths individually or in groups. Forests are also resistant to environmental changes like weather patterns due to redundancy at functional species level. There has been evidence of high resilience in the ecosystem, but low resistance towards perturbation. However, contrary situation is seen in well-developed forests, especially primary forests, having both the properties of resilience and resistance towards changes (Drever et al., 2006). Resistance denotes stability, showing the capability of ecosystem to maintain a dynamic equilibrium by absorbing disturbances and being constant over longer periods of time.

Issues of scale and resilience.

A theoretical method is dependent on its proper scaling. Majority of the studies based on resilience focus on the reason behind change or maintenance of a particular state, while scaling studies focus on the evaluation of phenomena responsible for steady state ecosystems (Holling, 1973). Species level beta diversity enhances ecosystem resilience to adapt for the large-scale climate change through redundancy level of regional species pool. Resilience needs a temporal component related to disturbance, frequency, and ecosystem recovery, which is considered over many decades to centuries (Thompson et al., 2009). The change in ecosystem is caused due to environmental change or disturbance which is having a high magnitude.

Genetic diversity and resilience to climate change.

As resilience attributes different levels in the biodiversity, the genetic species composition becomes the most fundamental feature. Molecular variation among species within forest community, within ecosystem diversity, across a geographical area shows biological diversity. This genotypic variation among population is the basic expression of biological diversity. Individuals at population level contributing to each level of ecological hierarchy undergo natural selection adding to resilience of species and forest ecosystem (Muller-Starck et al., 2005). Diversity fosters natural regeneration and help in adaptation towards climatic changes occurring in the quaternary period and needs to be maintained in order to face the challenges posed by anthropogenic global warming. Genetic variation forms the basis of natural selection of genotypes within species in response to environmental fluctuations (Etterson 2004; Reusch et al., 2005;

Schaberg et al., 2008). This largely depends on the in situ genetic variation among each population of species (Bradshaw 1991).

Exposure to environmental changes decides the rate of adaptation of that population, its dispersal, or its fate otherwise (Burger and Lynch 1995). Range of fundamental eco physiological tolerance of a species is the expression of its genetic diversity range. Interspecific competitive interactions, in addition to dispersal method, are the primary determinants of response to change in a particular species (Halpin, 1997). In addition to adaptation, migration also plays role in responding towards evident climatic change. Many researchers have suggested diversification as a best tool to adaptation towards unpredictable climatic conditions (Ledig and Kitzmiller 1992, Millar et al., 2007). The two main means of adaptation towards change as shown by a particular species, include the dispersal of seed or vegetative propagules towards favourable environmental condition for survival or through change in their gene frequency to encourage genotypes capable of adaptation to the climatic variation (Burdon and Thrall 2001; Reusch et al., 2005). Another method of adaptation includes phenotypic plasticity, if permitted by the genotype (Nussey et al., 2005). Gene flow is further enhanced by dispersal among fragmented trees species, resulting in maintenance of genetic diversity. Prevention of genetic drift and loss of genetic diversity caused due to inbreeding within small isolated community of tree species (Fuchs and Hamrick, 2010; Farwig et al., 2008).

In general, genetic diversity of a forest ecosystem is maintained through seed and pollen dispersal, affecting the silence over change in the long term with respect to space and time in addition to re-establishment on favourable grounds. However, this capacity may have been reduced owing to anthropogenic intervention in landscape and gene pool. Genetic and reproductive activity of populations is potentially affected by population fragmentation. This generates a concern regarding the idea of in situ resilience owing to potential genetic adaptation, there are both short and long term components with respect to adaptation at genetic level, which enables variability in gene frequencies promoting growth and reproduction in an altered environment. Higher degree of diversity within natural populations is responsible for population stability in different environments (Namkoong et al., 1996), potential pollutants (Kull et al., 2007; Cantin et al., 2020) and pest species (Thrall et al., 2001). These concerns exaggerate the need for genetically diverse species to overcome the predicted climate change (IPCC 2007), which is too quick for a species to be able to prepare itself for adaptation over the low diversity level species in the forest population.

Forests are generally undomesticated and exhibit a very high level of genetic diversity owing to effective population size, local adaptation, and neutrality in the evolution process among heterogeneous environment (Hamrick 1986). Operational programmes of tree reading and related infrastructure like seed and seedling production are active since mid-1900's. Forest biologists have used proven trials for seed selection of important commercial species over in the last 200 years and to assess the seed distance without compromising local adaptation under suitable climate (Aitken and Bemmels 2015, Langlet 1971). Molecular biology techniques are being utilised in this area since 1990's and early 2000s. Techniques like QTL mappings have facilitated the marker aided selection of growth, productivity, and other wood qualities. Since then, highly polygenic nature of economically and environmentally important traits have been evident (Manolio et al., 2009). Due to drop in cost of sequencing, the focus of forest genetics research has moved towards the search related to single genes with great impact in addition to testing small target set of genes in place of genome wide scan, in order to tackle the contemporary demand of climate change, forest health, adaptation, resistance and commercial issues pertaining to biotic and abiotic stress.

Forest genomics in insects and disease resistance and early detection.

Moving from economic trades like growth and wood quality are now replaced by pest resistance genes owing to non-native insects and disease impact in addition to some natives species of pest with increased range and impact pertaining to climate change. Genomic tools help to

a. Understanding genomic architecture of insects and disease resistance or tolerance.

b. To Select tree species which can survive/ thrive under the presence of these pests.

c. To detect the invasive species of pests and pathogens.

This can be better understood by American chestnut example (Castanea dentata) (Westbrook et al., 2019). Chestnut blight fungus (Cryphonectria paresilica) in USA is a threat to American chestnut tree population. To overcome this problem, the American Chestnut Foundation, TACF has started a breeding programme between blight resistant Chinese chestnut (Castanea mollissima) and American chestnut (Castanea dentata). Only a few major loci bear blight resistance and thus between (blight resistant Chinese chestnut) Castanea mollissima X Castanea dentata (American chestnut) (F1 generation) upon backcross over 3 generations and then inter-crossed to Castanea dentata (American chestnut) progeny resulted in large production of BC3F2 trees between 2000 to 2018. Among these BC3F2 trees, about 1/3 were identified as potential parents for further generations (Westbrook et al. 2019) have developed genomic prediction models for blight resistance and have found it accurate as compared to pedigree analysis which makes it cost and time effective all alone. They also revealed blight resistance as well as the trade-off between the two species followed polygenic inheritance. TACF considered different options in development of resistant trees, namely inclusion of different chestnut sources of resistance via marker-assisted introgressive system and secondly the technique to establish transgenic method to be used to develop resistant Castanea dentata (New House et al., 2014).

Distribution and abundance of insect pests are equivocal to climate change, making it a serious factor. As evident in case of mountain pine beetle (MPB: Dendroctonus ponerosae) apparent in western North America. Warmer winter temperatures have caused its increased population exponentially (Safranyik et al., 2010). MBP has resulted in substantial mortality in Lodgepool pine (Pinus contorta) and Jack pine (Pinus banksiana) in Western Canada. Being one of the dominant parts of the forest ecosystem, these have caused profound ecological and economic complications, leading to demand of MPB resistant species to be breed in order to restore the areas. Cullingham et al., (2019) identified two important loci related to resistance using transcriptional profiling and selection tests. One of these two loci show consistent association with resistance in case of Lodgepool pine (Pinus contorta). This may facilitate in the development of genome wide marker-aided selection or genomic selection tools in breeding programmes.

Adaptation to changing climate

Population Genomic approaches lead to understanding of adaptive capacity in a tree population and challenges faced in warmer climates. Majorly high-level genetic diversity and considerable phenotypic plasticity among tree species has contributed in survival through past environmental variability. However, there is need of better knowledge regarding degree of adaptation at the local level towards the climate as well as new methods of tolerance capacity prediction and adaptation to new climates. Genomic approach provides rapid identification alternatives with respect to environmental factors showing phenotypic – genotypic and environmental associations (Alberto et al., 2013; Sork et al., 2013).

Performance of genomic data compare to phenotype measurement among short-term seedling common garden was evaluated by (Mahoney et al., 2019) in addition to long-term provenance trials. They determined the adaptive variance patterns and climate features of selection using factors like bud phenology, cold hardiness and growth. About >32,000 sample SNPs for genotypes and climatic data for 281 populations were utilized (Pinus contorta). The results showed seedling phenotype markers giving better explanation of adaptive variation as compared to genomic data set or climatic data alone. GEA (genotype environment association) analysis proved better in identification of climatic factors causing diversity in cases where phenotypic data was unavailable, thus making species management easier without long-term trials.

Applied ecological genomics can help to predict the potential of evolution apparent in the local population with respect to climate change. Allele frequency shifts for adaptive Loci pertaining to climate shifts were addressed by Ingvarsson and Bernhardsson (2019) using Populous tremula (European aspen). Populous tremula was used owing to its long history available regarding its genetics, genomics and phenotype. About 94 species across 10° latitude were sequenced for the whole genome in the areas of Sweden. The data so obtained was subjected to genotype environment analysis (LFMM) and GDM modelling was done for the estimation of genetic offsets (Fitzpatrick and Keller, 2015). This resulted in the mall adaptation description of an individual having specific allelic composition when environmental shift is subjected. Large genetic adjustments were required even in a short period of nearly 50 years for specifically northern population in order to cope with their local climatic conditions as compare to the southern populations which show smaller genetic offsets and convergence with the disproportionate effects among sub artics towards climatic change (IPCC 2018).

Apart from higher focus on economically important species, there has been also studies which evaluate the influence of population genomics to realize the neutral and adaptive processes related to non-commercial but ecologically valuable species. Mayol et al. (2019), provided the evidence of adaptive divergence among growth and phonology to be correlated with the variation in temperature among provenances. The study also emphasized on the demographic decline of some species to be more pronounced as compare to others. The novel aspect of use of pathway analysis to assess thecollective effect of SNPs among biological categories revealed that flavonoid biosynthesis pathway has undergone differential selection, showing the functional relevance of oxidative stress or membrane stabilization required in cold temperatures (Schultz et al., 2016). Population genomics caters a wide span of genetic considerations owing to Forest health, forest resilience and climatic change including univariate SNP – environment and SNP – phenotype associations (Kremer and Le Corre, 2012) in addition to description of adaptation in terms of poly genic process, including various loci havingdistinctly small effects (Boyle et al., 2017). This clears the vision of genotypic mapping process of phenotypes and provides a better understanding.

Forest management addressing climate change in the contemporary scenario is considering implementation of assisted gene flow as an important genetic tool. This is made possible with its ability to apply or increase the pre-adaptive genotype frequency in new climate (Aitken and Whitlock, 2013). Genomic data has great contribution in enriching the conservation strategies by facilitating solid estimates, owing to population adaptive variations (Funk et al., 2019). Borrell et al. (2019), reported the potential of assisted gene flow framework and its limitations in a study on Betula nana (montane dwarf birch tree). They used genotype environment association (GEA) and environmental niche modelling in order to identify the maladaptive populations that is having allele frequency deviation in current and projected future environmental conditions (c – RONA, f - RONA). Vulnerability assessment through assessment of adaptive capacity of a particular species is a very challenging task. Godbout et al. (2019), reported genomic diversity to be the expression of its environment, including climate, soil, biotic interactions and many more and how it can be used to examine adaptive capacity .

Various species of tree show hybridization with cogeners, hence contributing towards local adaptation with respect to transitional environments (Bawa and Holliday, 2016). Many tree species have been hybridized to adaptive environment that is otherwise not typical to the species range like Populous Trichocarpa X Populous balsamifera (Suarez-Gonzalez et al., 2018), Pinus Strobiformis X Pinus Flexilis (Menon et al., 2019). Sequencing in this case was done using double digest RAD sequence and combination of individual based simulations and genetic cline analysis. The results showed northward integration due to non-concordance of morphological and genomic cline center estimates. Although appearing to be degrading the biodiversity, hybridization or introgression among tree species is a natural evolutionary trajectory characteristic which provides intermediate phenotypes among ectones and bydirectional transfer of adaptive variations.

Genomic evolution and genomic tools

Attainment of high-quality reference genomes have been difficult due to size and complexity of tree genomes. The first tree genome was sequenced in 2006 of Populus trichocarpa (Tuskan et al., 2006) and Picea Abies in 2013 (Nystedt et al., 2013). About 52 out of 200 unique plant reference genomes belong to trees species (Wegrzyn et al., 2019). The situation has been improved with the application of new genomics, bioinformatics and precision phenotypic tools. Angiosperm genomes are much easier than conifer as the later bear a large size and high repetition in genome making and is difficult to understand and work on (De La Torre et al., 2014). DNA sequencing techniques have provided important breakthroughs in case of large genomes like gymnosperms. Whole genome duplication events have characterized the evolution of angiosperms (Lee beans Mack et al., 2019). They also have higher rates of chromosomal, rearrangement and mutation rates than that of gymnosperms (Pavy et al., 2017). Adaptive evolution rates are compare using coding regions among gymnosperms and angiosperms. Lower rates of neutral evolution but higher rate of non-synonymous substitutions have been reported among gymnosperms than that of angiosperms (De La Torre et al., 2017).

Gymnosperms show higher gene family expansion which is related to defense responses, climatic tolerances as well as lignin and cellulose biosynthesis. In addition to genomics the phenomic tool like UAVs which use hyperspectral sensor to create leaf spectral indices helping in responding against drought stress or pest invasions are also very useful in forest resilience, climatic control and forest health (Calderon et al., 2015). Wegrzyn et al., 2019 reporteda gap between the current state of data integration for non – model species and model species. Thus implementation of the data standards, ontologies, analytical work flows and integrated databases into cyberinfrastructures and inclusionin best practices is beneficial in this context.

Conclusion

Forest health and its long-term maintenance is imperative to functioning of global ecosystem in general and to fight against climate change in particular. Trees are architects of forest ecosystem and are under challenge throughout their life span owing to biotic and abiotic stresses. There has been a rapid improvement in knowledge, owing to genomics and genetic tools as to inform forest management and conservation decision in addition to accelerating breeding programs and to take up the climate change challenges. In order to get acceptance by various stakeholders from different public decisions making authorities, a genetic tool, economic and ecologically low at cost and high at benefits should be taken into account. Genomic tools are highly versatile and provide the insight of the plant's history and this is one of the important criteria.

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■■■

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A REVIEW OF CHHATTISGARH'S FORESTED WATERSHEDS: RESEARCH GAPS AND RECOMMENDATIONS

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Abstract:

Forests play a crucial role in meeting agricultural, domestic and industrial needs. In addition, it also serves as the basis for providing numerous ecosystem services to society. The central Indian state of Chhattisgarh and third in terms of geographical area covered by forests with an area of 55,7171 km^2. These forests attract rain and are the main source of water for the watersheds.

This paper provides a detailed overview of the state's watersheds. The Mahanadi River Basin (MRB) is the most important and dominant river basin, covering 56.2% of the land area, followed by Godavari RB (28.6%), Ganga RB (13.6%), Bramahani RB (1.0%) and Narmada RB (0.6%). More than 100 research papers from renowned specialist journals were subjected to a detailed and in-depth review. Various aspects of forested watersheds include land use and land cover studies, biodiversity along the watershed catchment area, soil erosion and sedimentation status of dams and reservoirs, various aspects of watershed management, morphometric analysis, stream flow estimation, watershed modelling, and impacts of climate change. Due to steady population growth, industrialization and increasing demand for irrigation and industrial water, watersheds face moderate to severe water stress. River water quality has also deteriorated in various

locations due to the discharge of industrial effluents, overuse of agrochemicals and domestic sewage.

The current work also examined the different watersheds of the state of Chhattisgarh and their effective protection measures. The research also aims to examine the importance of forested watersheds in terms of climate change adaptation and the achievement of sustainable development goals. This review may further contribute to the efficient management of the state's forested watersheds.

Keywords: River Basin (RB), catchment area, management, forested watershed

Introduction

Chhattisgarh has vast forest resources and accounts for 44% of the state's total geographic area. These forests are the main reason for the great biodiversity, mineral resources, tribal population, crop diversity and much more. These forests attract rain and give rise to numerous stream/nalas that are converted into rivers. Forests help stabilize soils and filter pollutants (Krieger, 2001).

The watersheds are reservoirs with rich natural resources. The watershed profile divides the terrain into unequal segments with different terrain characterstics based on the natural environmental conditions such as flooding, drought, soil erosion, water-logging, soil erosion and riparian erosion etc. The Catchment area of the river basin are complex and interconnected, interacting with socio-ecological systems (Hand et. al., 2018, Dunham et. al., 2018). Healthy rivers meet all the basic needs of human survival and development (MEA, 2005).

The United Nations Sustainable Development Goals to achieve water quantity and quality are mentioned directly in SDG6 (Clean water and sanitation) and secondly in SDG3 (Health and well-being) and SDG11 (Sustainable cities and communities) as well as SDG12 (Responsible Consumption and Production) and SDG14 (Life Below Water) (UNDP, 2015). The state of Chhattisgarh has a geographical area of 1,35,100 km^2 and is divided into five river basins: Mahanadi Basin, Godavari Basin, Ganga Basin, Brahmani Basin and Narmada Basin. The Mahanadi Basin covers the maximum geographic area of 75,858.11 km^2 (56.15 %) in the state, followed by the Godavari Basin at 38,694.36 km^2 (28.64 %), the Ganga Basin at 18,406.65 km^2 (13.62 %), the Brahmani Basin with 1,394.45 km^2 (1.03 %) and the Narmada Basin with 743.66 km^2 (0.55 %). The major watersheds of the state are the Hasdeo, Sheonath, Arpa, Maand, Tandula and Kharung watershed.

Forested watersheds have a dynamic landscape that enriches the rivers. They play a very important role in meeting agricultural, domestic and industrial needs. Forested watersheds also provide diverse ecosystem services of immense value. These help capture and store water, allowing for seasonal water flow and thus contributing to the quantity and quality of water available. The amount and quality of water flowing from forested watersheds is important for agriculture, power generation, municipal water supply, recreation, habitat for aquatic fauna such as fish and wildlife species (Krieger, 2001) etc.

Sal is the predominant tree species found in most of the region's forested watershed. The other forest tree species found are Teak (*Tectona grandis*), Bija (*Pterocarpus marsupium*), Saja (*Terminalia tomentosa*), Mahua (*Madhuca indica*), Dhaora (*Anogeisus latifolia*), Arjuna (*Terminalia arjuna*), Tendu (*Diospyros melanoxylon*), Tinsa *(Ougeinia dalbergioides)*, Neem *(Azadirachta indica)*, Salai *(Boswellia serrate)*, Kasai *(Bridelia retusa)*, Harra (*Terminalia chebula*), Khair (*Acacia catechu*), Imli (*Tamarindus indica*), Amla *(Embilica officinalis*), *Amaltas (Cassia fistula)*, Khamhar (*Gmelina arborea)*, Babool (*Acacia nilotica*), Shisham (*Dalbergia letifolia),* Palash (*Beutea monosperma),* Gular *(Ficus glomerata),* Bhirra *(Chloroxylon swietenia),* Ber (*Ziziphus mauritiyana*)*,* Haldu(*Adina cordifolia*)*,* Karra (*Cleistanthus collinus*)*,* Baheda (*Terminalia belerica*), Bamboo (*Dentrocalamus strictus*)*,* Semal *(Bombax ceiba),* Bel *(Aegel marmelos),* Mango (*Mangifera indica L.*) etc. Wild fauna is rich in the forested watershed i.e. Tiger, Panther, Barking Deer, Langoor, Wild dog, Striped hyenas, Blackbucks, Spotted Deer, Gaur , Sambar, Sloth bear, Wild boar and Four-horned antelope etc.

Forested watersheds generally provide high quality for the integrated land management system. This paper provides an overview of the research being conducted in the state watersheds. Potential research gaps are identified and few recommendations for the proper and sustainable use of watersheds are mentioned.

Study area-The state of Chhattisgarh was seperated from Madhya Pradesh on November 1, 2000. The geographic extent of the state is between $17^{o}46'$ and $24^{o}5'$ N latitude and $80^{o}15'$ to $84^{o}20'$ E longitude (Jhariya et. al., 2015). The state has five major river basin i.e Mahanadi, Godavari, Ganga, Brahmani and Narmada. Most of the major rivers originates in the forested region in the form of small streams and later, after meeting their tributaries, turn into large rivers. The state's average annual rainfall is over 1200 mm. This state has distinct summer, monsoon and winter seasons.

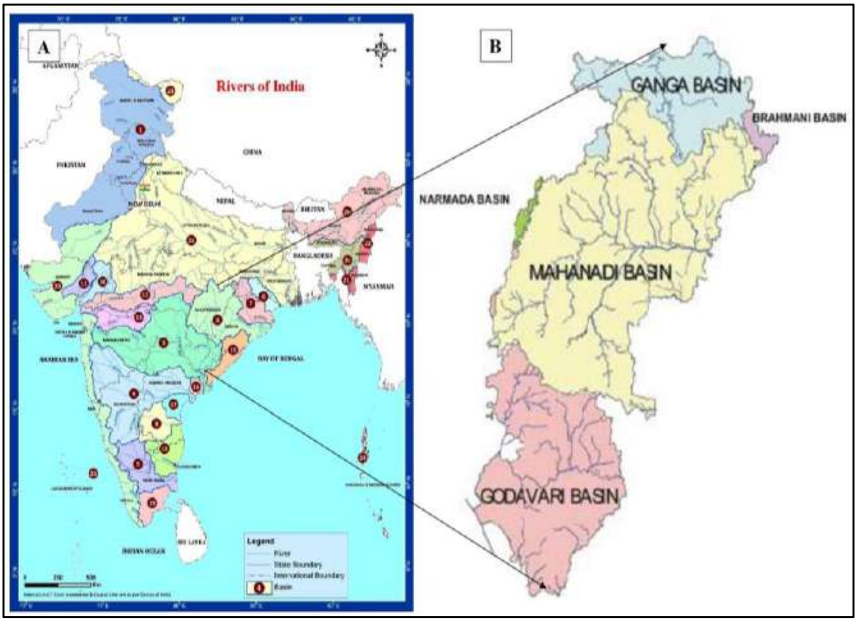

Fig 1. A) Map of India showing major river basin B) Major river basins of Chhattisgarh state

Materials and Methods

This article examines the watersheds of the state of Chhattisgarh using different approaches. It includes reviews and data collection. Literature searches on forested watersheds, watersheds, Chhattisgarh river basins, morphometric analysis, state dams and reservoirs etc. were conducted in online databases, published by researchers (from Science Direct, Web of Science, SpringerLink, Wiley, Taylor and Francis, MDPI etc). Secondary data was collected from the reports and data published by the central and state governments. From the publications between 2001 and 2023, reviews, theoretical and empirical works on the relevant topics were selected. The reviews focused on assessing of the Chhattisgarh state's watersheds, river basins, dams and reservoirs , forests types, watershed management practices, biodiversity and many more.

Results and discussion

Numerous researchers studied the water bodies, river basins and watersheds of the state of Chhattisgarh (Table 1) divided into different approaches such as impacts of dams/reservoir construction, land use land cover change analysis, geomorphological/ morphometric survey, water quality analysis, modelling, climate change and river meandering.

Table 1: Approach for studying the watersheds of Chhattisgarh

S. No.	Approach	Watershed studied	Brief discussion	References
1	Construction of dams/ reservoirs	Arpa River	Impact of the Arpa River Check Dams on the Bilaspur district microenvironment	Bhat and Geelani, 2013
		Kelo River	Development, displacement and rehabilitation of tribal communities, Raigarh	Kujur and Kumar, 2019
		Seismic hazard estimation	Major dams of C.G, Sindum dam	Tripathi et. al., 2009, Parashar et. al., 2015
		Sedimentation and soil erosion	Sedimentation of Ravi Shankar Sagar reservoir, Kodar reservoir, Kulhan watershed, Pairi watershed and other Chhattisgarh reservoirs	Jaiswal et. al., 2019, Dadoria et. al., 2017, Bikram and Tiwari, 2022, Ahmad and Verma, 2013, Devatha et.

				al., 2015, Kumar et. al., 2020
2	Land Use Land Cover analysis	Maniyari River, Gej sub watershed, Bamni sub watershed, Tangarbahri Milli watershed, Tesua sub watershed, Khudia dam	LULC change analysis and change detection of the watersheds catchment area.	Bej and Baghmar, 2022, Singh et al., 2019, Singh et. al., 2011, Bhagat et. al., 2019, Singh, A.K. 2017, Mahato, 2022
3	Geomorphological/ morphometric study/ estimation of stream flow/ Water balance modelling	Arang watershed, Arpa river basin, Mand river Piperiya watershed, Seonath river, Tandula reservoir	Geomorphological parameters of Arang watershed, Quantitative analysis of Arpa river Basin morphometric properties, Rainfall Analysis, Watershed Sustainability Index (WSI), statistical analysis of rainfall, Variation of water flow using SWAT Model	Kumari and Kumari, 2014, Koshale and Mahato, 2022, Baghel et. al., 2021, Chandniha and Kansal, 2017, Chandniha et. al. 2014, Swain et. al., 2018, Verma et. al., 2016, Jaiswal et. al., 2019, Soni et. al., 2022, Jaiswal et. al., 2009
4	Water quality	Kharun river	Assessment of water quality of the	Mise and Mujawar,

			Kharun River.	2017
		Hasdeo river	Organic and inorganic pollutants on the Hasdeo river water quality	Bhaskar et. al., 2020
		Rajim river	Pollution due to rice mill	Shrivastava and Sharma, 2020
		Tandula watershed	Nitrate pollution on ground water	Jhariya et. al., 2019
		Tandula Dam	Hydrobiological status	Meshram, 2013
		Somni watershed	Ground water pollution due to disposal of hazardous waste	Shrivastava, 2015
		Mahanadi river	Fish Fauna diversity of Mahanadi River in Raigarh district	Patel et. al., 2016
5	Biodiversity	Kelo and Maand river	Cat fish diversity of River Kelo and Mand	Tamboli and Jha, 2012
		Dhudwa dam	Study of Fungal diversity	Sharma and Praveen, 2011
		Balamdi watershed	Forest diversity	Bijalwan, 2010, Bijalwan et. al. 2009
6	Climate change, Management and	Mahandi river	Management of water resources for climate resilent	State Center for Climate Change, 2019

	significance	Arpa river	Cultural, Economic and Environmental Significance of Arpa River	Chandrakar and Dhuria, 2020
		Dhangaon microwatershed	Micro level planning for Dhangaon microwatershed	Patel and Khalkho, 2019
		Andhiyarkore watershed	Site selection for water storage	Vinze and Ahmad, 2022
		Samoda watershed	Delineation of ground water potential sites	Indulekha and Jhariya, 2020
		Arpa	Origin and Contribution of Important Tributaries to Arpa River	Bhat et. al., 2012
		Upper Kharun catchment	Climate change impact on water resources	Kumar et. al., 2017
8	River Meandering	Maniyari river	Meandering of Maniyari river	Mahato, 2023

Soil erosion is a common and serious problem of watersheds as reported by various researchers (Devatha et. al., 2015). The main reason for this are a shifting cultivation, over-expoitation of land, non-compliance with soil protection measures and exposure of the top layer of soil in hilly areas. Excessive erosion removes nutrient-rich soil and increases sedimentation of reservoirs, reducing their storage capacity.

Water quality is an important issue of global reflection and action (Al-abadi et. al., 2014, Jin and Ray, 2014). Jhariya (2019) assessed the nitrate pollution of the Tandula watershed using the GIS-based DRASTIC model. The study reported pollution of ground-water resources from over-use of nitrogenous fertilizers in agricultural fields. Kumar et al. (2020) studied different models to access soil erosion and sediment yield in the Pairi watershed using the USLE and MUSLE equations. Martin et. al. (2020) studied model performance in hydrological processes under climate, land scenario and forest management in small forested watersheds. Soni et. al. (2022) reported that the water demand of the capital Raipur is projected to increase by 52.38% by 2038 compared to 2016, but the river flow is likely to decrease by 35% due to climate change and land use changes.

The hydrological investigation and behavior of watersheds depend on geomorphological features. The morphometric study of watersheds of different river basins has been studied and analyzed by many researchers (Mandal et. al., 2022, Khoshale and Mahato, 2022, Baghel et. al., 2021, Kumari and Kumari, 2021). The result shows that most of Chhattisgarh's river basins are natural.

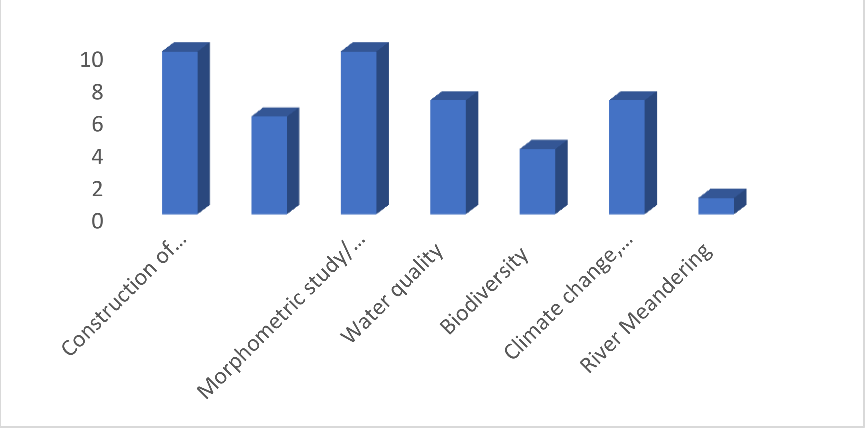

Fig 2. Approaches for studying watersheds of Chhattisgarh

Patel and Khalkho (2019) studied and evaluated microlevel planning of Dhangaon microwatershed in Bemetara district of Chhattisgarh. Their study described in detail about the site selection for establishment of water harvesting structures, thus enabling water conservation at local level.

Bijalwan (2010) studied the diversity of woody vegetation in the dry tropical forest of Chhattisgarh. This study found the highest IVI values for Diospyros melanoxylon, Boswellia serrate, Madhuca indica and Cleistanthus collinus in the understory of degraded forests in different directions. The study shows the poor regeneration pattern in the degraded forest. The effects of forest cover on water yield have been studied by numerous researchers (Li et. al., 2017). The delineation of ground-water potential zones of the Samoda watershed was studied by Indulekha and Jhariya (2020).

The Piperiya Watershed Sustainability Index (WSI) was compiled by Chandniha et. al. (2016). Their study found that this watershed flows in the hilly areas, that are mostly inhibited by tribal peoples and coal mines and coal washing plants are numerous, polluting both the surface and ground-water of the region.

Sharannya et. al. (2018) reported that pressures on water resources are likely to increase in the coming years due to increasing water demand, and drier and warmer climates. Much research (Mahato et. al., 2022, Lee et. al. 2018, De Girolamo et. al., 2017) has focused on the sustainable management of small forested watersheds. Giri and Mohanty (2022) focused on increasing land productivity through the use of agri-photovoltaic systems, which alongside energy production, may represents a better option for maximizing productivity and income generation for farmers.

Koshale and Mahato (2020) monitored the LULC of Ratanpur, which is well known for its water conservation structures especially ponds. The study found that the region’s water area decreased from 3.76% to 2.06% between 1989 and 2015. Thus, over a certain period of time, there has been a continuous decline in the water surface. Therefore, great attention should be paid to rivers and watersheds.

The biggest environmental crisis facing the world today is climate change, ground-water loss and biodiversity loss. The recently developed climate change scenario predicts an increase in air temperature of up to 5^{o}C and changes in precipitation patterns by the year 2100 (IPCC, 2014). Climate change is likely to affect water distribution, runoff, quality, rate of erosion and sedimentation pattern, rate of evaporation, and many other aspects. These changes affect human well-being by altering water availability, land use management and food production (Cai et. al., 2016, Reed et. al., 2013). A changing climate is likely to affect surface and ground water resources due to expected changes in received precipitation. Evapotranspiration (Garner et. al., 2017, Kirby et. al., 2016) and changes in precipitation frequency and intensity are likely to increase surface runoff, leading to flood risk and reduced ground water recharge (Trenberth, 2011). A rise in temperature is likely to increase evaporation rates in both lotic and lentic waters. This increases the need for irrigation, which is the largest water consumption (Wang et. al., 2012). Khanday and Javed (2008) studied the impact of climate change on the LULC of the Chopan watershed, M.P. The study concluded that bodies of water and wetlands have the property of retaining heat, thereby lowering the day-time air temperature of the surrounding areas. The result also showed that micro-scale climatic changes in terms of precipitation and temperature variations are related to albedo changes, which in turn could be LULC modifications.

Kumar et. al. (2017) studied the effects of climate change on the water resources of the Upper Kharun catchment area. Numerous studies on the impacts of climate change on watersheds and river basins have been conducted worldwide. Only the Kharun River in the state of Chhattisgarh has been studied (Soni et. al.,

2022) from a climate change perspective. Many rivers and water bodies are likely to dry in the near future (Uddin and Jeong, 2021, Sponseller et. al., 2013, Vorosmarty et. al., 2010, Tockner & Stanford, 2002), which would put a strain on existing water resources. Ground water consumption for many activities is likely to increase stress, which is likely to widen the gap between demand and supply. Therefore, fresh-water resources must be protected and effective water conservation and harvesting structures must be created at various locations. There should be a proper plan for surface water development sites, rain water harvesting sites, infiltration tanks, check dams, anicuts etc. They should be constructed in appropriate locations for in-situ water conservation as well as for replenishment of ground water resources.

Key research gaps

Research has evidently shown that forested watersheds plays a unique and critcal role in meeting society's water needs. It also provides protection for biodiversity. Unresolved issues include the occurrence of exotic aquatic flora and fauna in rivers and streams, declining water quantity and quality water demand and supply gap studies, ecosystem services provided by watersheds, conservation efforts, and water protection and biodiversity the region. Emphasis should also be placed on studies of riparian buffer zones, and the impact of mining and agriculture on water resources.

Only 3% of Chhattisgarh's water resource studies include potential future scenarios. Thus, there are immense opportunities for further research in river and watershed management.

Conclusion

This paper provides an summary of the current status of studies on watersheds in the state of Chhattisgarh state. The paper also identifies research issues that need to be addressed for the idea of conservation issues. The present paper will be helpful for the judicious and effective utilization of the water resources, as well as for the preparation of plan for an effective use and a water resource management plan. More broadly, there is a requirement for a improved understanding of the biodiversity of forested watersheds and their interplays with each other.

We hope that this work will provide policy makers, academicians and researchers with key information on how to maximize forested watershed conservation efforts, more regulated sand mining and the promotion of ground water recharge.

Recommendation

- Water loss through reservoir seepage/leakage and evaporative loss should be studied in detail to minimize water loss.
- Assess the diverse ecosystem services provided by the state's forested watersheds.
- Monetary valuation can help compare ecosystem services provided by forested watersheds. This will contribute to more effective use and conservation of natural resources. The lack of water resources can cause severe stress in the region. Thus, the assessment can also contribute to the restoration of damaged ecosystems.
- It involves the involvement of local and relevant authorities/ communities/stakeholders in watershed conservation.

Declaration of interest

None

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