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CHALLENGES AND STRATEGIES IN ELEPHANT CONSERVATION: A COMPREHENSIVE REVIEW OF LAND USE IMPACT AND MANAGEMENT APPROACHES IN DALMA WILDLIFE SANCTUARY, INDIA

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ABSTRACT

The Dalma Wildlife Sanctuary, a critical habitat for elephant conservation in the Dalma Landscape, is increasingly experiencing the multifaceted impacts of climate change. This study reviews secondary literature to examine the consequences of Land Use and Land Cover (LULC) changes on elephant populations, emphasizing the exacerbating effects of climate-induced alterations. The sanctuary faces challenges like habitat degradation and fragmentation, which impede wildlife movement and intensify human-wildlife conflicts, particularly with elephants. These issues are now compounded by climate change, which is altering vegetation patterns, water availability, and seasonal behaviours of wildlife, further straining the delicate balance of this ecosystem. This paper methodically dissects the literature, highlighting how climate change interplays with existing environmental stressors, affecting the conservation strategies and viability of elephant corridors. The review also considers management strategies, underscoring the need for adaptive measures that address the dual challenges of habitat degradation and climate change. By broadening the scope to include the climate change dimension, this research not only underscores the researcher's comprehensive understanding of the sanctuary's ecological challenges but also aligns the study with global environmental concerns, making it relevant in the context of contemporary wildlife conservation efforts. Through a structured approach, the paper is divided into sections that explore the sanctuary's ecological significance, the factors impacting elephant populations with a focus on climate change, and methods for studying human-elephant conflicts in the context of a changing climate. This comprehensive analysis aims to identify research gaps, propose adaptive conservation strategies, and contribute to the broader understanding of how climate change is reshaping wildlife conservation paradigms.

Keywords*:* Land Use/Land Cover (LULC), Dalma Wildlife Sanctuary, Elephant Corridor, climate change, Human Elephant Conflict (HEC)

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INTRODUCTION

Wild spaces continue to shrink and become fragmented (Shiweda *et al*., 2023), as human population continue to grow wild life is increasingly affected (Zhang *et al*., 2024) in several profound ways (Rana *et al*., 2021). These interactions often result in human-wildlife conflict (HWC) (Gunawansa *et al*., 2024), where competition for food (Songhurst, 2023), water (Rani *et al*., 2024), and space (Rana, Kumari, & Kumari, 2022) can lead to injury (Chardonnet *et al*., 2023) or death (Chardonnet *et al*., 2023) for both people and animals (Xu *et al*., 2024). Conflicts may arise from vehicle collisions (Utete & Matanzima, 2024), wildlife attacks on humans (de Silva *et al*., 2023), or the intentional killing or injury of animals (Thant *et al*., 2023) deemed nuisances. However, the most common impact is crop-foraging (Anoop *et al*., 2023) (also known as crop-raiding), where animals leave protected areas (Nad & Basu-Roy, 2024) to consume crops (Utete, 2024), severely impacting farming communities (Kumari *et al*., 2022). In retaliation, farmers often resort to harming wildlife (Chakraborty *et al*., 2024), as protecting their livelihoods becomes a priority (Natarajan, 2024). The situation is further exacerbated by climate change (Diksha *et al*., 2024), which worsens food (Nguyen *et al*., 2023) insecurity and heightens the risk of negative interactions (Farley, 2024) between humans and wildlife (Patterson, 2024). Wild elephants can be found in over 50 countries worldwide, primarily in Africa (Errami *et al*., 2024), with only 13 countries in Asia hosting these majestic creatures (Zakaria *et al*., 2024). The population of African savannah elephants has been decreasing yearly by 8 % as a result of land-use changes, habitat fragmentation, and illicit ivory harvesting. Severe crop losses are a problem in rural areas; 25 % of farmers report agricultural damage and 30 % indicate structural property devastation. Sadly, accidents with elephants are known to cause the deaths of about 500 people annually. Beyond the obvious effects, emotional stress and mental health difficulties are reported by 70 % of impacted people; these issues are frequently disregarded in conservation policies. Creating sustainable plans for coexisting with elephants requires an understanding of these long-term effects (Redmore, 2024).

The estimated population of Asian elephant's (Thant *et al*., 2023) ranges from 51,000 to 66,000, but only 35,000 to 50,000 of them live in the wild. Asian elephants are divided into three sub-species: the Indian, Sumatran, and Sri Lankan elephants (Köpke *et al*., 2023). Currently, elephants are found in five South Asian countries: Bangladesh, Bhutan, India, Nepal, and Sri Lanka (Köpke *et al*., 2021), (Budd *et al*., 2023). India has the largest elephant population among these countries, with an estimated 29,964 elephants, India had an elephant density of 0.0008 per km². However, with the country's rapidly growing human population and increasing economic development (Sutthiboriban *et al*., 2024), the conflict between humans and elephants has escalated dramatically in recent decades (Dahal *et al*., 2023). Once in balance, this delicate coexistence is now under immense pressure as habitat loss (Premlata *et al*., 2024), fragmentation (Zhanwen & Islam, 2024), and competition for resources increase (Abedin *et al*., 2024).

HEC in India is most prominent in 14 of its 28 states (Hussain *et al*., 2023), with significant elephant populations in Karnataka, Assam, Kerala, Tamil Nadu, and Odisha (Pandey *et al*., 2024). The conflict is often triggered when elephants (Xu & Liu, 2024), forced out of their shrinking habitats, raid crops, damage property (Rani *et al*., 2024b), or come into close contact with human settlements (Matsika *et al*., 2024). According to data from the Ministry of Environment, Forest, and Climate Change, HEC incidents (Fernando *et al*., 2024) have resulted in numerous fatalities on both sides (Belho *et al*., 2024). Odisha, for example, home to India's second-largest elephant population with an estimated 1,976 elephants, has been particularly hard hit. Expanding human settlements, agricultural activities, and mining projects such as in the Karo-Karampada Elephant Corridor have severely restricted elephant

movement, leading to frequent clashes (Tripathy & Chandra, 2024). In Odisha, particularly in the districts of Keonjhar, Champua, Barbil, and BJP range (Tripathy *et al*., 2021), mining activities have significantly disturbed elephant habitats (Tripathy *et al.,* 2021). The Keonjhar district is a prime example of how rapid industrialization and deforestation have driven elephants into conflict with local communities. Keonjhar's elephant population, including migratory elephants from neighboring Jharkhand (Chaudhary *et al*., 2024), frequently comes into contact with farmers, leading to significant crop damage (Tripathy, 2020). Efforts to mitigate the conflict include the restoration of elephant corridors like Karo-Karampada and Telkoi-Pallahara, the deployment of anti-depredation squads, and the use of modern technologies like drone surveillance and early warning systems.

The relationship between humans and elephants in India has always been intricate, influenced by cultural values, economic needs, and competition for land and resources (van de Water *et al*., 2022). The paper focuses on the ecological dynamics and challenges facing the Dalma Wildlife Sanctuary, a critical refuge for the conservation of elephant populations in the Dalma Landscape. The objective of this research is to provide a comprehensive understanding of the dynamics underlying HEC by synthesizing existing research, identifying key drivers, and exploring effective mitigation strategies. It aims to examine the ecological, environmental, and anthropogenic causes of conflict, such as habitat loss, agricultural expansion, and population growth, while highlighting regional variations in HEC across Dalma wildlife century of Jharkhand, India. The research also emphasizes the role of LULC changes, habitat fragmentation, and mining activities in altering elephant movement patterns, contributing to increased conflict. Special attention is given to how climate change exacerbates competition for natural resources, leading to more frequent conflict incidents.

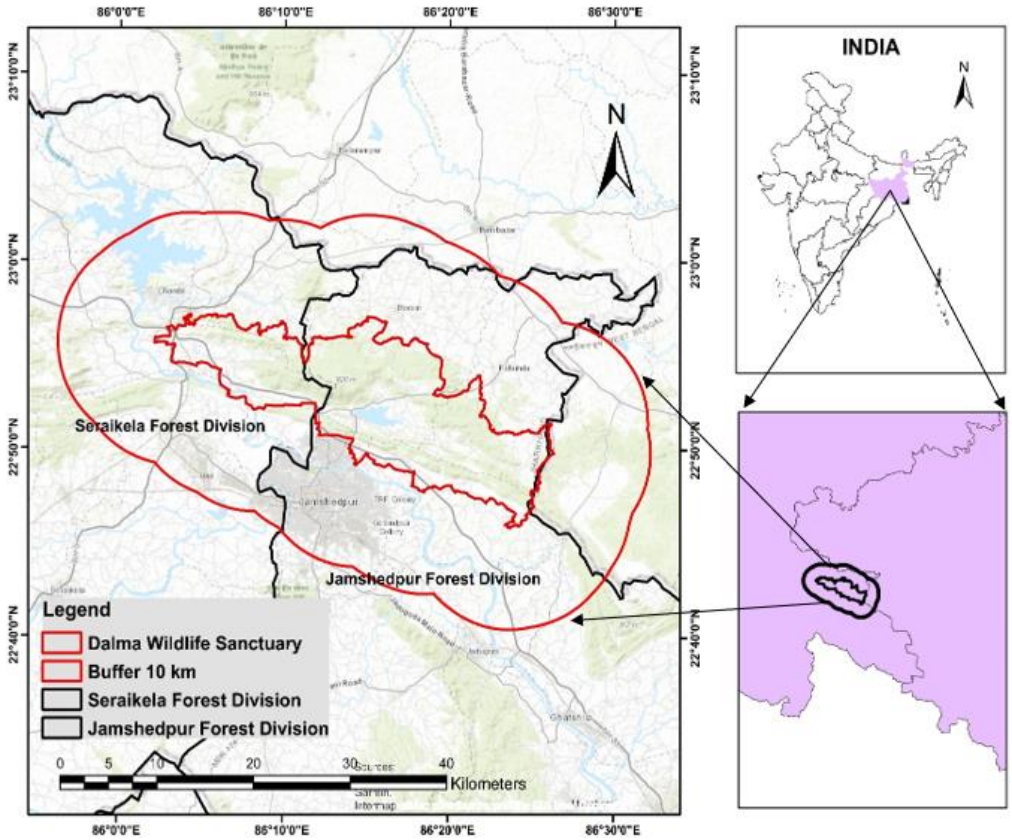
STUDY AREA

The study area consists of Dalma Wildlife Sanctuary with a ten-kilometre buffer as ten-kilometre is considered eco-sensitive area (Fig. 1). Situated in the diverse terrains of the Chota Nagpur Plateau, the sanctuary is a vibrant mosaic of flora and fauna, serving as a crucial habitat for numerous species, with a particular focus on elephants. A wildlife corridor is a movement pathway which connects different habitats of animals. Wildlife corridors are referred to in different terms, like 'conduits', 'landscape linkages', 'stepping stones', 'green belts', 'green ways', and myriad others. Elephant corridors help maintain demographic and genetic viability of the elephants. Indian Government's Elephant Task Force Report (Gajah Report) lists 88 such corridors in India. The preservation of elephant corridors is a central strategy for elephant conservation. This wildlife corridor is especially used by elephants among other wild animals and is surrounded by forest villages. These forest villages are inhabited by ethnic communities who are dependent on these forests for their livelihood, hardwood, fuel, and number of other commodities. The data of elephant population in the study area is provided in Table 1 with their corridors.

Table 1: Elephant population and respective corridors

Corridor Name	Elephant Population	Villages within Corridor	Corridor Dependent Villages
Gobarghusi – Jhunjhaka-Banduan	18	4	15
Dalapani - Suklara - Kankrajhor	28	0	5
Dalma - Chandil	4-5	6	20
Dalma - Rugai	6	1	8
Dalma - Asanbani	5	0	2

Fig. 1: The Dalma Landscape



Significance of Dalma Wildlife Sanctuary from the Ecological Point of View

The Dalma Wildlife Sanctuary, spanning an area of 193.22 square kilometers on the Chota Nagpur Plateau, presents a unique ecological space interwoven with rich biodiversity, intricate climatic patterns, and varied topography.

Biodiversity and Its Interconnections

At the heart of the sanctuary's ecological importance is its biodiversity. (Das Chatterjee, 2016a) comprehensive study on the Lepidoptera family, particularly moths, reveals the intricate balance within the ecosystem. These moths, often overlooked in broader conservation conversations, play a crucial role in pollination and serve as vital indicators of the ecological health of the sanctuary. The detailed taxonomic work rooted in historical research, including that of (Hahn & Brühl, 2016), demonstrates the sanctuary's long-standing role as a biodiversity hotspot. The classification framework, aligning with (Lindsay *et al*., 2017) positions the sanctuary not just as a refuge for elephants but for many other species, highlighting its broader ecological significance.

Flora and Fauna: A Symbiotic Existence

(Chatterjee & Chatterjee, 2014) exploration of the Dalma forest further illuminates the sanctuary's ecological web of life. The identification of 41 tree species belonging to 25 families underscores the forest's rich and diverse plant life. This diversity is not just a number but a reflection of the complex symbiotic relationships that sustain various life forms. Prasad's emphasis on the role of land use practices in shaping this biodiversity is particularly salient. His analysis, utilizing metrics like Basal Area and Alpha Diversity, paints a vivid picture of how human activities, both historical and contemporary, shape and sometimes distort the natural balance of this ecosystem.

Climate and Topography: The Underpinning Factors

The sanctuary's unique position on the Chota Nagpur plateau brings into focus the role of climatic conditions and topography in shaping its ecological character. The varied climate, as highlighted in Singh's work, creates a variety of habitats suitable for different species. This diversity in climatic conditions, coupled with the sanctuary's topographical features, contributes to the richness of its flora and fauna. The forests classified as North Tropical high deciduous by Singh resonate with this ecological diversity, driven by the combination of climatic factors and topographic variability.

Ecological Significance Beyond Elephants

While elephants are the flagship species and a key focus of the sanctuary, it is crucial to recognize the sanctuary's broader ecological significance. The sanctuary serves as a critical habitat for many species, some of which are endemic and others that are crucial for the ecological balance. Singh's study on moths and Prasad's analysis of tree diversity illustrates this point effectively. The sanctuary's role in conserving these species is not just about preserving numbers but also about maintaining ecological processes and interactions that are vital for the ecosystem's health.

Human Impact and Ecological Challenges

(Das Chatterjee, 2016a) insight into the threats posed to biodiversity by anthropogenic activities bring to light the pressing challenges faced by the sanctuary. Illegal interventions, particularly targeting valuable tree species, are not just a loss of biodiversity but a disruption of the ecological equilibrium. The sanctuary's ecological significance is thus closely associated with the need to address these human-induced challenges.

RESEARCH METHODOLOGY

The research methodology for this paper encompasses a comprehensive review and synthesis of secondary literature, focusing on the ecological aspects, human-elephant conflicts, and conservation strategies within the Dalma Wildlife Sanctuary. This methodical approach involves the critical analysis of existing studies, scholarly articles, and environmental reports, particularly drawing upon the works of key researchers like (Mandal & Das Chatterjee, 2023a). The process includes an extensive examination of data on habitat changes, wildlife movement patterns, and various human impacts on the sanctuary's ecosystem. GIS and remote sensing data, as utilized in these studies, are especially emphasized to understand spatial dynamics and changes over time. Additionally, this methodology involves the interpretation of statistical analyses presented in these sources, which provides a quantitative backbone to the qualitative assessments.

FACTORS ADVERSELY IMPACTING THE ELEPHANT POPULATIONS IN DALMA WILDLIFE SANCTUARY

The Dalma Wildlife Sanctuary is currently facing significant challenges that are adversely impacting its elephant population.

Habitat Degradation and Fragmentation

A primary concern for the elephant population in Dalma Wildlife Sanctuary is the degradation and fragmentation of their habitat. This is a multifaceted issue, as elucidated in the studies by (Mandal & Das Chatterjee, 2023b) and (Das Chatterjee, 2016c). Habitat degradation in the sanctuary is primarily a result of human activities such as agriculture expansion, illegal logging, and mining. These activities not only reduce the available space for elephants but also fragment their habitat, making it difficult for them to access various parts of their range for foraging and breeding.

(Jeganathan *et al*., 2024) research on the migration patterns of elephants provides insight into how habitat fragmentation is affecting the natural behaviour of elephants. The study shows that the disruption of traditional migratory routes due to human settlement and development projects forces elephants into closer proximity with humans, leading to conflicts.

Impact of Climate Change

While not directly highlighted in the previous studies, it’s crucial to consider the overarching impact of climate change on the sanctuary’s ecosystem. Climate change exacerbates the existing issues of habitat degradation and water scarcity, further stressing the elephant population. The alteration in rainfall patterns and temperature can affect the availability of food and water sources, essential for the survival of these large mammals.

Human-Elephant Conflicts

Another critical factor impacting elephant populations is the increasing incidence of human-elephant conflicts, as detailed in the study by (Chakraborty *et al*., 2024) The encroachment of human activities into the elephants’ natural habitat has led to a rise in these conflicts. As their habitat shrinks, elephants are forced to venture into human-dominated areas in search of food, leading to damage to crops and property, and sometimes resulting in human and elephant fatalities.

(Sekar & Srivastav, 2024) report sheds light on the gravity of this situation in Jharkhand, noting the significant number of human and elephant deaths over recent years. These conflicts not only result in immediate physical harm but also contribute to a longer-term negative perception of elephants among local communities, complicating conservation efforts.

Mining and Infrastructure Development

The role of mining and infrastructure development in fragmenting elephant habitats is particularly highlighted in (Thakur *et al.,* 2024) study. Mining activities and constructing roads and railways have created physical barriers that disrupt traditional elephant corridors. These disruptions not only limit the natural movements of elephants but also increase the likelihood of human-elephant conflicts, as the animals are forced to navigate around these obstacles, often coming into contact with human settlements.

Water Scarcity and Changes in Vegetation

Water scarcity, a growing issue in the region, is another critical factor impacting the elephant population. Elephants require significant amounts of water not just for drinking but also for bathing and thermoregulation. The decreasing availability of water sources, partly due to human usage and changing climatic conditions, is a significant stress factor for these animals.

Furthermore, changes in vegetation due to human activities and climate change affect the availability of food for elephants. The alteration in forest composition can lead to a decrease in preferred food sources for elephants, forcing them to adapt to new feeding habits or travel greater distances to find adequate food.

METHODS OF STUDYING THE HUMAN-ELEPHANT CONFLICTS IN DALMA WILDLIFE SANCTUARY

Understanding and mitigating human-elephant conflicts (HEC) in the Dalma Wildlife Sanctuary requires a comprehensive approach, utilizing various methodologies and analytical tools.

Geomatics and Remote Sensing

A significant method employed in studying HEC, as highlighted in the "Geomatics and Conservation Biology" chapter, involves geomatics technology, including Geographic Information Systems (GIS) and remote sensing. This approach is critical for mapping elephant habitats, movement patterns, and conflict zones. GIS tools allow researchers to integrate various data types (e.g., satellite imagery, and GPS tracking data) to visualize and analyse the spatial aspects of HEC.

Remote sensing, particularly using Landsat images, plays a vital role in monitoring land use and land cover changes over time, as mentioned in (Mandal & Das Chatterjee, 2021) study. Changes in forest cover, expansion of agricultural land, and development of human settlements can be quantitatively assessed, providing insights into the drivers of HEC. These tools enable the identification of critical areas where elephants and humans interact frequently, thereby helping in devising targeted strategies for conflict mitigation.

Field Surveys and Data Collection

Field surveys are another crucial method for understanding HEC. These involve direct observation, GPS tracking of elephant movements, and interviews with local communities. The importance of such surveys is evident in (Chaudhary *et al*., 2022) work, where GPS devices were used to delineate elephant corridors and assess changes in land use around these corridors. Interviews and interactions with locals provide valuable qualitative data on the frequency, nature, and impact of conflicts. This grassroots-level information is crucial for understanding the local dimensions of the problem and for engaging communities in conflict resolution strategies.

Analysing Elephant Behaviour and Movement Patterns

Understanding elephant behaviour and movement patterns is fundamental to addressing HEC. This involves studying elephant migration routes, feeding habits, and reactions to human activities. The work by (Daniel, 1980) in mapping elephant migration patterns from Dalma to the Panchent Forest Division exemplifies this approach. Tracking these patterns helps in identifying potential conflict zones and times of the year when conflicts are most likely to occur.

Utilizing Statistical and Data Analysis Tools

The application of statistical methods and data analysis tools is essential for interpreting the collected data. Studies like that of (Palei *et al.,* 2016) and (Das Chatterjee, 2016b) use statistical analyses to understand the relationship between various factors (such as land use changes, population density, and elephant movement patterns) and the frequency and intensity of HEC.

Data on elephant populations, incidents of conflict, demographic changes, and land use patterns are analysed to identify trends, correlations, and potential causes of conflict. This analysis is crucial for developing predictive models that can forecast potential conflict scenarios, allowing for pre-emptive action.

Participatory Methods and Community Involvement

Participatory methods involve local communities in the process of data collection and conflict mitigation strategies. Community-based approaches, as suggested in (Hussain *et al*., 2023) study, are crucial for sustainable conflict management. These methods include community surveys, participatory mapping, and involving local stakeholders in decision-making processes.

When we engage with communities it not only provides additional data but also helps in building trust and cooperation, which is essential for the successful implementation of any conflict mitigation strategy.

Technology and Innovation in Conflict Mitigation

In addition to traditional methods, innovative technological solutions are being explored to mitigate HEC. These include the use of early warning systems, electric fencing, and bio-fencing with plants unpalatable to elephants. The integration of technology in monitoring and managing human-elephant interactions is an emerging field that offers promising solutions to reduce conflicts.

KEY STRATEGIES IN ELEPHANT LANDSCAPE CONSERVATION IN THE DALMA WILDLIFE SANCTUARY

The Management Plan of Dalma Wildlife Sanctuary was prepared in 2020 by the Forest, Environment & Climate Change Department, Government of Jharkhand. The plan outlines the objectives, strategies, and action plans for the conservation and management of the Dalma Wildlife Sanctuary for the period of 2020-2030. It is an extensive document organised into two broad sections. The first section outlines the existing situation of the Sanctuary, while the second section proposes the plan for the time ahead.

The management plan aims to conserve the biodiversity of the sanctuary and maintain the ecological balance of the region. The plan also aims to promote sustainable use of natural resources and promote ecotourism in the sanctuary. The plan identifies several objectives for the conservation and management of the sanctuary. These include the protection of the forest cover, conservation of wildlife species and their habitats, restoration of degraded habitats, and the prevention of illegal activities such as poaching and mining.

To achieve these objectives, the management plan outlines several strategies and action plans. These include:

1. **Strengthening of the institutional and legal framework:** The management plan proposes the strengthening of the institutional and legal framework for the management of the sanctuary. This includes the establishment of an effective monitoring system and the enforcement of regulations to prevent illegal activities such as poaching and mining.
2. **Habitat management:** The management plan proposes the restoration of degraded habitats and the management of forest cover. This includes the establishment of nurseries for the propagation of indigenous plant species and the implementation of measures to prevent soil erosion.
3. **Wildlife conservation:** The management plan proposes the conservation of wildlife species and their habitats. This includes the establishment of anti-poaching units, the creation of waterholes, and the management of grasslands.
4. **Ecotourism promotion:** The management plan proposes the promotion of ecotourism in the sanctuary. This includes the establishment of infrastructure for tourists such as camping sites, interpretation centres, and nature trails.
5. **Community participation:** The management plan emphasizes the importance of community participation in the conservation and management of the sanctuary.

This includes the involvement of local communities in habitat restoration, wildlife conservation, and ecotourism promotion.

6. **Financial Resources:** The management plan also identifies the financial resources required for the implementation of the proposed strategies and action plans. The plan proposes the mobilization of funds from government sources, private sector investments, and donor agencies.

Overall, the Management Plan of Dalma Wildlife Sanctuary outlines a comprehensive strategy for the conservation and management of the sanctuary. The plan identifies several objectives, strategies, and action plans for the protection of the biodiversity of the sanctuary and the promotion of sustainable use of natural resources. The plan also emphasizes the importance of community participation in the conservation and management of the sanctuary.

Future research should focus on integrating these diverse methods to develop a holistic understanding of HEC. There is also a need for continuous monitoring and adaptation of strategies based on changing environmental and social dynamics. Community participation

and the use of innovative technologies should be emphasized to ensure the effectiveness and sustainability of conflict mitigation efforts.

7. **Way Forward**

Dalma Wildlife Sanctuary is a microcosm of ecological diversity, playing a pivotal role in the conservation of not just elephants but a multitude of species that form the fabric of this ecosystem. The studies by Singh, Prasad, and others underscore the sanctuary's significance from an ecological standpoint, highlighting the intricate balance between biodiversity, climate, topography, and human impact.

Future research and conservation efforts in the sanctuary need to adopt a holistic approach, one that encompasses the sanctuary's diverse ecological roles and addresses the challenges posed by human activities. The preservation of this unique ecological haven is not just about protecting a single species but about maintaining the complex web of life that it supports. The Dalma Wildlife Sanctuary, in its full ecological significance, represents a crucial node in the broader landscape of biodiversity conservation, meriting concerted efforts to understand, preserve, and sustain its ecological integrity for generations to come.

The factors adversely impacting the elephant populations in the Dalma Wildlife Sanctuary are complex and interlinked, encompassing environmental, socio-economic, and anthropogenic dimensions. To mitigate these issues, a multi-faceted approach is required, one that addresses habitat conservation, human-elephant conflict resolution, and sustainable development practices.

Conservation strategies should include habitat restoration, the establishment and maintenance of elephant corridors, and the implementation of sustainable agricultural and development practices that minimize conflict with wildlife. Additionally, community engagement and education are vital in fostering a harmonious coexistence between humans and elephants.

The future of the elephant population in the Dalma Wildlife Sanctuary hinges on the effective management of these challenges. It requires a concerted effort from conservationists, policymakers, local communities, and researchers to ensure that these majestic creatures continue to thrive in their natural habitat for generations to come.

The methodology for studying human-elephant conflicts in the Dalma Wildlife Sanctuary is multi-dimensional, integrating technological, ecological, and social approaches. Future research should focus on integrating these diverse methods to develop a holistic understanding of HEC. There is also a need for continuous monitoring and adaptation of strategies based on changing environmental and social dynamics. Community participation and the use of innovative technologies should be emphasized to ensure the effectiveness and sustainability of conflict mitigation efforts.

TRENDS AND GAPS IN LITERATURE

In identifying trends within the research concerning the Dalma Wildlife Sanctuary, a notable emphasis is laid on the ecological aspects and direct human impacts on elephant populations, such as habitat fragmentation, human-elephant conflict, and the effects of agricultural expansion. Study like those of (Mandal & Das Chatterjee, 2021) have significantly contributed to understanding the spatial dynamics of these conflicts, employing advanced geomatics and data analysis techniques. However, there is a discernible trend towards a predominantly data-driven approach, with less emphasis on the socio-economic dimensions of the conflicts. The research, while thorough in ecological and geographic aspects, often underrepresents the cultural, economic, and social factors that influence human-elephant interactions. This includes the perspectives and attitudes of local

communities towards conservation efforts, their socio-economic dependencies on the land, and the impact of traditional practices on wildlife management.

Regarding gaps in the research, one noticeable area is the limited exploration of long-term ecological changes, particularly in the context of climate change and its indirect effects on elephant habitats and behaviour. While current studies, like those by (Shaffer *et al*., 2019), provide a detailed account of the forest composition and immediate anthropogenic threats, there is a paucity of information on how shifting climatic patterns might alter the sanctuary's ecosystem in the future. Furthermore, research on innovative mitigation strategies for human-elephant conflict is relatively nascent. Techniques such as the use of bio-fencing, community-based early warning systems, and other non-invasive conflict mitigation methods have not been extensively explored. Such strategies could play a crucial role in sustainably managing human-elephant interactions, considering the increasing human population and development activities around the sanctuary. Therefore, future research directions could benefit from a more holistic approach, incorporating socio-economic, cultural, and climate change aspects to enhance the effectiveness of conservation strategies in the Dalma Wildlife Sanctuary.

CONCLUSION

In conclusion, the research conducted on the Dalma Wildlife Sanctuary provides an extensive understanding of the ecological dynamics, challenges, and human-elephant conflicts within this crucial habitat. Studies by (Wilson *et al*., 2015), (Kitratporn & Takeuchi, 2022), and (Anuradha *et al*., 2019) have been instrumental in highlighting the intricate interplay between wildlife, particularly elephants, and human activities, offering insights into habitat degradation, spatial movement patterns, and conflict zones. However, the research also underscores the need for a broader, more integrated approach. This encompasses not only the ecological and geographical dimensions but also the socio-economic, cultural, and climatic factors that are equally pivotal in shaping the sanctuary's future. An in-depth analysis of these areas will offer a more comprehensive understanding of the sanctuary's challenges and greatly enhance the development of effective, sustainable conservation strategies.

Looking ahead, future research and conservation efforts in the Dalma Wildlife Sanctuary must adopt this holistic perspective by bridging the current gaps, particularly in understanding the long-term ecological impacts of climate change and incorporating community-based approaches to conflict mitigation. This will result in strategies that are more robust and inclusive. The integration of advanced technologies and innovative methods, along with traditional knowledge and practices of the local communities, could offer novel solutions to the pressing challenges faced by the sanctuary. Ultimately, the goal should be to ensure the coexistence of humans and elephants in this shared eco-scape, preserving the ecological integrity of the Dalma Wildlife Sanctuary while also respecting and supporting the needs and values of the local communities.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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