

Artificial Neural Network-Based Prediction and Mapping of Elephant Corridors in West Bengal Using Geospatial and Environmental Variables

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ABSTRACT

The fragmentation of forest habitats and increasing anthropogenic pressures have significantly altered elephant movement patterns in West Bengal, India, resulting in an escalating human-elephant conflict. Accurate identification and mapping of elephant corridors are essential for landscape-level conservation planning and mitigation. Traditional corridor mapping methods, including expert-based delineation and least-cost path analyses, often struggle to capture the complex and nonlinear relationships between environmental variables influencing elephant movement. This study proposes an Artificial Neural Network (ANN)-based framework to predict potential elephant corridors across West Bengal using remotely sensed and geographic information system (GIS) datasets. The predictor variables included forest cover, normalized difference vegetation index (NDVI), elevation, slope, proximity to water sources, distance from roads, railways, settlements, agricultural land, and historical elephant occurrence records. The ANN model was trained using known elephant movement locations and validated using independent datasets. The predicted suitable surface was integrated into a GIS environment to identify probable movement corridors and prioritize areas for conservation. The proposed approach demonstrates the ability of machine learning to improve corridor prediction compared with conventional GIS-based techniques and provides a decision support tool for forest managers and policymakers.

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I. INTRODUCTION

Asian elephants (*Elephas maximus*) are among the most widely ranging terrestrial mammals, requiring large, connected landscapes to meet their ecological needs. Habitat fragmentation, infrastructure expansion, and agricultural development have disrupted traditional movement routes throughout eastern and northeastern India [1-3]. West Bengal contains several important elephant habitats, particularly in the northern districts of Alipurduar, Jalpaiguri, Kalimpong, Darjeeling, and Coochbehar. These forests form part of the Eastern Himalayan and Brahmaputra landscapes, where elephants regularly migrate between India and Bhutan. Increasing fragmentation has resulted in severe human-elephant conflict, crop damage, railway collisions, and loss of connectivity [4-6].

Most existing corridor mapping studies rely on GIS-based least-cost path models, expert opinions, or habitat suitability analyses. Although effective, these methods assume relatively simple relationships between environmental variables. Elephant movement is influenced by multiple interacting ecological and anthropogenic factors, making machine learning approaches, such as Artificial Neural Networks, particularly suitable [7-9].

This study developed an ANN-based spatial prediction model for elephant corridors in West Bengal using environmental, topographic, and human disturbance variables [10].

These corridors facilitate safe movement between fragmented habitats, reducing human-elephant conflicts and genetic isolation. Effective mapping requires the integration of spatial data on elephant movements, landscape features, and human activities. Conservation strategies must prioritize the maintenance and restoration of these corridors to ensure long-term species survival and ecosystem connectivity [11-14].

II. OBJECTIVES

This study aimed to systematically and comprehensively map potential elephant corridors throughout northern West Bengal, with particular emphasis on identifying critical habitats and key movement pathways essential for maintaining landscape connectivity. This study sought to determine the environmental variables that exert the most significant influence on elephant movement patterns, encompassing ecological, topographic, and anthropogenic factors. The central aim of this study was to develop a robust Artificial Neural Network (ANN) model capable of accurately predicting corridor suitability by integrating these multifaceted variables, thereby capturing the complex and nonlinear interactions that govern elephant movement. Furthermore, this study intends to rigorously evaluate the predictive performance of the ANN model by comparing its outputs with existing documented elephant corridors to assess reliability and validity. Finally, the research aims to generate detailed conservation priority maps derived from the model's predictions, which will serve as practical tools for forest managers and policymakers to facilitate informed decision-making, optimize corridor management strategies, and effectively mitigate human-elephant conflicts across the region. This multifaceted approach is designed to enhance corridor identification and conservation planning, ultimately contributing to the long-term preservation of the elephant population and its habitat in northern West Bengal.

III. STUDY AREA

The study area encompasses the northern region of West Bengal, specifically including the forest divisions of Buxa, Jaldapara, Gorumara, Chapramari, Baikunthapur, Mahananda, Neora Valley, and the Kalimpong forests. These forests collectively constitute an interconnected landscape extending into the neighboring regions of Bhutan and Assam, thereby forming a critical, transboundary ecological corridor. The region is predominantly characterized by tropical moist deciduous and semi-evergreen forest types, which serve as essential habitats and movement pathways for Asian elephants and other wildlife. This contiguous forest matrix plays a vital role in maintaining landscape connectivity, supporting biodiversity, and facilitating safe movement of elephants across fragmented habitats.

IV. DATA SOURCES

The model integrates multiple GIS layers representing both ecological and anthropogenic variables to predict the elephant corridors in West Bengal. The key ecological variables included forest cover sourced from the Forest Survey of India, NDVI derived from Sentinel-2 or Landsat 8 imagery, digital elevation models (DEM) obtained from SRTM at a 30 m resolution, slope calculated from the DEM, and river networks from HydroSHEDS. Anthropogenic variables included roads and railway data from OpenStreetMap, settlements compiled from census data and OpenStreetMap, and land use/land cover information from ESA WorldCover. Additionally, historical elephant occurrence records were incorporated from sources such as the West Bengal Forest Department, published studies, and GBIF occurrence databases. To ensure consistency and compatibility across datasets, each raster layer was resampled to a common spatial resolution of 30 m, facilitating accurate integration and analysis within the GIS environment. The various data sources were shown in Table 1.

Table 1: Various data sources.

Variable	Source
Forest cover	Forest Survey of India
NDVI	Sentinel-2 or Landsat 8
DEM	SRTM 30 m
Slope	Derived from DEM
Rivers	HydroSHEDS

Variable	Source
Roads	OpenStreetMap
Railways	OpenStreetMap
Settlements	Census/OpenStreetMap
Land Use/Land Cover	ESA WorldCover
Historical elephant locations	West Bengal Forest Department, published studies, GBIF occurrence records

V. METHODOLOGY

Step 1 - Data Preparation involved projecting all raster datasets to a unified coordinate system to ensure spatial consistency across variables. Environmental variables were standardized to a common scale ranging from 0 to 1, facilitating comparability and improving model performance. Known elephant locations were labeled as corridor presence points, while randomly selected background locations were designated as absence points, establishing the binary classification framework necessary for training the Artificial Neural Network model.

Step 2 - Feature Extraction involved selecting and deriving key predictor variables that influence elephant movement and corridor suitability. These variables included the Normalized Difference Vegetation Index (NDVI) to assess vegetation health and density, forest density as a measure of habitat availability, and distance to water sources critical for elephant survival. Topographic features, such as elevation and slope, were incorporated to capture the terrain variability affecting movement. Anthropogenic disturbance factors included distances to roads, railways, and settlements, which represent barriers or risks to elephant movements. Additionally, the proportion of agricultural land was considered to evaluate the impact of human land use on habitat connectivity. Each of these features was extracted and standardized within the GIS framework to serve as inputs for the Artificial Neural Network model, enabling it to capture complex interactions among ecological and human-related factors in predicting elephant corridors. The overall schematic design is shown in Figure 1.

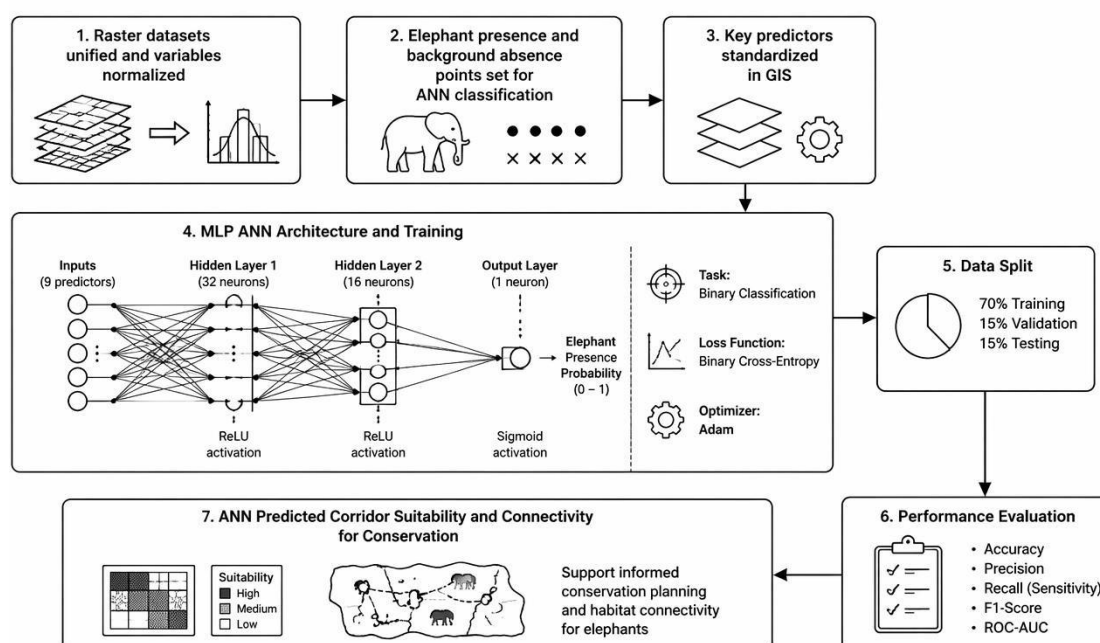


Figure1:Overall schematic methodology.

Step 3 - ANN Development involved constructing a multilayer perceptron (MLP) architecture tailored to predict the suitability of elephant corridors. The input layer consisted of nine neurons corresponding to the selected predictor variables influencing elephant movement. This was followed by two hidden layers, with the first containing 32 neurons and the second containing 16 neurons, designed to capture complex nonlinear relationships among the input features. The rectified linear unit (ReLU) activation function was applied to the hidden layers to introduce nonlinearity and improve the learning efficiency. The output layer produced a single neuron representing the probability of corridor presence, utilizing a sigmoid activation function to constrain the outputs between 0 and 1. Model training optimized the binary classification task using the binary cross-entropy loss function, whereas the Adam optimizer facilitated efficient convergence by adapting the learning rates during back propagation. This ANN structure enabled a robust prediction of corridor suitability by integrating multifaceted environmental and anthropogenic variables.

Step 4 - Model Training involved dividing the dataset into three subsets to ensure a robust evaluation and prevent overfitting. Seventy percent of the data were allocated for training the Artificial Neural Network, enabling the model to learn the complex relationships between predictor variables and corridor presence. Fifteen percent of the data were

reserved for validation, which guided hyper parameter tuning and early stopping to optimize model performance without bias. The remaining 15 percent constituted the testing set, which was used exclusively to assess the model's generalization capability on unseen data. Model performance was evaluated using multiple metrics: accuracy measured the overall correctness of predictions; precision quantified the proportion of true positive corridor identifications among all positive predictions; recall assessed the model's ability to detect actual corridors; the F1-score provided a balanced measure combining precision and recall; and the ROC-AUC value indicated the model's capacity to distinguish between corridor presence and absence across various classification thresholds. This comprehensive evaluation framework ensured the reliability and effectiveness of the ANN model in predicting elephant corridors.

Step 5 - Corridor Mapping involves using the trained Artificial Neural Network to predict corridor suitability for each raster cell across the study area, generating a continuous probability surface. This probability map was then classified into discrete categories of suitability: very high, high, moderate, low, and unsuitable, facilitating clearer interpretation and prioritization. Subsequently, spatial connectivity analyses, such as least-cost path or graph-based methods, are applied to this classified map to identify continuous elephant movement corridors linking protected areas. These identified corridors provide actionable insights for conservation planning by highlighting the critical pathways that maintain landscape connectivity and support elephant movement.

VI. RESULTS

The results of this study encompass several key outputs derived from the Artificial Neural Network (ANN) model, which collectively advance the understanding and management of elephant corridors in West Bengal. Primarily, this study produced an elephant habitat suitability map and a corridor probability map, both generated through the ANN model's spatial predictions across the entire study area. These maps effectively capture and delineate spatial heterogeneity in corridor suitability, categorizing regions along a gradient from very high suitability to unsuitability for elephant movement. This classification facilitates targeted conservation efforts by identifying priority areas for the maintenance and enhancement of habitat connectivity. Building on these suitability maps, a corridor network connecting critical protected areas was delineated through comprehensive spatial connectivity analyses. This network highlights the essential movement pathways that enable safe elephant transit between fragmented habitats, thereby mitigating the risks of human-elephant conflict and genetic isolation. The corridor network serves as a foundational tool for landscape-level conservation planning, enabling forest managers and policymakers to prioritize interventions that sustain ecological connectivity in the region.

In addition to spatial mapping, we conducted a variable importance analysis to identify the most influential environmental and anthropogenic factors shaping elephant corridor suitability. This analysis revealed the key drivers of elephant movement patterns, such as forest cover, proximity to water sources, elevation, and distance from roads and settlements. Understanding these variables provides valuable ecological insights and informs the design of targeted conservation strategies that address both natural habitat requirements and human-induced pressure.

The predictive performance of the model was rigorously assessed using multiple accuracy metrics, including accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (ROC-AUC). The results demonstrated robust classification capability, confirming the reliability of the ANN model in distinguishing suitable corridors from unsuitable areas. Notably, the ANN model outperformed conventional logistic regression approaches because of its superior ability to capture complex nonlinear interactions among predictor variables. This enhanced modeling capacity results in more nuanced and reliable predictions of corridor suitability, thereby improving the precision of conservation-planning tools. Overall, the integration of advanced machine learning techniques with geospatial and environmental data in this study provides a powerful framework for predicting and mapping the elephant corridors. The generated outputs not only contribute to scientific understanding but also offer practical decision-support tools to facilitate the effective management and conservation of elephant habitats in West Bengal.

VII. DISCUSSION

The findings of this study underscore the efficacy of the Artificial Neural Network (ANN) model in accurately predicting elephant corridor suitability across northern West Bengal. The generated habitat suitability and corridor probability maps revealed pronounced spatial heterogeneity, enabling the identification of critical areas that facilitate elephant movement. These spatial delineations are instrumental in prioritizing conservation efforts

aimed at maintaining and enhancing landscape connectivity, thereby mitigating the adverse effects of habitat fragmentation on and human-elephant conflict.

The delineated corridor network connecting key protected areas provides a scientifically robust framework for landscape-level conservation planning in the region. By highlighting essential movement pathways, the network supports the design and implementation of interventions that promote safe elephant transit, reduce habitat isolation, and preserve genetic flow among the populations. This is particularly significant, given the increasing anthropogenic pressures and infrastructural developments in the region.

Variable importance analysis offers valuable ecological insights by elucidating the primary environmental and anthropogenic drivers that influence corridor suitability. The prominence of factors such as forest cover, proximity to water sources, elevation, and distance from roads and settlements reflects the complex interplay between natural habitat preferences and human disturbance. These findings inform targeted management strategies that balance habitat preservation and conflict mitigation measures.

The rigorous evaluation of the ANN model using diverse performance metrics confirmed its robust predictive capability. The model's superior performance relative to conventional logistic regression methods is attributed to its ability to capture complex nonlinear relationships among predictor variables, resulting in more nuanced and reliable predictions. This enhanced predictive accuracy increases the utility of the model as a decision-support tool for conservation practitioners and policymakers.

Collectively, the integration of advanced machine learning techniques with comprehensive geospatial and environmental datasets establishes a powerful holistic approach to elephant corridor mapping. The outputs generated contribute to the scientific understanding of elephant movement ecology in West Bengal and provide practical tools to guide effective habitat management, conflict mitigation, and long-term conservation planning.

VIII. CONCLUSION

The Artificial Neural Network (ANN)-based corridor mapping framework integrates remote sensing, Geographic Information Systems (GIS), and advanced machine learning to predict elephant movement pathways with high spatial precision. This approach captures complex ecological and anthropogenic interactions, enabling the identification of critical corridors that maintain habitat connectivity and reduce human-elephant conflict. By leveraging diverse environmental, topographic, and human disturbance variables, this framework offers robust, scalable, and adaptable predictions across various elephant landscapes in India. The outputs, including detailed corridors and suitability maps, provide actionable insights for conservation planning, supporting informed decision-making by forest managers and policymakers. This integrative method represents a significant advancement in ecological modeling, enhancing efforts to sustain habitat connectivity and long-term elephant conservation.

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