Sustainability and Biodiversity Conservation

Mapping of the Asian elephant (*Elephas maximus*) corridors of Rajaji National Park using GIS and remote sensing techniques

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Abstract
Habitat fragmentation is a major factor in biodiversity loss and forest degradation around the globe. In this case, wildlife corridors are the most crucial landscape elements since they play a pivotal role in maintaining the ecosystem's balance in various habitats that the impacted species prefer. Linear infrastructure development, urban sprawl, and fragmentation of the current habitats present in the study area are some of the major causes of the destruction of Asian Elephant habitats. The landscape fragmentation analysis shows that the major portion of the large core (>600 acres) has been converted into small and medium cores, patches were increased (due to the enhancement of either built-up or agricultural land) and a vast amount of the vegetated land is perforated. This formulates that there is a considerable decrease in the forest cover of the study area. The corridors present there are delineated using least cost path mapping namely Kansrau- Barkote, Tinpani, Motichoor- Gohri, Chilla- Motichoor, and Rawasan-Sonanadi which provided insight into the most suitable path for the movement of the Asian Elephants. These corridors are likewise subject to numerous concerns. The greatest way to find the best pathways for any species at risk is through the mapping of corridors, which also aids in keeping track of the status of the corridors.

Keywords: Fragmentation, Land Use Land Cover (LULC), Least Cost Path (LCP)

Introduction

Elephas Maximus is believed to have descended during the later Pleistocene from *Maximus* Corridors, the fossil remains of which are found in the Shivaliks in the Indian subcontinent. The natural range of the Asian elephant is today confined to the Asian continent (Maglio, 2008). The species is considered "Endangered" as per the IUCN Red List and a Schedule 1 species according to the Indian Wildlife Protection Act 1972 (Baskaran et al., 2011). Presently in the Asian continent, India accounts for the largest surviving population of the Asian elephant, approximately 50% of the total world population of the species (Williams et al., 2020). Wild elephants are presently confined to the forested hilly tracts of four different regions: (I) the foothills of the Himalayas in the north (ii) the north-eastern states (iii) the forests of east-central India, and (iv) the forested hilly tracts of Western and Eastern Ghats in southern India (Ly, 2011). Rajaji National Park is one of the potential sites to observe wild elephants in their natural habitat. The Shivalik in Uttarakhand harbors an elephant population of around 1350 as per the wildlife census of 2008 (Maria, 2014). The challenges confronting elephant conservation in most elephant Range States are habitat loss and fragmentation, human-elephant conflict, and poaching and illegal trade of elephants (Williams et al., 2020). The patchy and fragmented landscape has altered the movement of the elephants inside as well as outside of the protected area leading to genetic isolation, limitation of dispersal, migration, and the decline of populations of the animals requiring large habitat ranges (Fahrig & Merriam, 1985). In the past few years, human settlements and agricultural practices have increased around the protected area which has led to the shrinking of the natural paths (Joshi & Puri, 2019). The human-elephant conflict mainly arises in the regions with major agricultural land. Crop raiding has been identified as the primary cause of conflict between elephants and humans in Asia (Williams et al., 1973). Every year, crops damaged by elephants range in value from a few thousand dollars to millions of dollars. More than 100 people as well as 40 to 50 elephants are killed in crop raiding each year in India (Ogra, 2009). The larger conflict in the study area is caused by overlapping resource use, specifically between the elephants and the Gujjar livestock (Sah & Mallick, 2020). The corridors in this scenario where the habitats are fragmented and degraded play a very important role in providing continuity between the patches that allow the fauna of those regions to venture for different parts in search of food, mate, or other purposes (Newmark, 1993).

Material and methods
Study area

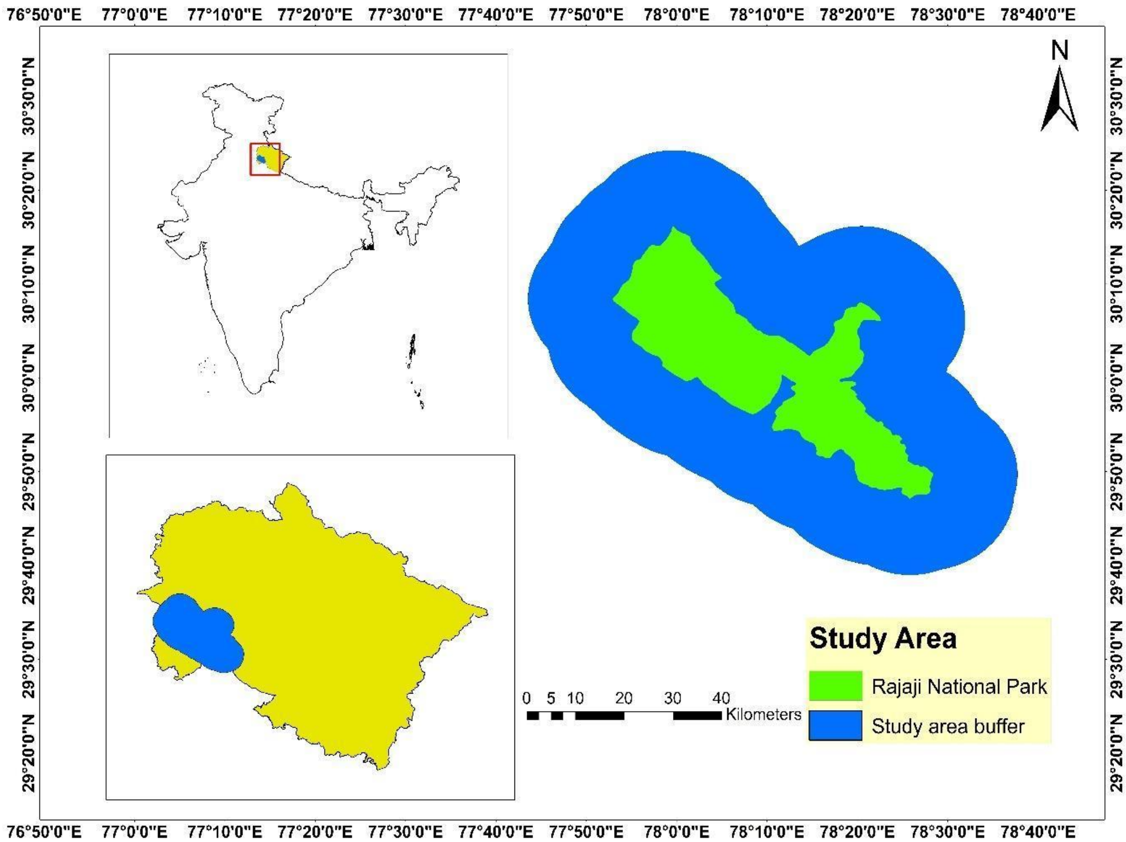

Figure 1. Study area map.

The study area has been taken as a buffer from the Rajaji National Park with a diameter of about 15 km. The study area thereby comprises a wide area apart from Rajaji and includes the Haridwar district, Dehradun, some parts of Roorkee, some hilly terrains of Pauri Garhwal, etc. The center of the study area is the Rajaji National Park (29˚15ˈ to 30˚31ˈ North, 77˚52 ˈ to 78˚22ˈ East). It lies between the altitude of 302 to 1000 m covering an area of 820.42 sq. Km in and around the Shivalik's (Joshi, 2016). It covers three districts of Uttarakhand: Haridwar, Dehradun, and PauriGarhwal. River Ganges divides the landscape into two parts namely western and eastern Rajaji. The western Rajaji part consists of the Ramgarh, Kansaro, Motichur, Haridwar, Dholkhand, and Chillavali ranges. The part comprises of eastern Dehradun range and the Lansdowne range of the Pauri Forest division. The Rajaji National Park comprises five major corridors that act as a passage for the movement of elephants, tigers, and many other mammal species. The Kansrau-Barkote corridor (connects the Kansarao range of the Rajaji National Park with the Barkote range of the Dehradun Forest division), Tinpani corridor (connects RNP with the

Dehradun Forest division), Motichur-Gohri Corridor (connects the Motichur and Gohri ranges of RNP), Chilla- Motichur (connects Motichur and Chilla ranges of RNP), Rawasan-Sonanadi corridor (connects the RNP with Corbett National Park) (Menon et al., 2017).

For Landscape Fragmentation

For the fragmentation analysis of the study area, the ArcMap tool extension i.e., Landscape Fragmentation Tool 2.0 was used (Sharma et al., 2016). The Normalized Difference Vegetation Index of the study area was calculated using the ERDAS IMAGINE version 2014. The Stacked image was used as an input file and then the bands were selected as per the below-mentioned formula for calculating the NDVI.

$$NDVI = (NIR- RED)/(NIR+RED)$$

The values of NDVI were 0.746 and 0.540 for the years 1998 and 2021 simultaneously. Then the NDVI was reclassified into two classes (Forest and Non-Forest) in the ArcMap using the Reclassify tool. Then the tool for fragmentation is used (Landscape Fragmentation Analysis) to analyze the degradation and fragmentation of the vegetation in the study area (Aditya et al., 2018). The resulting image after the successful execution of LFT came with four major classes i.e.:

1. Patch: The "edge effect" entirely degrades small fragments. Patch forests are completely engulfed by the edge effect and do not contain any forest pixels that are more than 100 meters from non-forest. Forest pixels are little patches of forest encircled by non-forested terrain. Core forest pixels and patch forest pixels must be separated.

2. Edge: Large non-forested land cover features and the core forest are separated by forest pixels. The edge forest must be next to the core forest and within 300 feet of a significant non-forest land cover feature.

3. Perforation: The inside edge of small non-forested areas within a core forest, such as a house constructed within the woods, comprises the least-disturbed category, perforated pixels. Within the wooded terrain, forest pixels mark the boundary between the core forest and relatively minor clearings (perforations)

4. Core (further classified into three subclasses): forest pixels that are comparatively far from the perimeter of the forest. These are essentially forests encircled by other forests. To demonstrate the viability of the core patches about patch size, the core forest was divided into three categories:

- small core (area < 200 acres).
- medium core(area > 200 < 600 acres).

o large core(area > 600 acres)

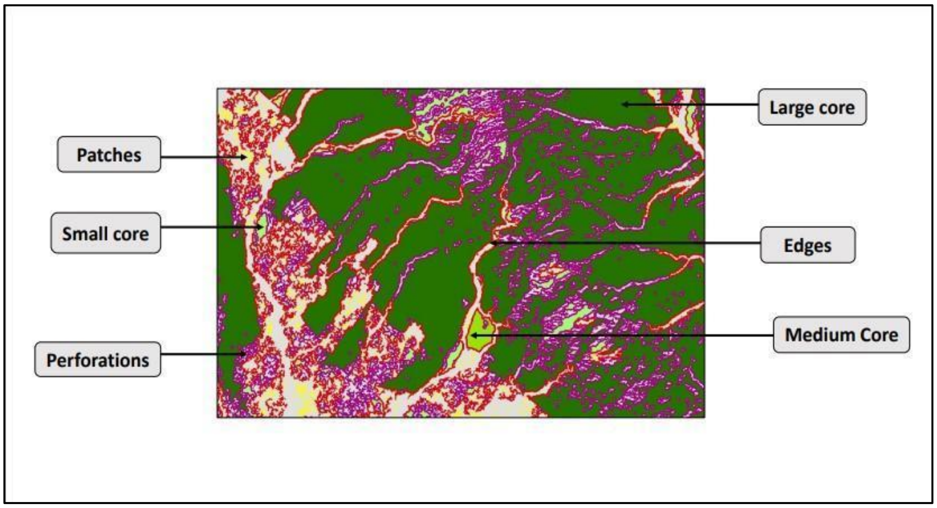

Figure 2. Classes of LFT

For the Least Cost Path

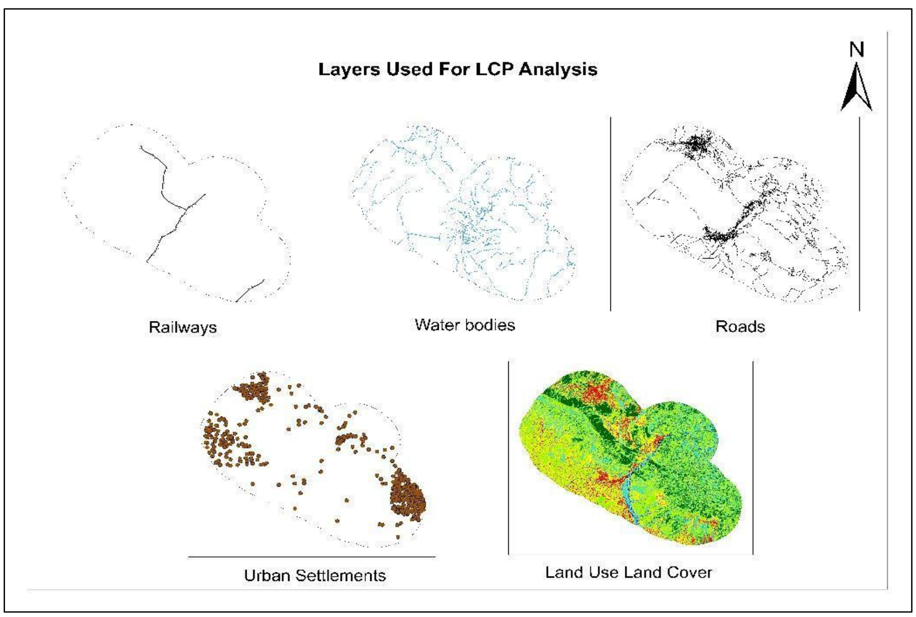

Figure 3. Layers used for LCP analysis

Preparation of the layers

The layers used for the Least Cost Path Modelling were buffers from roads, railways, settlements, and waterbodies. Land Use The Land Cover layer was prepared using the Unsupervised classification (Naithani et al., 2018) in the ERDAS IMAGINE software.

Proximity analysis was done in ArcGIS using the Euclidean Distance tool from the Arc toolbox in which the values of the distance in meters were put into the tool keeping in mind regular intervals and the tool gave the output in the form of a raster.

Preparation of the resistance layer

All the layers were obtained in a raster format. The LULC layer was also reclassified into 6 classes in which the values of the pixels in the raster are reclassified or changed. Weights were assigned to each class of raster. The layers of roads, railways, towns, settlements, and water bodies were assigned values from 1 to 5, and LULC was given values from 1 to 6 according to the degree of resistance faced by Asian Elephants for movement. After reclassifying, a weighted sum tool was used to assign weights and combine multiple layers to form an integrated layer in raster format, and then the values were reversed to represent the cost of travel correctly. Then the cost raster was prepared.

Least Cost Path

After the preparation of the cost raster layer cost distance was calculated from the spatial analyst tool to calculate the least weighted distance for each cell to the nearest source across the cost raster and the cost backlink tool was used that determine the route and identify the direction of the Least Cost Direction for each cell back to the source. For the preparation of Cost Distance and Cost Backlink, the location of the source was used

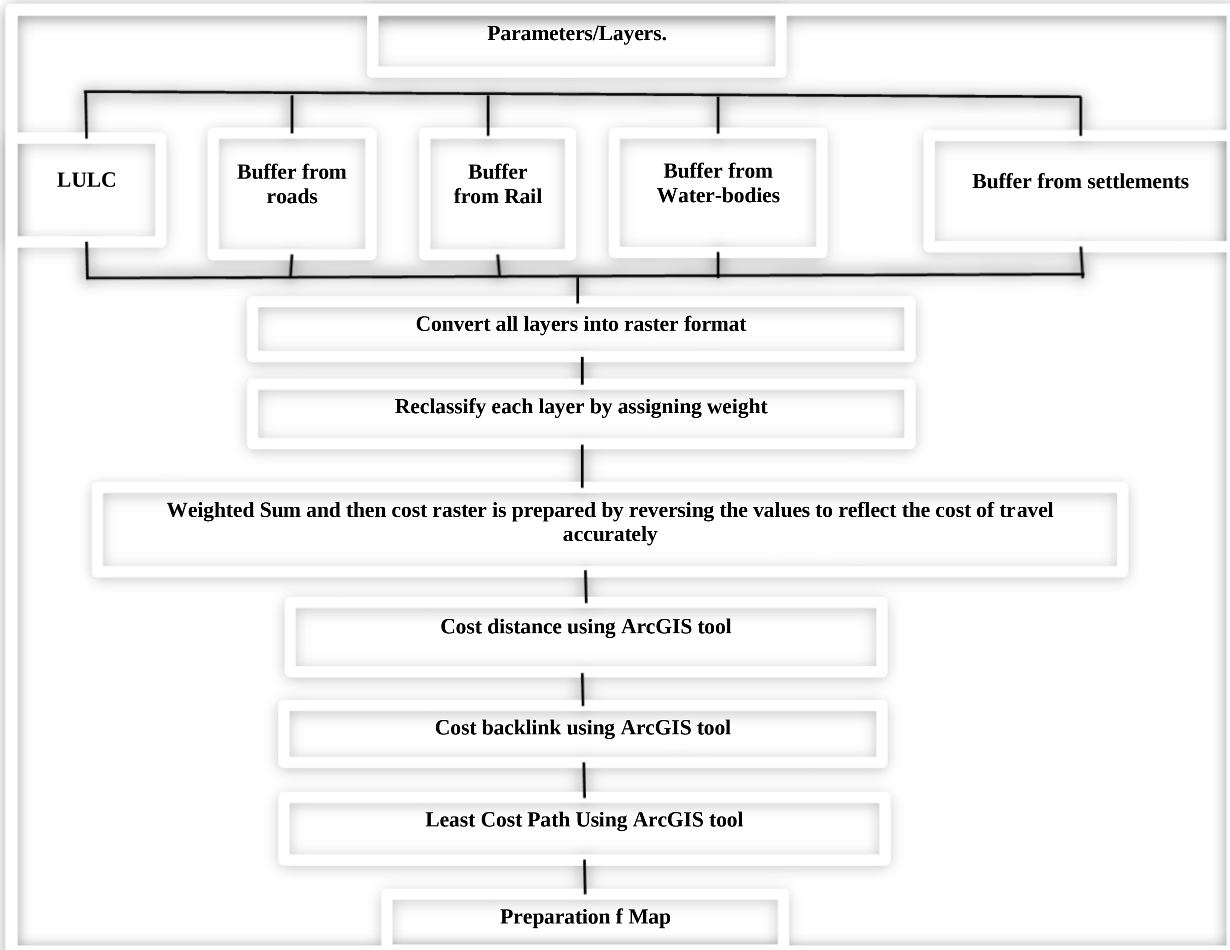

Figure 4. Flow chart of the steps involved in LCP

Results

The fragmentation map depicts that the fragmented patches have increased from 1998 to 2021 by 0.49 square km. The edges have increased by 3 square km over 20 years. Perforated forests have also increased by 3.77 square km. The core area that had been classified as small core, medium core, and large core has shown an overall decrease (Srinivasan et al., 2022). The area of the small and medium cores has increased by 1.86 and 0.59 square km respectively, which means that more of the larger core was fragmented and deteriorated due to various anthropogenic activities and the class also shows a decrease in the area by 13.08 square km. This increase in anthropogenic disturbances will increase fragmentation and thus indirectly decrease the forest cover of the protected area (Abhijitha et al., 2021).

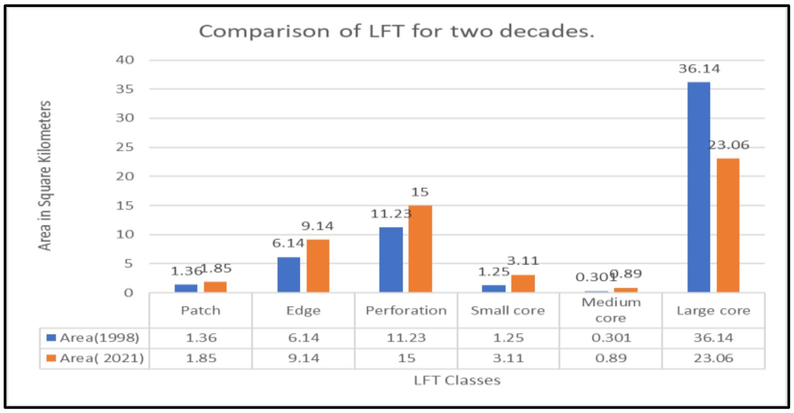

Figure 5. Area Comparison for Two Decades

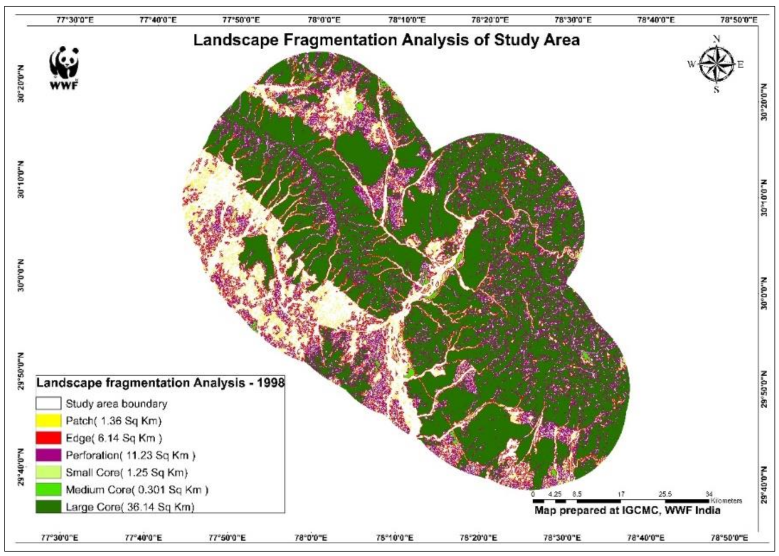

Figure 6. LFT in 1998.

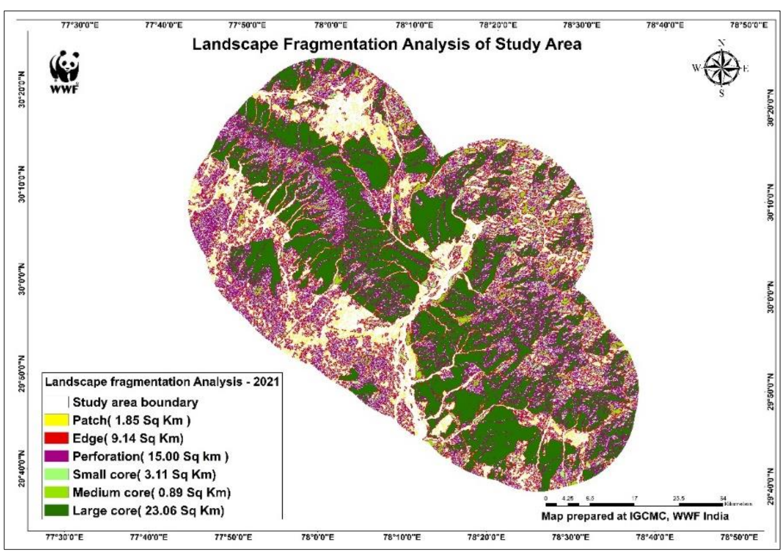

Figure 7. LFT in 2021

For LCP

The study area's land use land cover, urban areas, railways, roads, and water bodies were the layers that served as input layers for the Least Cost Path algorithm. Elephant mobility is restricted by layers like roads, railroads, urban settlements, and places adjacent to them; on the other hand, elephant movement is less restricted by layers like water bodies and woodlands that are farther away (Abhijitha et al., 2021). In the LULC, dense forests, open forests, and waterbodies will improve the ease of movement whereas agricultural and built-up areas will act as a barrier in their path, which will eventually result in conflicts between humans and elephants.

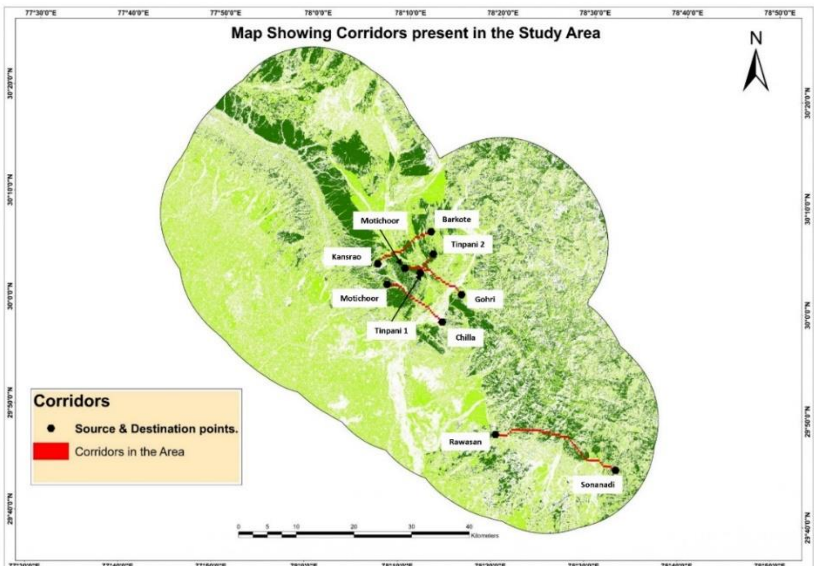

Figure 8. Corridors were delineated using LCP in the study area.

The figure displays the identified corridors (Kansrao-Barkote, Tinpani, Motichoor-Gohri, Chilla-Motichoor, Rawasan-Sonanadi) (Menon et al., 2017) that would serve as the best routes for the movement of the species without any obstacles or danger to their lives. These corridors were identified using the output of the LCP tool while taking into account all resistance layers**.**

Conclusion

The study showed that GIS and remote sensing could be utilized to plan the corridors using least-cost path mapping, which was highly helpful in determining the best acceptable path for elephants and other species under concern (Abhijitha et al., 2021). In the present scenario, when most of the natural habitats are subjected to fragmentation due to several anthropogenic factors, corridors play an important role in maintaining the movement of wild animals over various habitat patches for food, mate, or other requirements (Lemming, 2011). The fragmentation analysis showed an overall increase in each class. The patches have increased either due to agriculture or to the increase in built-up (Joshi et al., 2010). Edges have increased, which will in turn degrade the forest health due to the edge effect. The large cores have been transformed into either small or medium cores (Srinivasan, 2022). Various linear infrastructures that pass through the protected area disturb the movement of the elephants. Roadkill and death due to railway accidents are prominent in the PA which adds to making the species more vulnerable (Williams et al., 2020). Using least-cost path mapping the corridors were identified (Kansrau-Barkote, Tinpani, Motichoor-Gohri, Chilla-Motichoor, Rawasan-Sonanadi) (Menon et al., 2017) that would serve as the best routes for the movement of the species with the least hindrance to their movement. These routes can be used for the effective management of the elephant populations and the conservation management in the area (Lemming, 2011).

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