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Geospatial modelling of overlapping habitats for identification of tiger corridor networks in the Terai Arc landscape of India

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ABSTRACT

Wildlife corridors in a landscape include local vegetation, topography, prey base, water and are associated with isolated wildlife habitat patches. They facilitate maintenance of ecological structure and function as well as provide connectivity to faunal populations supporting genetic transfers, and are elements critical to wildlife management. In this work, habitat patches for tiger, both inside as well as outside of Protected Areas have been identified by developing a Habitat Suitability Index model utilizing Remote Sensing and Geographical Information System datasets for the Terai Arc landscape, India. By using a computational approach based on the framework of theory of complex networks, for exclusively pairwise interactions between the habitat patches, a potential tiger corridor network has been structurally identified and studied in this landscape. The interactions between these habitat patches on a spatial scale has been analyzed as a clique of the corridor network. Further, the Clique Percolation Method has been applied to detect overlapping communities of habitat patches in the landscape. The Cliques required for maintaining contiguity between the habitat patches in order to support tiger movement are validated using field observations of tiger communities within the landscape matrix. The model developed for identification of tiger corridors in this study could potentially be of a vital importance for wildlife stakeholders to better understand and manage tiger populations both within and outside of protected areas. The study also highlights Critical Habitat Patches and their importance in maintaining landscape connectivity for tiger dispersal in the landscape. Using a report published by the Government of India as a benchmark, the model presented in the work is found to have an accuracy of 90.73% in predicting tiger carrying patches and the corridor network in the focal landscape.

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1. Introduction

Wildlife habitat patches are zones in the landscape that provide food, water and ecological conditions, for suitable habitat of individuals or populaces of wildlife species, to thrive and propagate (Morrison and Mannan 2007). In effect, wildlife habitats are the natural environment of flora and fauna sustained by management strategies (Glass and Pienaar 2021). Various forest successional processes create the wildlife habitats suitable for animals or plants through systematic modification of forest vegetation, etc. The conservation of wild animals necessitates a comprehensive understanding of their ecosystems (Brawn 2017). Water, shelter and food serve as key factors of the habitat that decide the presence and survival of fauna in a landscape. Wildlife habitat suitability of the target species is therefore to certain degree influenced by the weather and terrain of the region. When planning for wildlife protection, each aspect of wild life suitability must be accounted for (Johnsingh and Joshua 1994), food, being one of the most essential components that supports organism's requirement of nutrients to live, grow, and reproduce (Smith et al. 1997). Functional and structural attributes of habitats are physical and biological arrangements within which organisms live and interact among themselves and with the external components of the environment (Krebs, 1985; Jones 1987; Jones et al. 1994). Thus, wildlife habitats need to provide shelter, food, and ability for reproduction of the focal species and such areas are vital segments of ecological systems. Due to anthropogenic pressures, two of the major factors that have influenced and reshaped wildlife habitats are habitat fragmentation and habitat loss (Chetkiewicz et al. 2006). This has resulted in discontinuity in the habitats of the focal species at the landscape level, which forces the species to use the mosaic of managed ecosystems for their requirements (shelter or food or reproduction) (Dale et al. 2001).

Studies during the last few decades have largely supported habitat conservation through development of habitats and wildlife corridors between fragmented habitat patches (Harris and Gallagher 1989; Hanski and Gilpin 1991; Hanski and Ovaskainen 2000; Conard et al. 2010; Shanu et al. 2019). Wildlife corridors are segments of natural or managed vegetation, which encourage the movement of organisms between the regions of intact habitats, thereby provide landscape connectivity. The reason for structuring corridors as a conservation and management plan is fundamentally to reduce the consequences of habitat fragmentation and habitat loss on flow of matter and information in the ecosystem and, additionally support continuance of land use for various anthropogenic activities in the region (Shanu et al. 2019). Wildlife corridors with careful planning can help limit the ill impacts of habitat discontinuity to some extent (Perault and Lomolino 2000; Rayfield et al. 2011). The wildlife corridors may be obtained by using habitat patches supporting tiger populations in the focal landscape as vertices and the interaction between these vertices as edges. In the work through interaction between the vertices, we signify the support of movement of focal species from one habitat patch to another.

The objective of this work aims to use the Clique Percolation Method (CPM) to compute a viable tiger corridor network in the Terai Arc landscape. The steps used to achieve the objective include, (i) obtaining a tiger HSI in the Terai Arc landscape, (ii) use a computational approach to extract a tiger corridor network connecting different habitat patches (both Protected Areas (PAs) and potential habitat) in the landscape complex, and (iii) identify the most critical habitat patches and their underlying overlapping communities (Doreian and Conti 2012).

Two major factors shape the processes of tiger dispersal and habitat occupancy. First, tigers cannot be compelled to disperse from one habitat patch to another; rather, they can disperse to several habitat patches depending on the reason for migration (Reddy et al.

2012). This can be illustrated very well by using polygons instead of lines in the landscape matrix. Second, tigers do not only live in PAs, but also in the territorial region outside of PAs, where conservation is equally important (Dutta et al. 2016; Jhala et al. 2020). Thus, the conjecture based on field studies explains that interactions between habitat patches and is useful to model a wildlife corridor network based on it.

Designing and studying the interactions among the habitat patches using graph theory is one way to achieve the above goal. Each suitable habitat would be treated as an element of the vertex set V in such a graph and the interaction between these vertices as the set of edges E. Interaction between a set of vertices V indicates that the elements of V with the underlying region between them, in the landscape complex have suitable structural and functional attributes for supporting tiger populations and movements. Habitat Suitability Index (HSI) is one of the key models in determining the mentioned interactions in the real world for a particular species. Over a landscape, HSI for a species is calculated using Remote Sensing and Geographic Information System (GIS) datasets (Dale et al. 2001; Matisziw and Murray 2009; Erős and Lowe 2019).

Remote Sensing (RS) and Geographic Information System (GIS) in the recent years have played an important role in developing the spatial distribution of the landscape and habitat patches for effective modelling of the landscape level connectivity (Singh et al. 2010). Level 2-land use and land cover maps, as well as forest density maps, created using moderate resolution multispectral satellite data (Gaur et al. 2015) is a critical input for wildlife habitat identification. In this paper, we use vegetation/land use type and Forest density map of Terai Arc Landscape (Uttarakhand) using moderate resolution satellite data to identify the habitat patches, by modelling HSI with tiger as the focal species.

The problem of identifying potential habitat and supportive links for tiger movement is defined as a suitability-clustering problem (Dutta et al. 2016). Further, by creating clusters of data points obtained through HSI modelling, we integrate the tiger movement preferential features, through cumulative landscape aspects. These clusters aid in identifying the most important landscape matrix elements that could sustain a viable tiger population and relative movement (Yumnam et al. 2014). Finally, we define the tiger corridor network and identify the essential cliques that could serve as a diverse interlinking of habitat patches, based on the suitability of each feature as determined by the clusters of supportive parameters (including both potential habitat patches and Protected Areas). After obtaining the cliques, we used the CPM to obtain overlapping communities (Pattabiraman et al. 2015) in the landscape matrix in order to verify and preserve the landscape complex's contiguity.

For the purposes of this work, a community of habitat patches and areas in the landscape refers to a collection of habitat patches and areas among which interactions exist, share common characteristics and are located in close proximity to one another. Different communities may form in a network, and the particular communities that share similar vertices are referred to as overlapping communities (Palla et al. 2005; Bordenave et al. 2018). We classify the communities to see if they overlap, as this indicates if the landscape is contiguous for tiger movement. The overlapping communities also highlight the importance of the vertices or habitat patches that lie at the intersection of the overlapping communities for maintaining landscape contiguity (Matisziw and Murray 2009). We found six such habitat patches in the Terai Arc Landscape complex using our model run over the HSI for tigers in the landscape.

2. Terai Arc landscape

The Terai Arc Landscape is 810 km stretch of land between the River Yamuna in the west and the River Bhagmati in the east, encompassing the Shivalik slopes, the connecting

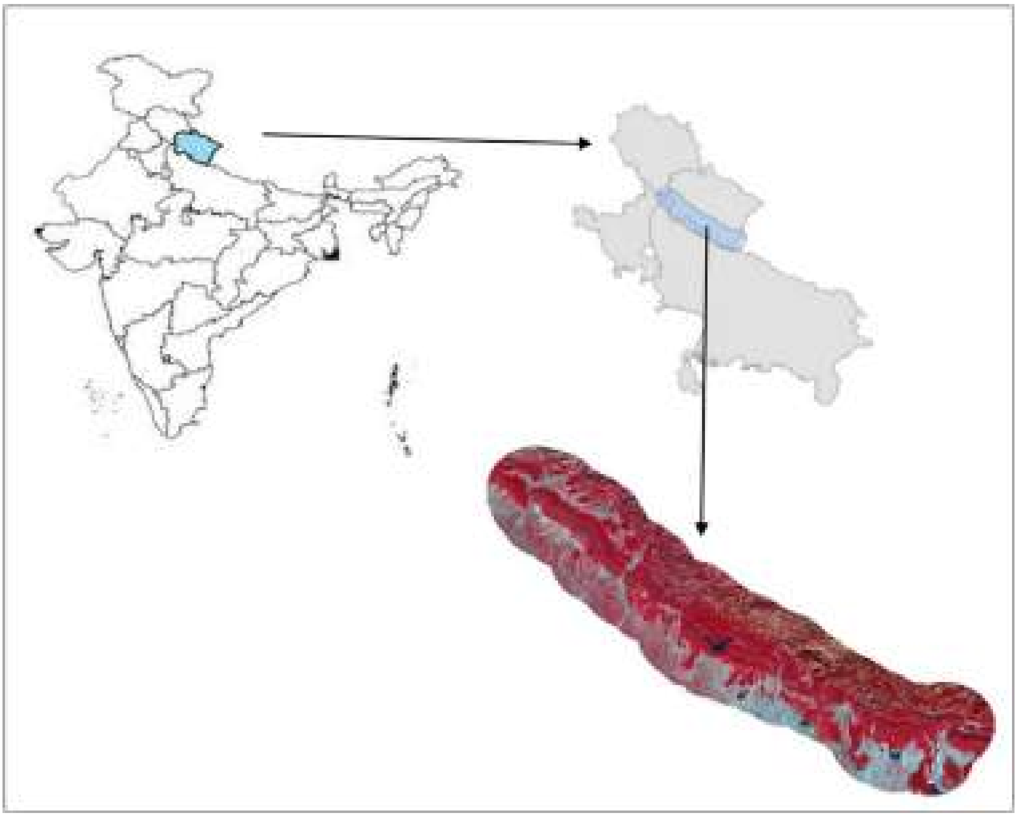


Figure 1. Location of the study area.

bhabhar zones and the Terai floodplains, for the most part spread more than three states in India viz., Uttarakhand, Uttar Pradesh and Bihar from west to east in the Himalayan foothills. The landscape was chosen for this study as it contains large tracts of contiguous forest patches suitable for harbouring tiger populations given its abundant prey base, vegetation cover, and water availability (Chanchani et al. 2014).

The study area lies in Terai Arc Landscape of Uttarakhand extend from Yamuna River (30˚30 to 77˚30′) marks its western limit and the Sharda River (27˚20′ to 81° 22′) bounds it on the east. Study area also covers some parts of Haryana, Himachal Pradesh, Uttar Pradesh and Nepal as shown in Figure 1. However, it must be noted that the portion of Nepal that falls in the study area has not been considered in our work for analysis and argument. The region experiences a hot summer with maximum temperature reaching 40 °C in May and June, while the winters are cold with minimum temperatures going well below 10 °C. The annual precipitation over this region ranges between 1000 mm to 2500 mm. The natural vegetation in the region is dominated by moist and dry deciduous forest with Sal being the dominant species in the region.

3. Materials and methods

3.1. Database creation

To prepare a land use and land cover map of the study area, satellite data from Landsat-8 from two seasons, March and November 2016, having a resolution of 30 m, was classified into 13 classes using the Hybrid classification system. The Normalized Difference Vegetation Index (NDVI) derived from the same satellite data was used to classify forest cover density into three groups, low, medium, and high density, using the density slicing method with ground validation using a hypsometer. The aspect, slope, height, and altitude maps were created using data from the Advanced Space borne Thermal Emission and Reflection (ASTER) digital elevation model (DEM) with a 30 m resolution downloaded from the USGS website. Open street maps were used to obtain the shape files for highways, water bodies, and railways (Sonawane and Bhagat 2016).

3.2. Habitat suitability index (HSI)

Modelling of suitable corridors and identification of potential habitats for tigers was done using two different approaches. This section, describes both these approach for better integration.

Modelling HSI by applying analytic hierarchy process (AHP) using RS derived data in GIS environment help in spatially identifying the potential habitats of the different fauna in the focal landscape using a clustering approach. Habitat suitability indices are a proportion of the suitability of habitat for a given animal dependent on an evaluation of habitat qualities. HSI are records as in, they as a rule join various factors, (e.g. height, soil type, and land spread) into a solitary composite measure. HSI models commonly predict habitat quality and species distributions (Zajac et al. 2015). The HSI is defined as a value in the range of $[0, 1]$ with the value 1 being the best quality of the habitat in the landscape for the focal species.

The AHP, presented in Saaty (1990), Assad, and Wójcik and Kurdziel (2018), is a powerful tool for managing complex dynamics of decision-making and has been used in this work for checking the consistency of the manager's assessments for HSI evaluations, decreasing the inclination in the dynamic procedure of decision-making.

Next, we propose the computational model of tiger corridor network in the focal landscape using the HSI for tigers in the landscape. To make the section self-contained, certain preliminary concepts required for the previously mentioned modelling like Networks, graph, clique, centrality, community, overlapping community, and the CPM are reproduced from standard mathematical texts, and are discussed. One of the major arguments made in the paper has been consideration of interactions between habitat patches, as vertices within the landscape that would help to explain the tiger movement between them. Networks can be very useful in studying and designing such models since they consider the interaction of vertices (Upadhyay et al. 2017). The region between the vertices supporting tiger movements is significant because we have considered tigers not only inside the PAs but also outside the PAs for this study. Outside the PAs, tigers use the entire area as a territorial bound wherever the HSI is above "Suitable" class, indicating the importance of regions rather than points or lines in the landscape matrix. We use clique to understand the interaction in the tiger corridor network once it has been modelled. Different cliques can be adjacent to each other, and Participatory centrality (PC) was used to find the vertices of different cliques that support the adjacency of two cliques (Ghalmane et al. 2019). The adjacency of cliques represented as a clique graph in this work indicates the presence of vertices at the intersection of two separate regions that sustain the tiger population and movement. A good approach to design the corridor networks would be to identify the community obtained from the cliques, which denotes the structural as well as functional connectivity in the fragmented landscape providing higher degrees of freedom for movement to the focal species. The overlapping communities in the tiger corridor network are also determined using clique graphs. The communities in this paper describe a set of vertices, associated links to these vertices, and the area enclosed between them that share structural and functional characteristics that support tiger population and movement. This is useful for defining the set of vertices that can be interpreted as creating multilevel pairwise interactions between them. Overlapping communities are formed when two separate communities share one or more than one similar vertices. These common vertices are significant because they aid in linking the communities, preserving continuity, and thus providing a gradient of structural and functional attributes for tigers to migrate from one to the next (Palla et al. 2005; Fortunato 2010; Tóth et al. 2013; Bordenave et al. 2018).

3.3. Network and graph

Complex systems can be described in a formal and comprehensive way using networks. Typically used to simulate experimental data where interactions are important and evolve over time in a specific domain. The interaction between habitat patches is important for the work in this paper, because it may evolve over time and space. Hence, to model such complex systems we adopt a perspective using the theory of complex networks for modelling.

A network N is a four tuple $(V_\lambda, E_\lambda, \psi_\lambda, \Lambda)$ with an algorithm β such that for $\Lambda \neq \phi$, $k \in \Lambda$, V_λ is a set of vertices V_k, E_λ is a set of edges E_k, ψ_λ is incidence function $\psi_k : E \to [V]^2$ where $[V]^2$ is the set of not necessarily distinct unordered pairs of vertices such that (V_k, E_k, ψ_k) is a graph given by the algorithm $\beta(k)$. The incidence function ψ provides structure to a graph by associating to each edge an unordered pair of vertices in the graph as $\psi(x) = \{v_k, v_q\} : v_k, v_q \in V, \forall x \in E \subseteq [V]^2$. Here k is the temporal component by virtue of which a network can evolve as per the given algorithm β (Upadhyay et al. 2017).

An unlabelled graph represents an isomorphism class of otherwise labelled graphs in an algebraic object known as a graph. As a result, a graph is used to represent a network. For the purpose of our work in this paper, we define an ecological network as a network N in which V_λ is the set of habitat patches for the tigers, and E_λ is the set of relations encoded as edges representing the movement of tiger between two distinct habitat patches (Upadhyay et al. 2017; Shanu et al. 2019). Having argued as above in this paper, we shall use the terms graph and networks interchangeably.

3.4. Clique

Definition: A set of vertices C is a clique of the graph G, if and only if $C \subseteq V(G)$; $x, y \in C$ *and* $x \neq y \Rightarrow \{x, y\} \in E(G)$, where $V(G)$ represents the Vertex set of G, $E(G)$ represents the set of edges of G and $\{x, y\}$ represent a edge between vertex x and vertex y (Bondy and Murty 2008).

A clique is a complete subgraph in which every vertex is connected to every other vertex. A k-clique denotes a clique of size k, where each vertex has a certain degree $\geq (k-1)$, and vertices with a certain degree $< (k-1)$ will not be included in the clique. We use a greedy method to find a clique in the sub-network after recursively applying a pruning technique to sample a sub-network from the specified network (Hatcher 2002; Estrada and Ross 2018). Figures 2 shows 3-cliques obtained over a hypothetical network.

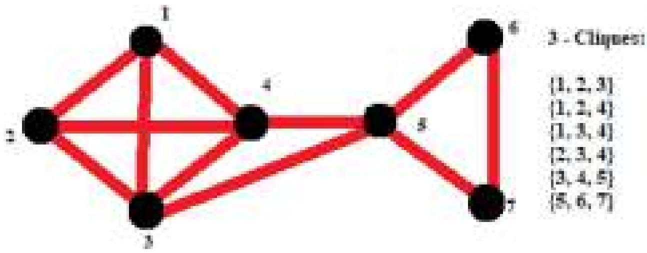


Figure 2. 3-cliques obtained over a hypothetical network.

3.4.1. Communities

Communities in a social network might represent related real social groupings, perhaps by interest or background; communities in a metabolic network might represent cycles and other functional groupings; communities on the web might represent pages on related topics and communities in the landscape may reflect regions with structural and functional similarities with respect to some focal species. (Girvan and Newman 2002; Doreian and Conti 2012; Kuikka 2021). Being able to identify these communities could help us to understand and exploit these networks more effectively. In the tiger corridor network, communities represent sets of habitat patches, their associated links and the region enclosed by their links that are related by some similar features (Shanu et al. 2019). Identifying and studying such communities could prove to be instrumental in further deepening our understanding of specie's behaviour and their travel patterns. Furthermore, detecting community aids in identifying the critical vertices in the tiger corridor network needed to maintain landscape continuity.

3.4.2. Overlapping communities

A network is said to have communities if its vertices can be easily grouped into (potentially overlapping in the case of overlapping communities) sets of vertices, each of which is tightly connected internally (Palla et al. 2005). The communities overlap when there are several communities formed in a network and all of these communities are connected to each other because they share some or all of the vertices (Bordenave et al. 2018).Although the mathematical definition of a community is not fixed but only largely agreed upon in the scholarship, we shall define below the motion of overlapping communities fore use in this paper.

Definition: Let G be a graph with n-communities $\{C_1, C_2, C_3, \ldots, C_n\}$, if $C_i \cap C_j \neq \{\} \; \forall \; i, j \in \{1, 2, 3, \ldots, n\}$, then all the communities are said to be overlapping communities in the graph.

The detection of overlapping communities is required for the study in this research because it aids in the identification of crucial vertices or habitat patches that are important for maintaining landscape contiguity for tiger migrations (Shanu et al. 2019) as well as interaction in the tiger corridor.

We use a PC for analysis of the tiger corridor network. We shall use the CPM based on PC for detecting the overlapping communities in the network.

Centrality measures were first introduced as a basic concept of social network research (Bayleas, 1948; Bayleas, 1950). Since then, their reach has greatly expanded, and their widespread application to ecological networks has proved to be very fruitful (Cantwell and Forman 1993; Chetkiewicz et al. 2006). As mentioned in the following description of a structural index, the outcome of a centrality measure, determined by the network's structure:

3.4.3. Structural index

Let $\Gamma_1\left(V(\Gamma_1), E(\Gamma_1), \ \Psi_{\Gamma_1}\right)$ be a graph and let X represent the set of vertices or edges of Γ_1. Then, $s : X \rightarrow \ \mathbb{R}$ is called a structural index if and only if the following condition is satisfied: $\forall x \in X : G =^{\sim} H \Longrightarrow s_{\Gamma_1}(x) = s_{\Gamma_2}(\phi(x))$, where $\phi : V(\Gamma_1) \rightarrow V(\Gamma_2)$ is an isomorphism, and $s_{\Gamma_1}(x)$ denotes the value of $s(x)$ in Γ_1.

Minimally, a centrality measure c is required to be a structural index and therefore, induces at least a semi-order on the set of vertices or edges of the network in consideration. Thereby, we say $x \in X$ is at least as central as $y \in X$ if $c(x) \geq c(y)$.

In order to define the key vertices responsible for community identification, we define a simple combinatorial measure, the PC of vertex as defined below.

3.4.5. Participatory centrality (PC)

The number of cliques to which a vertex v can belong is defined as the Participatory centrality of the vertex v. for a graph G where n *number of* $k-$*cliques* are formed, the Participatory centrality of a vertex v is given by,

$$PC(v) = \ \sum \alpha_{cb}(v)$$

where $\alpha_{cb}(v)$ is the number of cliques that have v as a vertex.

The guiding logic for PC is that vertices which belong to more than one clique may represent having multiple alternative ways and resources to reach goals and thus be relatively advantaged, thereby making such vertices more important (Gupta et al. 2016; Ghalmane et al. 2019).

In the current network, high participation of a vertex (habitat patch) indicates a higher number of landscape elements incident to it, thereby implying a higher rate of species traffic through the vertex. Therefore, the conservation of vertices with a high PC is essential in our case, as any compromise on such vertices directly affects a large number of species, which rely on the higher number of pathways incident to it, for their movement.

3.5. Clique percolation method (CPM)

Definition: The $k-$*clique* community is the union of all connected $k-$*clique* (Fortunato 2010; Tóth et al. 2013).

For detecting overlapping communities in our network, we use the CPM, based on internal community links that are likely to form clique as well as intercommunity links that are unlikely to form clique.

The CPM detects overlapping communities in the simplicial complex. If any vertex in the simplicial complex belongs to more than one community, overlapping communities are possible (Fortunato 2010; Wang et al. 2015). We consider a parameter k and a given network as inputs in the CPM. In the given network, all cliques of size k are detected, and a clique graph is generated. The clique graph is created by connecting the cliques that have *(k-1)* vertices in common and putting all of the cliques as vertices. The union of each linked clique in the clique graph forms a community. The communities obtained for the hypothetical network of Figure 2 is shown in Figure 3.

4. Methodology and modelling

To begin, we used the HSI to model the focal landscape in order to identify the most important sites that could serve as potential habitats for tigers in Protected Areas (PAs)

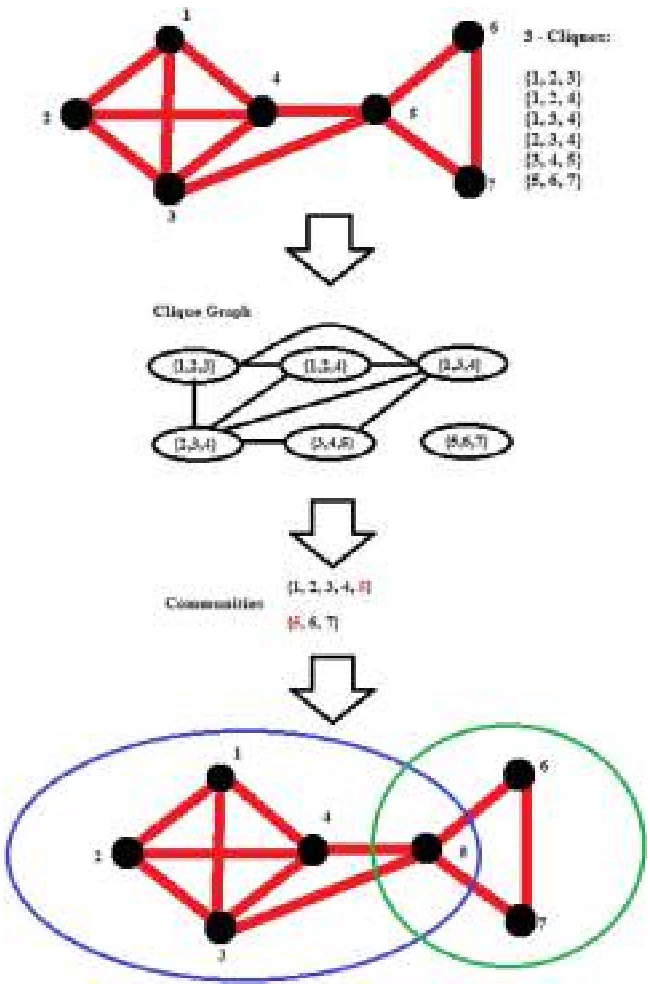


Figure 3. Community detection using the CPM on the hypothetical landscape by obtaining the 3-cliques.

as well as territorial tigers in the corridors. Secondly, we developed upon the algorithm and propositions to obtain an overlapping community in the tiger corridor network.

4.1. Habitat suitability index (HSI)

The HSI is focused on the assessment of species-specific parameters as well as the suitability of key habitats (Tirpak et al. 2009). In the Terai-arc landscape complex, factors related to tiger distribution and abundance of its prey species were taken into account using data from various field surveys, expert research, and literatures as input data for HSI modelling. The HSI model identifies spatially the HSI for Tiger and its prey species viz. Sambar deer (*Cervus unicolar*), spotted deer (*Axis axis*), Barking deer (*Muntiacus muntjak*), Wild boar (*Sus scrofa*), Blue bull (*Boselaphus tragocamelus*).

Information on potential factors affecting species habitat, as well as their topographical dispersion, is essential for constructing HSI and delivering important planning yields (Duflot et al. 2018). Based on previous habitat evaluations, vegetation type, forest density, slope, aspect, distance from water, and distance from anthropogenic disturbances were chosen as critical criteria for tiger habitat suitability and prey suitability. We determined priority values for these eight environmental variables based on their ecological significance for the species within each layer for each class.

The modelling framework incorporates different spatial datasets from remote sensing and ancillary sources along with field information and assesses them for tiger habitat suitability utilizing multi-criteria approach. The weights of different factors were computed using the above analysis and linear additive equation. The pairwise comparison matrices are shown in Appendix A.

4.2. Habitat suitability map of tiger

The habitat suitability map for Tiger includes the suitability layer of their prey. For each variable, an output map was created with four levels of suitability: very highly suitable, highly suitable, moderately suitable, and least suitable. Each variable was given a weighing dependent on the importance of the prey. To create the habitat suitability diagram, all of the output layers were overlaid. The weights were established using the pair wise comparison, and the linear additive equation was determined as follows:

$$HSI = (Sambar*0.43) + (0.30*Chital) + (0.17*Barking\ \ Deer) + (0.07*Wild\ \ boar) + (0.03*blue\ \ bull)$$

It has been ensured that the dependent variables for the individual habitat suitability index of the prey do not have any functional relationship with each other to avoid statistical collinearity among the input variables.

4.3. Corridor network modelling and community detection

In continuation to the above discussion, a model is developed that detects communities in the corridor network built using the HSI model. The process also includes detecting possible habitat patches once the Habitat Suitability Index has been measured. Protected Areas (PAs) and the potential habitat patches serve as vertices *(P)* in the tiger corridor network. The interaction between these habitats act as the links *(E)*, and the availability of Habitat Suitability conditions in the landscape acts as the algorithm *(A)* for determining vertex interaction in the network.

We expect to do so because tigers are specialist animals (Walsh et al. 2011), and landscape contiguity at a regional level, which is represented as a polygon on the landscape matrix, allows them to migrate from one habitat patch to the next (Minor and Urban 2007; 2008; Wang et al. 2014; Flowers et al. 2020). When corridors are described solely in terms of connecting vertices through paths, which are expressed as lines on the landscape matrix, tiger's movement is restricted on simulations that may or may not be accurate. A region-based interaction between vertices, in addition to the above discussion, will help decide communities created by the vertices, so that those within the community can communicate with each other more frequently, compared to those outside the community.

To achieve the aforementioned goal, we first identify the cliques in the network by examining the adjacency matrices obtained from the vertices (that is, protected areas and potential habitat patches) of the tiger corridor network and the connections between them. The cliques have been obtained while discussing the environment and habitat patches in the landscape because they help to provide an overall linkage in the network (Erős and Lowe 2019). The movement of tigers in the landscape is unrestricted in the absence of anthropogenic disturbances, but it is restricted in the presence of a high level of anthropogenic disturbances and a varied level of biotic help. Cliques, as complete subgraphs, aid in the identification of key adjacencies in the corridor network that can handle these constraints, as well as ties to remote habitat patches. The comprehensive algorithm for identifying network cliques for this work is defined and presented as:

```
1   Algorithm 1: Clique_from_Network
2   //input: Network N
3   //output: Cliques in the network
4   DECLARATION SECTION
5   x, y, e, t, a, p, n, k as integer
6   V, L, R as set of nodes
7   PROCEDURE SECTION
8       for k = 2 to n
      Empty R
9         n = no. of nodes in the Network
10        for x = 1 to n
11            insert x in V        // Each node for which we begin to see all the
                  cliques it belongs to are inserted in V
12            for y = 1 to n
13              e = adj(x, y)        // adj(x, y) can be check from the Adjacency
                  Matrix obtained for the network
14              if e = 1 then
15                V = V U {y}
16                if |V| = k then
17                  Goto Line 21        // To check for the cliques using all
                  links of x
18                end if
19              end if
20            end for
21            Check_Clique (x, V-{x}, k)
22            Empty V        // to restart the process with a different node
23          end for
24          if |R| != k, Stop        // to check the maximum clique that can be
                  obtained in the network and then stop.
25        end for
26  RESULT SECTION
27        k - Cliques obtained
28  Function Check_Clique (a, L, p)
29        n = |L|
30        Insert a in R
31        for t = 0 to n-1
32          if adj (L(t), L(t + 1)) = 1 then
33            R = R U { L(t), L(t + 1) }
34            if |R| = p then
35              Goto 39
36            end if
37            L = L - L(t)
38        End if
39        Record R
```

```
          Update R id          //id updated to store new set of sets.
          Check_Clique (a, L, p)
    Output: Set R that is a set of all p-cliques in the network.
```

We use the CPM over the results of the designed algorithm to detect overlapping communities. Overlapping communities are one of the most important aspects of this work, since the key issue, the work focuses on is maintaining landscape contiguity (Guidance on the maintenance of landscape connectivity features of major importance for wild flora and fauna 2007). We classify overlapping communities in order to identify related habitat patches and the gradient of landscape features as a tiger moves from one community area to the next. This is useful for preparing and strategizing conservation plans because it can help distinguish movement trends in different spatiotemporal domains. The algorithm to classify overlapping communities uses clique graphs. A detailed algorithm for recognizing overlapping communities in a simplicial complex is defined and presented as:

```
Algorithm 2: Clique_Percolation
//input: output obtained from the Algorithm 1 i.e., set R.
//output: Overlapping Communities in the network
DECLARATION SECTION
k, n, m, I, q, j as integer
R, A, V', E', Comm as sets
PROCEDURE SECTION
        for k = 2 to n
    m = |R[k]|
          for i = 1 to m-1
             A[k] = R[k] (i-1) ∩ R[k] (i)
             if |A(k)| = k-1 then
                V' = V' □ {R[k] (i-1), R[k] (i)}          // each set of node
                  becomes a set of vertex
                E' = E (R[k] (i-1), R[k] (i))          // each edge obtained between
                  set of vertices
             end if
          end for
       end for
       Construct Clique Graph G = (V', E')          // update graph ID from
                 New clique
       B = Adjacency matrix of Clique Graph
       q = |V'|
       for i = 1 to q
          for j = 1 to q
             if adj(i, j)= 1 then
                Comm = Comm □ {i, j}
             end if
          end for
       end for
       Publish Comm          // updation for new cliques
       clear V', E', Comm.
 RESULT SECTION
       Set of Overlapping Communities.
```

5. Result

A few steps were taken in this work in order to build a viable tiger corridor network, and the results gained using these processes are explained in this section. The relationships between habitat patches that are favorable for tiger populations were first discovered and then modelled. As shown in Table 3, the modelling produced a graph H with 18 vertices in the landscape, as well as 27 linkages between these vertices that defined the interaction between the vertices. Next, the cliques in H were computed using algorithm 1, yielding 10 3-cliques in the tiger corridor network as shown in Table 4. The discovery of these cliques revealed that when tigers travel from one habitat patch to another, various regions can be used to detect their presence. Different cliques are also interconnected, extending the range of tiger movement even further. The application of PC is used to acquire the connections of different cliques as well as the essential vertices required for these connections, as shown in Table 5. The linkage of various cliques and the migration of tigers through several cliques demonstrate the existence of communities of habitat patches in the landscape matrix. The habitat patches in the same community have some structural and functional characteristics in common, but they are distinct from those in other communities. The communities in the network have been derived using a clique graph with all 3-cliques as vertices and the existence of an edge if at least two vertices are common between two cliques, as shown in Table 6. The data in Table 6 were evaluated, and it was determined that every community in the network had at least one common vertex with every other community, resulting in overlapping communities. On the tiger corridor network, the CPM described in algorithm 2 was used, and overlapping communities were discovered. The HSI of the tiger was used to make all of the decisions, including the suitability of two habitat patches to enable the interaction between these habitat patches. In this section, the results from the various steps in the order in which they were received are discussed.

Forest cover, prey availability, distance to the water body and disturbances were the most important factors determining the habitat suitability for Tiger. The required input parameters were integrated to generate the habitat suitability maps in the study area. The satellite data was transformed into land use/land cover map using unsupervised classification as shown in the Figure 4. Table 1 shows the area covered by various vegetation types and a Land use Land cover (LULC) map. Forest canopy density map of study area was derived through NDVI and classified into different categories of tree crown cover, that is, Very high density (>60%), High density (40–60%), Medium density (20–40%), Low density (10–20%) is shown in the Figure 5.

As suggested above, tiger presence is primarily determined by the availability of adequate prey (Jordan et al. 2006). As a result, habitat suitability models for each of the prey species were obtained, and a composite tiger model was developed based on prey species. The HSI for the dominant prey species was modelled in the study area using the linear additive model, and Habitat Suitability maps were obtained, as shown in Figure 6. The ecological information on the distribution of prey species and their abundance regions is obtained by pairwise comparison for assigning weightage-using AHP to derive the habitat suitability maps in Figure 6. Table 2 summarizes the area that is suitable for the various prey species in the landscape.

The habitat suitability map of the tiger was created based on prey base distribution and anthropogenic influences (Figure 7). Around 3198 km^2 was estimated to be very suitable for Tigers in the study area. The total highly suitable areas was estimated to be 4697.96 km^2. The areas of reasonably suitable habitats was around 3593.42 km^2, while the least suitable habitats, located in settlements and agricultural fields, totaled 10450.41 km^2.

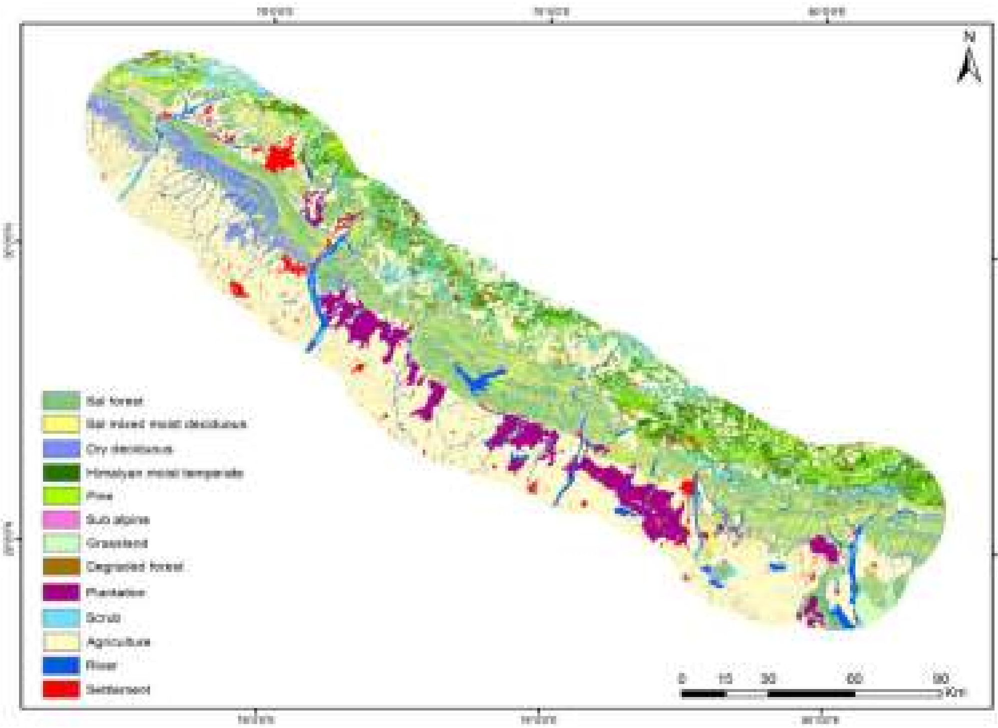


Figure 4. Land use Land cover Map.

Table 1. Percentage of different forest cover and LULC types.

Sl. no	Cover types	Percentage
1	Agriculture	39.8
2	Sal Forest	14.5
3	Sal Mixed Moist Deciduous	10.5
4	Scrub	6.04
5	Pine	5.87
6	Plantation	5.29
7	Himalayan Moist Temperate	5.01
8	River	4.60
9	Dry Deciduous Forest	4.20
10	Settlement	2.05
11	Degrade Forest	1.67
12	Grassland	0.50
13	Sub Alpine Forest	0.01
Total		**100.0**

We expected to detect communities between the regions identified by the tiger's Habitat Suitability map as a major aim of this research. The result obtained in (Figure 7) is evaluated using data mining techniques (Han 2021) to derive the association between suitable habitats and Habitat Patches, and a set of 18 nodes, as shown in Figure 8, is obtained. These newly discovered nodes have the potential to help viable tiger habitats as well as serve as connectors between different habitat patches, allowing tigers to travel freely between them.

Based on the HSI computations, the potential habitat patches identified in the landscape include both protected areas and other vegetated areas that may serve as potential habitat patches. In order for tigers to migrate in the region, there must be continuity in

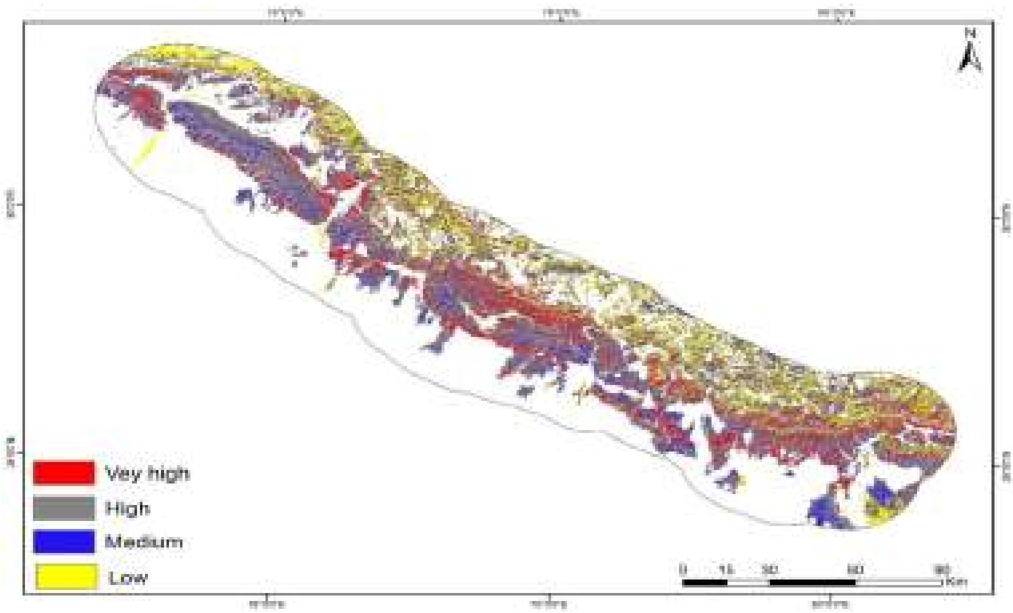


Figure 5. Forest density map.

the landscape (Taylor et al. 1993; Shanu et al. 2019). Various biotic and abiotic parameters that have been considered in the HSI model contribute to the conservation and management of this contiguity. Literature suggests that tiger's awareness of movement is dependent on the best survival conditions (Smith et al. 1997; Singh et al. 2009). As a result, a region within the landscape matrix must be marked to facilitate tiger movement, thereby indicating high-sensitivity conservation zones.

We compute the potential cliques in the landscape by operating on the network shown in Figure 9, which is obtained by the suitability index of various landscape matrix components, in order to obtain the polygons or overlapping communities within the landscape matrix.

Corridors are important elements in managing tiger movements and, as a result, conservation. The suitability values computed via HSI are used to determine the adjacencies between the vertices in the tiger corridor network. By displaying the suitability of landscape between the two vertices, these values demonstrate where the smooth interaction, that is, movement of tigers, exists. Table 3 shows the Adjacency matrix in the landscape constructed between the nodes from the obtained network shown in Figure 9.

We use the Algorithm 1 described in the section on Modelling Approach to find the cliques in the network. Table 4 shows the results of the established cliques along with the comments. In the tiger corridor network, the cliques reflect complete mutuality. The complete mutuality is significant because it provided the context for defining the PC of the vertices and, as a result, the value of maintaining landscape contiguity.

PC is performed on the network using ten 3-cliques to classify potentially significant patches. Table 5 shows the vertices (habitat patches) ranked (highest to lowest) by PC ranking, highlighting the importance of habitat patches in conjunction with the vertices needed for forming the communities.

We use the Algorithm 2 described in the section on Modelling Approach to find the clique graphs and the overlapping communities in the network. Table 6 shows the results of the clique graphs and the overlapping communities along with the comments.

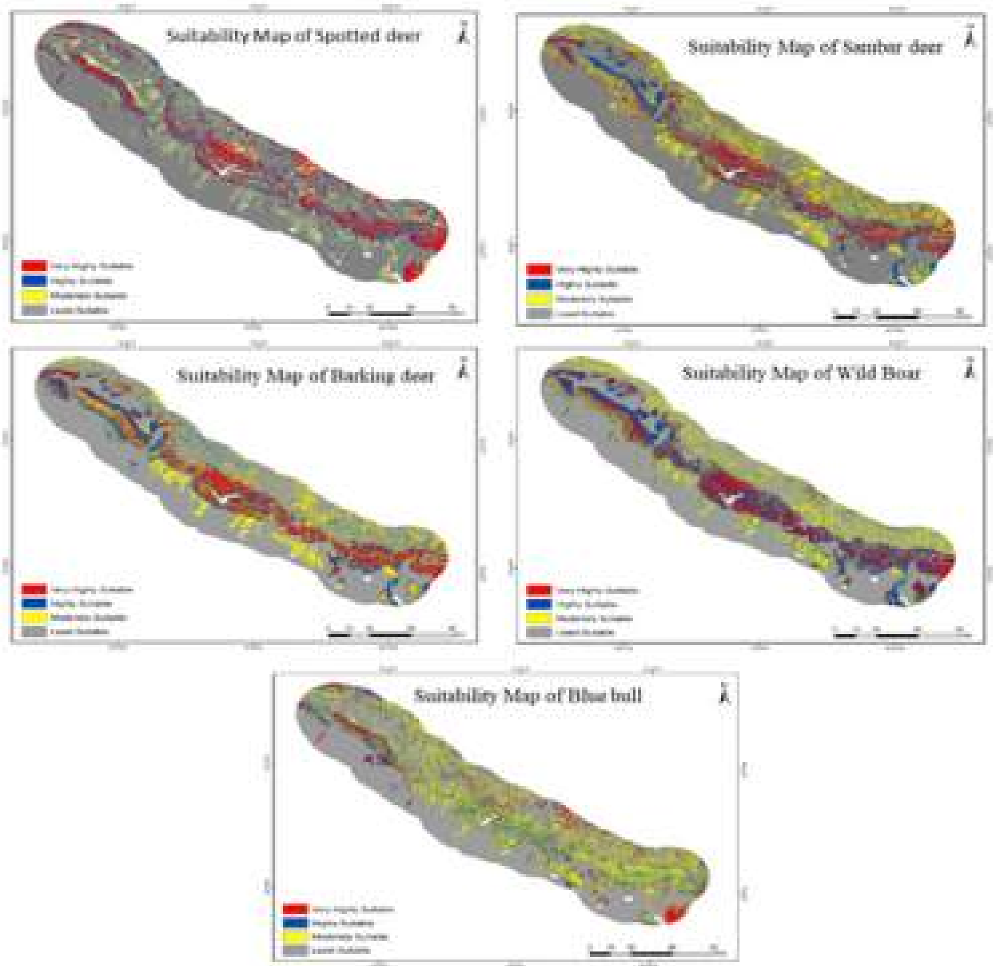


Figure 6. Habitat suitability map of prey species (See Appendix A).

Table 2. Habitat suitability status of Prey species (Area in sq. km).

Sl. no.	Suitability classes	Spotted Deer	Sambar	Barking Deer	Wild Boar	Blue Bull
1	Very Highly suitable	2715.96	1974.3	2162.30	2191.59	1229.40
2	Highly Suitable	4559.56	3862.75	3571.41	4489.76	3681.47
3	Moderately suitable	3542.39	3728.85	3325.21	3187.88	4409.039
4	Least Suitable	11122.69	12374.71	12881.69	12071.38	12620.7
Total area		21940.61	21940.61	21940.61	21940.61	21940.61

The colored (other than black) elements in the "Communities" column of Table 6, shows the essential vertices responsible for community overlap. It is essential to note that in two different communities C_1 & C_2 if $C_1 \cap C_2 \neq \{\}$, then the element of intersection between C_1 & C_2 is shown with same color. For example, within 2 different communities $\{1, 2, 3\}$ and $\{3, 4, 5\}$, the common element *"3"* is shown with red color.

When the landscape level matrix is evaluated, the results obtained in Table 6 are shown in Figure 10 and indicate that there are seven major communities. The results

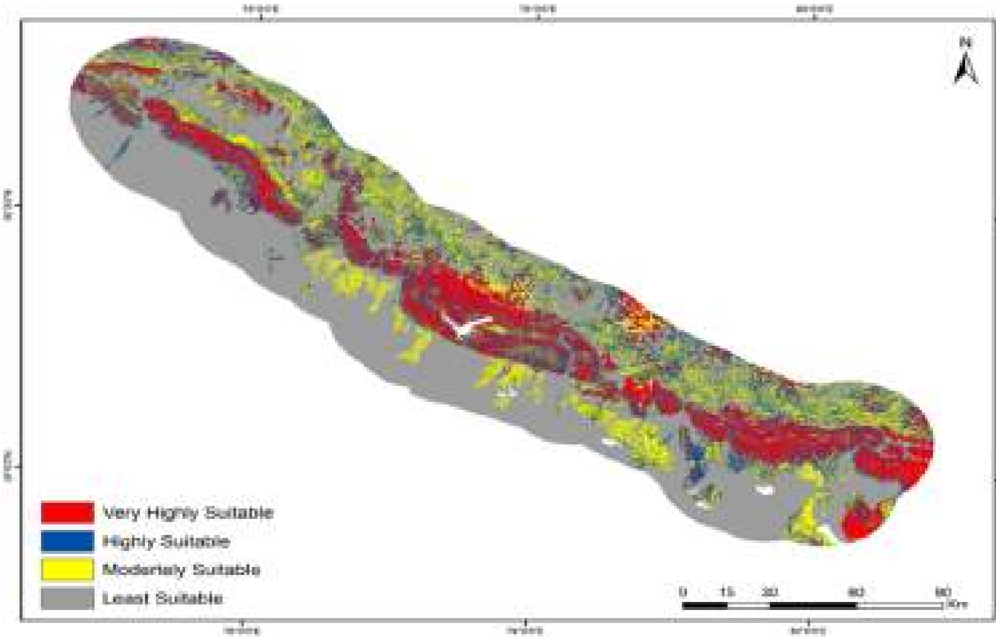


Figure 7. Habitat suitability map of tiger.

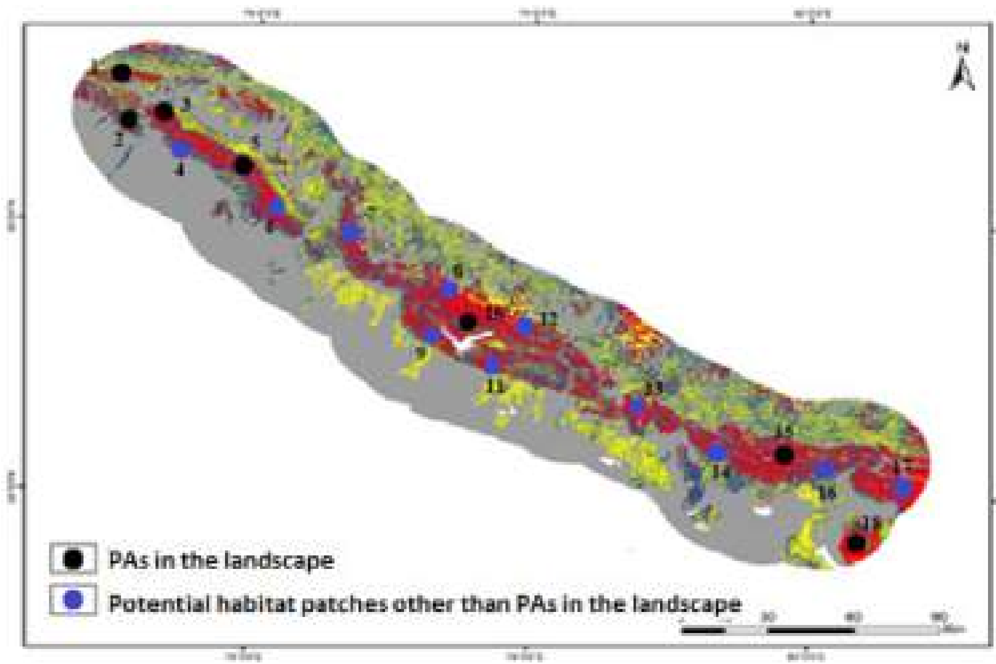


Figure 8. Tiger Habitat Suitability Map showing the landscape habitat patches that could support a viable tiger population.

obtained from the model also suggests that there are a few key habitat patches that lie at the confluence of two distinct communities and play an important role in preserving landscape continuity as well as overlapping community features.

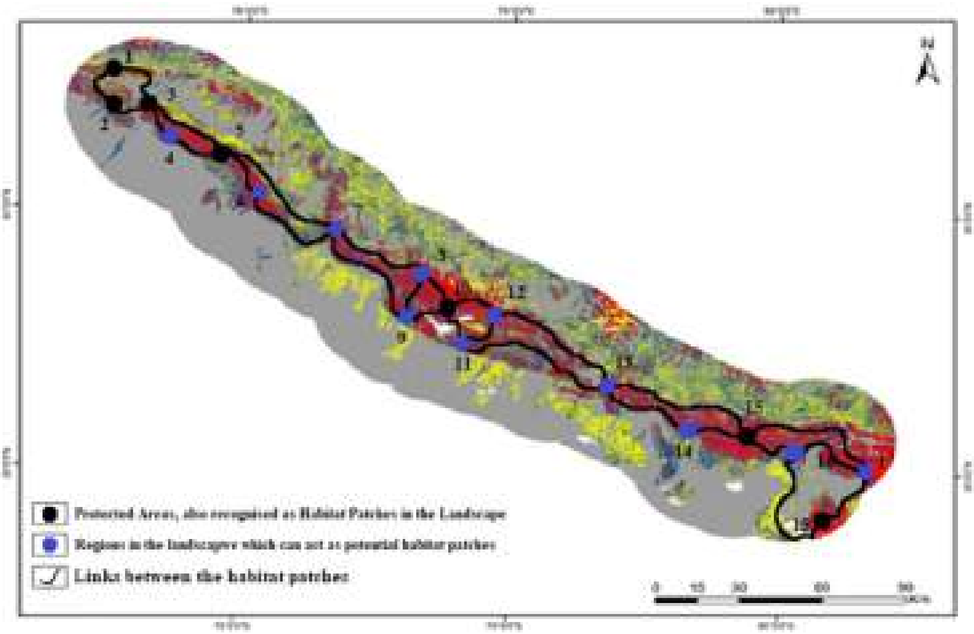


Figure 9. Network obtained in the focal landscape, working with the nodes found in Figure 8 and using the same HSI model to detect connectivity between these identified habitat patches.

Table 3. Adjacency matrix with respect to the identified habitat patches in the tiger corridor network in Terrai Arc Landscape.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1	1															
2			1															
3				1	1													
4					1													
5						1	1											
6							1											
7								1	1									
8									1	1								
9										1								
10											1	1						
11												1	1					
12													1					
13														1	1			
14															1			
15																1	1	
16																	1	1
17																		1
18																		

6. Discussion

Tiger corridors are natural features of the landscape that allow tigers to migrate from one habitat patch to another. According to several models created in the past, using various algorithms, the wildlife corridor must be optimal in both structural and functional connectivity. The findings of this study, based on the cliques, imply that a corridor does not need to be ideal, but rather connect habitat patches in a landscape complex, taking into account all structural and functional characteristics of habitat suitability for tiger

Table 4. The cliques obtained from the Tiger Corridor Network using Algorithm 1.

N	Clique of size n	Remarks
2	{1,2}, {1,3}, {2,3}, {3,4}, {3,5}, {4,5}, {5,6}, {5,7}, {6,7}, {7,8}, {7,9}, {8,9}, {8,10}, {9,10}, {10,11}, {10,12}, {11,12}, {11,13}, {12,13}, {13,14}, {13,15}, {14,15}, {15,16}, {15,17}, {16,17}, {16,18}, {17,18}	The 2-Cliques denote the connection between the nodes, which can be a landscape field.
3	{1,2,3}, {3,4,5}, {5,6,7}, {7,8,9}, {8,9,10}, {10,11,12},{11,12,13}, {13,14,15}, {15,16,17}, {16,17,18}	The 3-Cliques represent the interaction of three nodes within a defined area.
4	{}	Since there are no 4 Cliques, the algorithm comes to a halt here.

Table 5. Ranking of tiger habitats by PC over the 3-cliques.

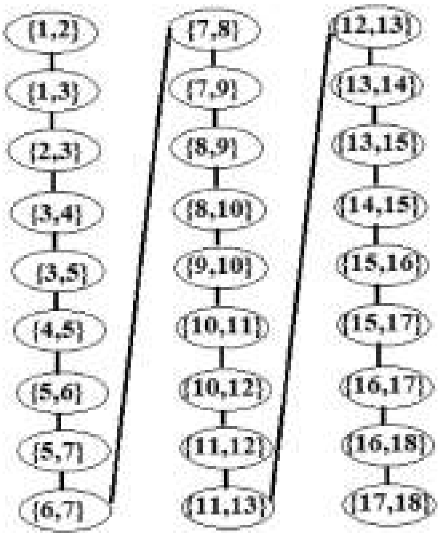
Vertex	PC	Rank
1	1	2
2	1	2
3	2	1
4	1	2
5	2	1
6	1	2
7	2	1
8	2	1
9	2	1
10	2	1
11	2	1
12	2	1
13	2	1
14	1	2
15	2	1
16	2	1
17	2	1
18	1	2

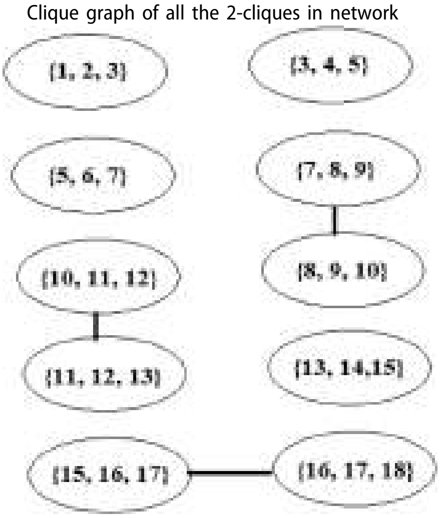
movement. The results of algorithm 1 also show that there can be loops between the vertices of a landscape, which deviates from the tiger corridor criteria provided in (Shanu et al. 2019).

One of the most important factors in supporting tiger movement in a landscape is the landscape contiguity. Tigers, being specialist animals, require a contiguous path for movement that meets all of their requirements for survival and mitigation (Jhala et al. 2020). Thus, in order to develop and construct tiger corridor networks, it is necessary to first identify landscape contiguity. Contiguity in the landscape has been detected using the concept of overlapping communities. The model proposed in this research uses algorithm 2 to identify the critical overlapping communities in the tiger corridor network produced using CPM. The network's overlapping communities are extracted from habitat patches both inside and outside of the PAs. The overlapping communities demonstrate the importance of a few vertices in maintaining the landscape's continuity, as well as how conservation strategies must be planned to encourage tiger movement.

Though tiger's conservation is emphasized in protected areas in their range countries, the species is known to frequent in forests and adjacent landscape with varying levels of protection (Rai et al. 2019). The Terai belt, which was once forested, is now mostly agricultural, with wildlife limited to remnant forest patches (Chanchani et al. 2014). Analysis of habitats for wildlife sustenance is being viewed as increasingly significant for the

Table 6. The clique graph and overlapping communities obtained using Algorithm 2.

<table>
<tr><th>n</th><th>Clique graph</th><th>Communities</th><th>Remark</th></tr>
<tr><td>2</td><td>

Clique graph of all the 2-cliques in network</td><td>{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,15, 16, 17, 18}</td><td>This demonstrates that the entire landscape is a single community, and that tigers are free to travel from one habitat patch to the next. The existence of 2-cliques and the community created by 2-cliques also implies that the entire landscape must be contiguous.</td></tr>
<tr><td>3</td><td>

Clique graph of all the 3-cliques in network</td><td>{1, 2, 3}
{3, 4, 5}
{5, 6, 7}
{7, 8, 9, 10}
{10, 11, 12, 13}
{13, 14, 15}
{15, 16, 17, 18}</td><td>When we increase our precision over the number of cliques, we see that there are seven main communities, which also reveals the landscape's mesoscale features. This also indicates the critical nodes needed to preserve landscape contiguity for Tiger movement.</td></tr>
</table>

planning and management of protected areas. The impacts of habitat loss and fragmentation, anthropogenically altered and influenced by landscape design are influence explicitly the size, shape and format of habitat fragments (Saunders et al. 1991). With increasing fragmentation and diminishing size of habitats, it has become important to develop spatial database on habitat quality, which is critical for habitat conservation. Geospatial modelling can significantly help in spatial modelling of Habitat suitability for faunal species, without detailed ground based information on their physiology and behavior. Habitat models extract the study of Ecological procedures, which are exceptionally complex and hard to predict whether it affects species abundance or distribution (Krebs, 1985; Reichert and Omlin 1997).

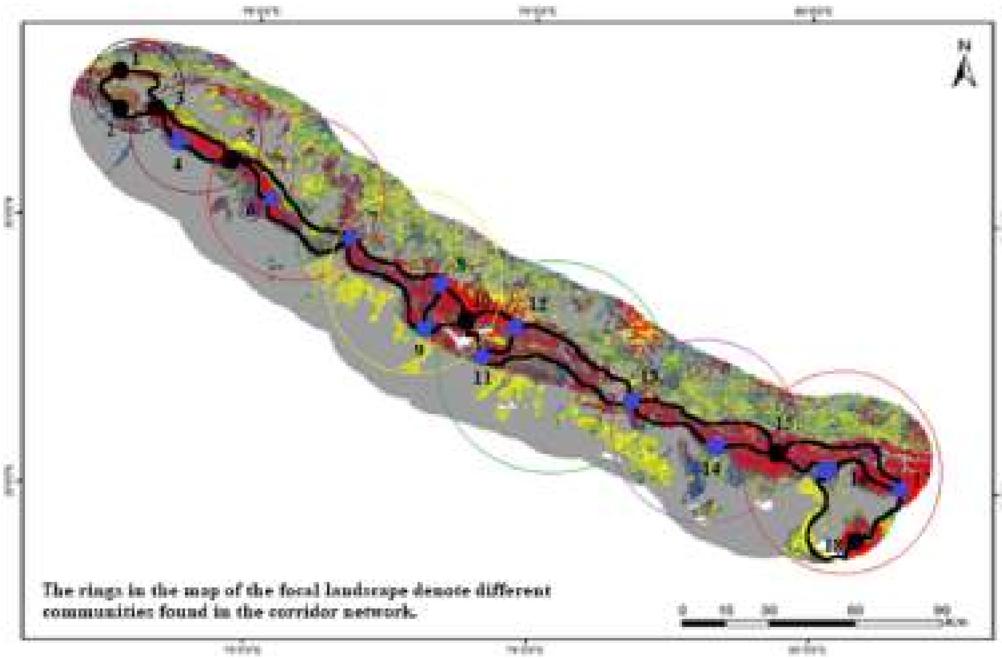


Figure 10. Landscape level communities detected in the Tiger Corridor Network.

The identification of LULC and vegetation types, shown in Table 1, Figures 4 and 5 was beneficial because it revealed the spatial regions that must be considered when considering tiger movements. As a result, a network based on habitat patches, links between habitat patches, and the enclosed area by the links provides a good assessment of the tiger corridors in the landscape. In addition, the HSI model and data clustering revealed a few habitat patches that are not protected areas but can serve as good landscape elements for tiger populations to thrive. These habitat patches have also been considered vertices in the landscape with the PAs.

The high rank vertices defined by PC reflect the essential vertices responsible for maintenance of interaction between the vertices and thus the community creation in the network. Table 5, which shows the rankings between the vertices, aids in defining the vertices that are critical for maintaining landscape contiguity with overlapping communities. The model is able to find the most important habitats as the vertices of the tiger corridor network with the support of HSI evaluated for tigers in the focal landscape.

Figure 10 depicts the landscape's schematic position of the described communities. The fact that all of the communities overlap on one or the other is a significant finding in Figure 10. The overlapping of communities is due to the sharing of just one vertex between the communities, as the highest clique contained in the work is a 3-clique. These mutual vertices are the key vertices or Critical habitat Patches, and they aid in preserving landscape contiguity to sustain tiger movement. As a result, both ecologically and in terms of landscape design, the preservation of these vertices is critical. These essential vertices are listed in Table 7 for the obtained tiger corridor network and landscape.

In order to confirm the accuracy of the model suggested in this study, a map of the Terai Arc landscape within the political boundaries of India was obtained from the Tiger Report 2018, released by the Government of India (Jhala et al. 2020). From camera trap-based capture-mark-recapture and variables of tiger signs, prey, and human disturbance,

Table 7. Essential vertices of overlapping communities and related information.

Vertex number	Vertex name	Protected area	Potential habitat
3	Kalesar National Park	Yes	Yes
5	Rajaji Tiger Reserve	Yes	Yes
7	Kortdwar Forest Division	No	Yes
10	Corbett Tiger Reserve	Yes	Yes
13	Haldwani Forest Division	No	Yes
15	Nandhaur Wildlife Sanctuary	Yes	Yes

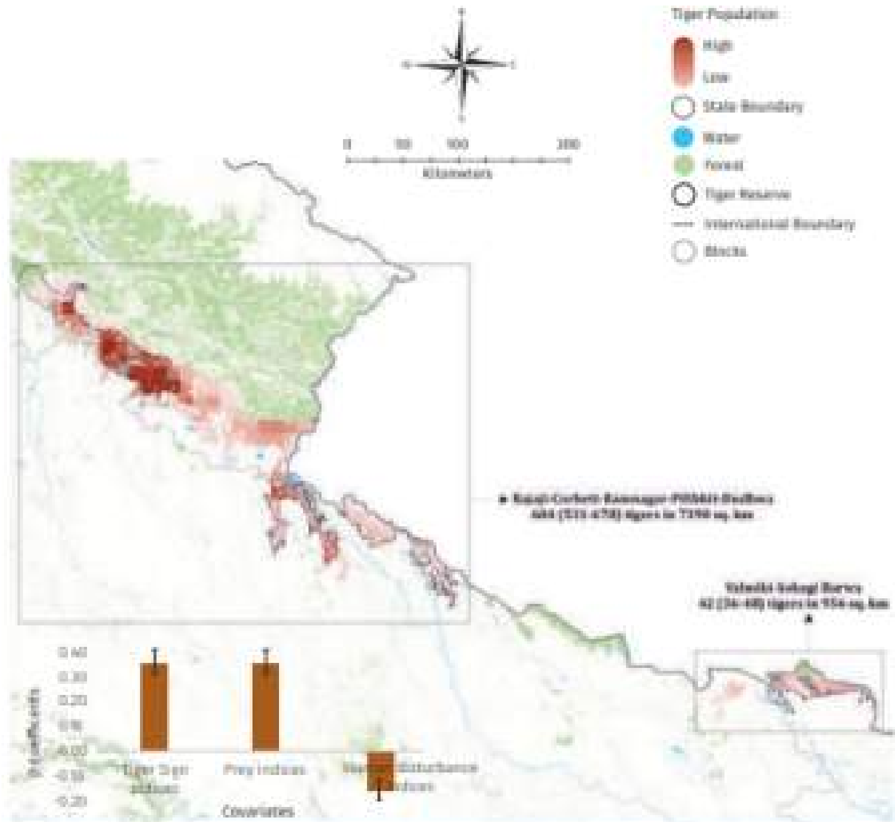


Figure 11. Map obtained from the Tiger Report 2018, highlighting the presence/absence of tigers in the focal region (Jhala et al. 2020).

the report proposes a spatially explicit tiger density model. The report includes a map of the focal region that illustrates the presence and absence of tiger population density, reproduced as Figure 11. This map was extracted and digitized with respect to the latitude and longitude of the focal region and was used as the reference benchmark to identify the accuracy of the suggested model in this study. Further, the image superimposition was used to place a set of grids on the extracted map as shown in Figure 12. As shown in Figure 13, similar grids were also placed on the corridor network map of Figure 9, which was obtained using our proposed model. After obtaining the images with grids, a matrix was created corresponding to each image, indicating the presence/absence of tiger population within each grid. The matrices obtained from the occupancy map of the report and that obtained from the result of the proposed model are shown respectively in Tables 8 and 9.

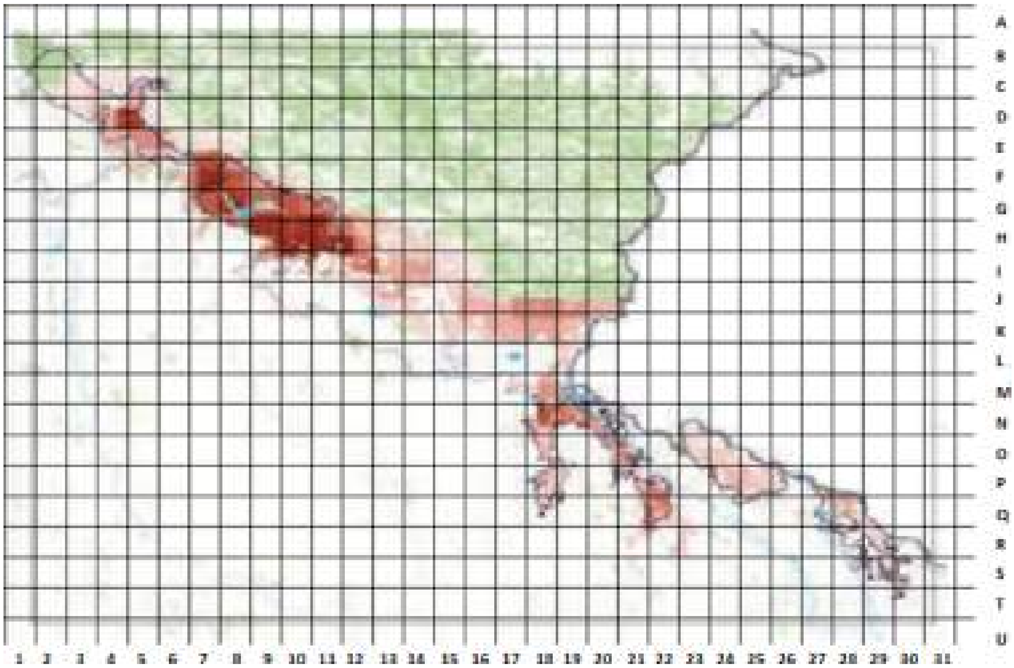


Figure 12. Set of grids overlaid on the focal region after digitizing from Figure 11.

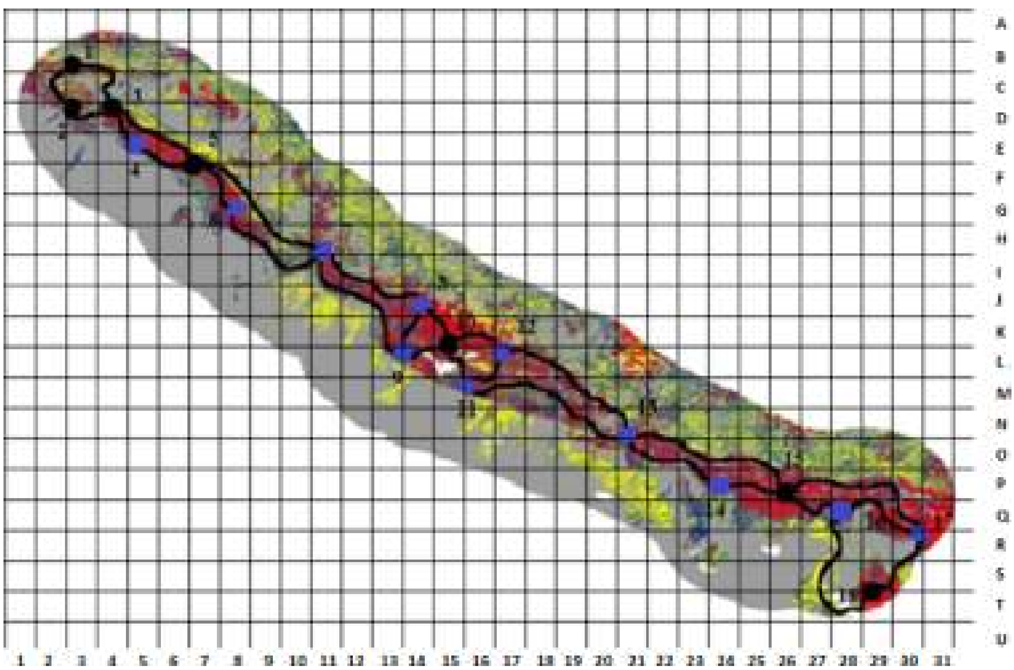


Figure 13. Set of grids overlaid on Results obtained through proposed model.

After obtaining the images and constructing the matrices for the aforementioned data, two distinct methodologies were adopted to determine the accuracy of the suggested model. The first approach was superimposing the two acquired images and determining

Table 8. Matrix O, constructed using Figure 12 where "1" shows presence of tiger and "0" shows absence of tiger.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	0	0	0	0	0	0																									
B	0	1	1	1	1	0																									
C	0	1	1	1	1	1	0																								
D	0	1	1	1	1	1	1	0	0																						
E	0	0	0	1	1	1	1	1	1	0	0																				
F			0	1	1	1	1	1	1	1	1	1	0	0	0																
G				0	0	1	1	1	1	1	1	1	1	1	0	0	0														
H						0	1	1	1	1	1	1	1	1	1	1	0														
I							0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0									
J									0	0	0	1	1	1	1	1	1	1	1	1	1	0									
K										0	0	0	1	1	1	1	1	1	1	1	0	0									
L											0	0	0	0	1	1	1	1	1	0	0	0									
M												0	0	0	0	0	1	1	1	1	0	0	0	0	0						
N													0	0	0	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0	0
O														0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0
P															0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Q																0	0	1	1	0	1	1	0	1	1	0	1	1	1	0	0
R																	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0
S																		0	0	0	0	0	0	0	0	0	0	1	1	1	0
T																			0	0	0	0	0	0	0	0	1	1	1	1	0
U																															

Table 9. Matrix E, constructed using Figure 13 where "1" shows presence of tiger and "0" shows absence of tiger.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	0	0	0	0	0	0																									
B	0	1	1	1	1	0																									
C	0	1	1	1	0	1	0																								
D	0	1	1	1	1	1	1	0	0																						
E	0	0	0	1	1	1	1	1	0	0	0																				
F			0	1	1	1	1	1	1	1	1	1	0	0	0																
G				0	0	0	0	1	1	1	1	1	0	0	0	0	0														
H						0	0	1	1	1	1	1	1	1	1	0	0														
I							0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0									
J									0	0	1	1	1	1	1	1	1	1	1	1	0	0									
K										0	0	0	1	1	1	1	1	1	1	1	0	0									
L											0	0	1	1	1	1	1	1	1	1	0	0									
M												0	0	0	1	1	1	1	1	1	1	0	0	0	0						
N													0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
O														0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0
P															0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0
Q																0	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0
R																	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0
S																		0	0	0	0	0	0	0	0	0	1	1	1	1	0
T																			0	0	0	0	0	0	0	0	1	1	1	1	0
U																															

accuracy by pixel overlaps (Scott and Ritchie 2006), as shown in Figure 14. The second method involved determining the difference between the observed (O) and the expected (E) matrices constructed using grid overlaps and then calculating the percentage of accuracy (Wang and Chen 2018). The grid overlaps between O and E matrices are as shown in Table 10 performed using this method. It was observed that 24 grids out of a total of 259 do not match between the matrices, as shown in Table 10. This implies that the proposed model is 90.73% accurate.

7. Conclusion

Complimentary to the existing methods of tiger corridor designing, the method proposed in this work by combining GIS and remote sensing with network analysis allows us to

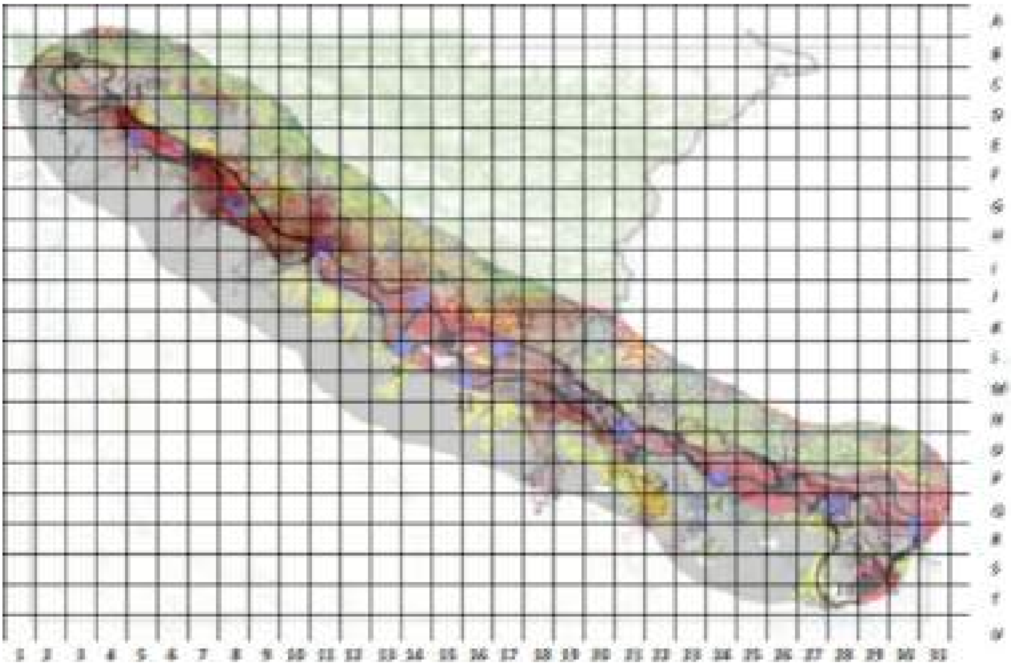


Figure 14. Superimposition of images to obtain the accuracy proposing 85.06% overlap.

Table 10. Difference between observed and expected Matrices (O-E), where "1" in the grids denotes that there exists a difference between the report map and the map obtained through proposed model.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A																															
B																															
C					1																										
D																															
E									1																						
F																															
G						1	1						1	1																	
H							1									1															
I																	1														
J											1										1										
K																															
L													1	1						1											
M															1	1					1										
N																						1									
O																															
P																				1									1	1	
Q																		1								1				1	
R																															
S																											1				
T																															
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integrate various spatial information and develop a spatial understanding of the problem (Cantwell and Forman 1993; Gastner and Newman 2006; Wang et al. 2008). In this study, the habitat patches include not only the PAs of the landscape but also areas adjacent to them having the potential to hold tiger populations. The application of CPM helps us yield the overlapping communities in the landscape obtained by tiger corridor network formed via HSI, which is a key finding of this work as shown in Table 7. Overlapping communities of habitat patches in the landscape allow maintain a landscape contiguity of populations.

The tiger habitat suitability map shows that most of the Terai arc landscape contains potential tiger habitats, and the geophysical characters of the landscape serve as a foundation for establishing links between these patches, which have been computed as a corridor network, and communities in this work. Through the application of PC to the tiger corridor network in the focal landscape, eleven major habitat patches that are outside of the PAs have been identified as shown in Figure 8, which aid in the maintenance of interaction between the vertices as well as cliques and thus lead to the creation of important communities. In addition to the above, six most important habitat patches have been identified through overlapping communities in the landscape, all of which are critical to preserving the population contiguity in the landscape.

The model proposed in this work shows a high accuracy referenced against the latest tiger abundance report published by the Government of India in 2020. One of the major limitations of this study is that only binary interactions are considered while designing the corridor network in the landscape, although studying n-ary group interactions with multiple impacts for each interaction could serve more practical and improve the accuracy of the model. In the future, research along similar lines may be undertaken utilizing few essential components of Artificial Intelligence like the recurrent neural networks for computing, which would account for the complex interactions of higher orders.

The analysis presented in this work to obtain the corridor network model has the potential to be useful for identifying the critical tiger bearing components of a landscape of interest and for developing and identifying corridor networks for tiger dispersal within the landscape.

Disclosure statement

No potential conflict of interest was reported by the authors.

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