Spatial Zoning Design for Multi-Species Protected areas using Marxan and Hotspot analysis

By

Noor-ul-Ain

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Institute of Geographical Information Systems
School of Civil and Environmental Engineering
National University of Sciences and Technology
Islamabad, Pakistan

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Signature: ____________
Name of Supervisor: Dr Javed Iqbal
Date: 20-9-24

Dr. Javed Iqbal
Professor IGIS, SCEE, NUST
H-12, Islamabad

Signature (HOD): ____________
Date: 26-9-24

Dr. Muhammad Ali Tahir
HoD & Assoc. Prof. SCEE (IGIS)
NUST, H-12, Islamabad

Signature (Principal & Dean SCEE): ____________
Date: 27 SEP 2024

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

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DEDICATION

To

My Parents

ACKNOWLEDGEMENTS

All praises, obedience, and submission to ALMIGHTY ALLAH, the propitious, the benevolent and sovereign whose blessings and glory flourish my thoughts and thrive my ambitions. I have the only pearls of my eyes to admire the blessings of the compassionate and the omnipotent because the words are bound, knowledge is limited, and time is short to express His dignity. My special praise for Holy Prophet Muhammad (PBUH) who is forever a torch of knowledge for humanity.

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Noorulain

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ABSTRACT

Systematic conservation planning has become crucial for protecting biodiversity and sustaining ecosystem resilience in Alula, a Saudia Arabia County where distinctive habitats are threatened by urbanization and climate change. Despite the pressing need to safeguard biodiversity and ecosystem services, traditional conservation efforts frequently fail to optimize cost-effectiveness while addressing complex ecological and socioeconomic issues. Spatial zoning of terrestrial areas using Marxan approach provides a systematic, data-driven alternative that may overcome these constraints and improve conservation outcomes. This research aimed to use Marxan to identify biodiversity hotspots in Alula and create an effective network of protected areas for species conservation and ecological connection. This study employed ArcGIS for topographical analysis, followed by the Getis ord approach for hotspot analysis. Marxan is used to create a protected area network with conservation objectives of 30%, 50%, and 70% for species representation, respectively, together with a Boundary Length Modifier (BLM) to reduce fragmentation and Penalty Factors (SPF) to prioritize rare species. The findings showed that the 30% target allocated 55% of the area for human use, 39% for strict protection, and 5% for mixed-use; the 50% target resulted in 49% human use, 39% strict protection, and 12% mixed-use; and the 70% target assigned 23% for human use, 39% for strict protection, and 38% for mixed-use. The study found that, although a 50% conservation target efficiently met biodiversity objectives, larger targets, such as 70%, encountered difficulties in accomplishing habitat conservation in response to the complexity of objective defining and resource allocation. Future conservation initiatives should incorporate adaptive management approaches and the involvement of stakeholders to improve the efficacy and sustainability of spatial zoning and conservation assignments.

Chapter 1

INTRODUCTION

1.1.Background Information

Biodiversity conservation is crucial to the stability and well-being of the ecosystems on our planet. Maintaining the balance of nature depends heavily on biodiversity, which is the variety of living forms on Earth, including plants, animals, microbes, and their genetic composition. To maintain ecosystem resilience and their ability to provide basic services like clean water, air, and rich soil, conservation initiatives seek to safeguard and preserve this variety. Threats to natural habitats and human well-being are substantial because of biodiversity loss caused by overexploitation, pollution, habitat degradation, and climate change. We protect the complex web of life that provides billions of people with food security, healthcare, and a means of subsistence by preserving biodiversity. Protecting natural habitats, repairing damaged ecosystems, and encouraging sustainable fishing, forestry, and agriculture activities are all part of the effort to maintain biodiversity. The Convention on Biological Diversity is one of the major international accords and regulations that coordinates international efforts to address biodiversity loss. Another essential element of biodiversity protection is raising public awareness and educating the public, which helps people realize how important it is to preserve the natural environment. Local communities are empowered to actively participate in environmental preservation through community-based conservation projects Community-based conservation projects empower Local communities to actively participate in environmental preservation.

Furthermore, comprehension of the intricacies of ecosystems and the creation of successful conservation plans depends on scientific research and observation. Preserving biodiversity is more crucial than ever as we confront unheard-of environmental issues. By giving priority to the preservation of the many life forms on our planet, we help ensure a sustainable future for all living things. Since our combined activities impact the world, we live in, individuals, governments, and organizations have to protect biodiversity.

Reduced biodiversity is a worldwide severe problem that affects economies, ecosystems, and human welfare in a variety of ways. With species extinction happening at a pace of up to 1,000 times the normal background rate, biodiversity i.e. the variety of life on Earth, is disappearing at an alarming rate. Human actions such as habitat loss, pollution, overuse of resources, invasive species, and climate change are the main causes of this reduction. According to the 2020 Living Planet Report published by the World animal Fund, since 1970, the average reduction in animal populations worldwide has been 68%. Over 80% of terrestrial species live in forests, which are disappearing at a rate never seen before. Deforestation is thought to be responsible for the loss of 10 million hectares annually. With almost a third of all marine animals in danger of extinction and about 33% of reef-building corals facing extinction, marine ecosystems are likewise extremely threatened.

Human health and livelihoods are impacted directly and indirectly by biodiversity loss. For instance, food security is under risk due to the reduction of pollinators like bees and butterflies, since around 75% of world crops rely on animal pollination. Furthermore, ecosystems become less able to provide basic functions like disease prevention, climate management, and clean water and air access. Economic effects are also associated with biodiversity loss. According to estimates from the World Economic Forum, nature and its services generate $44 trillion in economic value or more than half of the global GDP. Ecosystems become less adaptable to environmental changes as biodiversity decreases, which raises the possibility of ecological collapse and the loss of ecosystem services that sustain human existence. The loss of biodiversity is being exacerbated by climate change, as altered precipitation patterns and rising temperatures are upsetting the survival of species and their ecosystems. Because coral reefs are extremely susceptible to temperature fluctuations, global warming has resulted in widespread coral bleaching and the global loss of many reefs.

International accords like the Convention on Biological Diversity, which strives to safeguard ecosystems and species, and the Sustainable Development Goals of the United Nations, which highlight the need to stop biodiversity loss, are two examples of efforts being made to prevent dwindling biodiversity. To halt or reverse biodiversity loss, conservation efforts, habitat restoration projects, and the creation of protected areas are crucial. Since little activities may add up to bigger conservation efforts, public awareness and involvement are also essential in tackling this issue. People may contribute to preserving biodiversity by cutting back on waste, encouraging environmentally friendly behaviors, and speaking out in favor of conservation. We must acknowledge the interdependence of all species on Earth and take coordinated action to save the natural environment as we confront the twin problems of declining biodiversity and climate change. The Marxan model is a popular conservation planning method that is intended to assist in the cost-effective identification and prioritization of places for preservation. Ian Ball and Hugh Possingham created Marxan in the early 2000s, and governments, NGOs, and scholars all around the globe utilize it as a standard instrument in the field of systematic conservation planning. It is highly regarded for its ability to balance economic concerns and biodiversity preservation, making it a useful model for conservation initiatives. To find groups of places, or "planning units," that satisfy conservation goals at the lowest feasible cost, Marxan uses a mathematical procedure. Usually, depicting species, habitats, or ecosystems that require conservation is used to determine these goals. Marxan theory allows for several cost definitions, such as the land's economic worth, the possibility of land-use conflict, or the opportunity cost of giving up alternative land uses. Marxan makes it possible to create conservation programs that are both practically and ecologically sound by including these expenses.

Marxan's capacity to find several solutions to a conservation issue as opposed to only one "best" answer is one of its main features. Because of this adaptability, conservation planners may investigate several situations and select the one that best fits their requirements and limitations. Marxan, for instance, can assist in identifying regions that are essential for safeguarding threatened species while reducing the impact on nearby residents or businesses. Because of this, the model is especially helpful in locations that frequently experience conflicts over land use, such as those with substantial natural resource extraction or high agricultural value.

One of Marxan's main advantages is how affordable it is. The model ensures that limited conservation resources are used as effectively as possible by concentrating on decreasing costs while reaching conservation aims. This is particularly crucial in underdeveloped nations or areas where money for conservation is scarce. To maximize the effect of available resources, Marxan can assist in prioritizing places that give the highest conservation value for the least amount of money.

Numerous case studies demonstrate how useful Marxan is for practical conservation planning. Marxan was used to create a network of protected areas in the Great Barrier Reef Marine Park that enhanced biodiversity preservation by more than 30% and lessened the impact on commercial fishing by more than 60%. Marxan also assisted in determining the most important sites to conserve the Cape Floristic Region, a hotspot for biodiversity, in South Africa with the least amount of agricultural land displacement. Another benefit of using Marxan is its flexibility to accommodate different sorts of data. It may incorporate geographical data on human activities, habitat types, and species distributions, enabling a thorough examination of conservation requirements and any conflicts. Because of this, it's an effective tool for spatially explicit conservation planning, in which the location of conservation efforts is just as crucial as the activities themselves. Marxan can also be applied in concert with other conservation strategies and instruments. For example, it may be used with stakeholder engagement procedures or decision support systems to guarantee that conservation strategies are socially and scientifically acceptable. In complex, multi-stakeholder contexts striking a balance between ecological, economic, and social goals is essential, this integration is especially beneficial. Marxan has limits even with its advantages. The quality and availability of the data determine how efficient the model is; in some areas, data on species distributions or habitat conditions may be limited or out-of-date. Furthermore, although Marxan can reduce expenses, it does not take into consideration all possible social or political issues, which call for the use of complementary tactics and stakeholder involvement. To sum up, the Marxan model is an effective and adaptable conservation planning tool providing a low-cost way to preserve biodiversity. Marxan contributes to the sustainability and effectiveness of conservation activities by weighing ecological objectives against economic factors. Its implementation in diverse global contexts has proven its capacity to provide noteworthy conservation achievements while mitigating adverse effects on human activities, rendering it a crucial tool in the worldwide endeavor to conserve biodiversity.

1.1. Literature Review

Biodiversity conservation is crucial to ensure the sustainability of natural resources. However, biodiversity is declining for several reasons, resulting in an unprecedented, increased extinction rate. The increase is primarily due to human activities. There is significant biological diversity in Saudi Arabia; 79 terrestrial mammals and 432 birds have been recorded yet (Alatawi, 2022). Wildlife conservation and the sustainability of natural habitats are important topics in Saudi Arabia due to the typically limited availability of resources in arid habitats. AlUla, a region with a unique natural environment and diverse ecosystems, has been a custodian of rich biodiversity and cultural heritage for centuries. However, human activities like droughts, overgrazing, wood cutting, and unorganized arid land cultivation have led to significant degradation in recent decades. Many studies are being carried out to conserve Species that are on the brink of extinction using systematic planning approaches especially zonation through Marxan. Some of them are listed below.

Delavenne et al., (2011) compared the results from two popular conservation-planning, decision-support programs, Marxan and Zonation. The objective of this study was to see if the software selection affects where priority areas are located. The findings were compared using biological and socioeconomic data from the eastern English Channel, and it was demonstrated that while the very wide range of habitat types and species evaluated gave great flexibility, the two software systems revealed similar groups of priority locations. Furthermore, the similarity grew as the spatial limitation increased, particularly when real-world cost data was used. The results showed that software selection is less important in conservation-planning assessments than the cost metric selection. The most suitable software program will, however, rely on the overall objectives of the MPA planning process, since Marxan typically delivered more efficient results while Zonation produced outcomes with higher connection.

Esfandeh et al., (2015) examined the principal advancements made in the field of systematic conservation planning in landscapes using Marxan software throughout 11 years beginning in 2005 and ending in 2015. Following a scan of numerous publications in this topic, the amount of previously published works is recognized and categorized. Most planning articles consider biophysical and socioeconomic information, demonstrating the critical role these data play in decision-making. It has also been shown that in recent years, systematic conversation planning using toolboxes based on optimization algorithms like Marxan has received increased attention. The results showed how frequently Marxan software is used for methodical conservation planning in landscapes, it can serve as a reference for scholars working in this area.

Nhancale and Smith (2011) worked on the concerns raised due to the software constraints by using a dataset from southern Africa and quantify the impact of modifying the size, form, and baseline of planning units on the conservation planning assessments' outcomes. They demonstrated that portfolios created with hexagonal planning units instead of square ones are more efficient and less fragmented, whereas portfolios created with bigger planning units are less efficient but are more likely to select the same priority areas. Furthermore, they demonstrated that incorporating practical limitations into the analysis i.e. lowering socio-economic expenses and minimizing fragmentation levels, minimizes the impact of planning unit characteristics on the outcomes. Consequently, they contend that future research endeavors should take a similar tack when examining conservation evaluation variables.

Esselman and Allan (2010) focused on the specific limitations of reserve design in river ecosystems and constructed a reserve network to solve major obstacles to freshwater conservation using Marxan conservation planning software. Marxan utilized the projected range limits of 63 fish species in Mesoamerica to create a network of conservation focus areas that cover 15% of each species' range in places with minimal danger of environmental deterioration. The intensity of upstream risk was assessed by propagating landscape-based sources of stress downstream along the direction of flow in GIS. To account for basin divides, they limited Marxan solutions and identified essential management zones comprising significant habitats that reduced risks and promoted species persistence. Of the research area, 11% was covered by the planned reserve network, of which half was included inside already-existing protected areas. They found significant protection gaps within their exercise. Since the method considered the propagation of terrestrial-based environmental concerns across the river network, target regions were limited to catchments with low levels of upstream human activity. The network area was increased by one-fifth with the addition of crucial management zones, such as fish migratory corridors and riparian buffers. Because of Marxan the longitudinal connection and topographic impediments to species mobility were considered. The reserve network was enlarged by the addition of key management zones, which was essential to the network's ability to conserve biodiversity.

Watts et al., (2009) in their work provided a significant expansion of Marxan i.e. Marxan with

Zones, a decision support system that offers alternatives for land-use zoning in geographic areas for the preservation of biodiversity. They outlined additional features intended to improve and broaden the use of the original Marxan software as a tool for decision assistance. The goal was to ensure that various conservation and land-use objectives were met while minimizing the overall cost of zoning plan implementation. They described the features, restrictions, and extra data needed for this new program and compared it to the first iteration of Marxan. They provided many case studies to illustrate the software's capabilities and showed how adaptable it is for handling a variety of challenging spatial planning issues. Their study illustrated the zoning of forest use in East Kalimantan and the establishment of multiple-use marine parks in California and Western Australia.

Abarca et al., (2022) conducted a study on planning and conserving protected Areas. The Biodiversity Strategy for 2030 aims to address this by expanding protected areas (PAs) like Natura 2000. Using the Montseny Natural Park in NE Spain, a spatial optimization tool integrates species, habitat, and human activity distributions to design multi-zoning schemes for PAs. Results indicate minimal trade-offs between nature conservation and human uses, but challenges arise with fragmented management zones for large human-use target.

De Alban et al., (2021) worked on examining the diversity of wildlife species and forest types in Tanintharyi's 11,241 km2 protected area (PA) network. To meet the 30% representation target, the methodology used spatial prioritizing algorithms to find new priority conservation places beyond the current network. The findings showed that within the current PA network, 32 out of 60 vulnerable wildlife species and six out of eight forest types were underrepresented. To effectively reach the desired representation for all species and forest types, the study recommended a moderate extension of 4032 km2, or 8.4% of Tanintharyi's land area, with 31% of that area being near to the current PA network (De Alban et al., 2021).

Kockel, (2018) addresses the global threat to biodiversity and fisheries through the application of systematic conservation planning (SCP) for marine protected areas (MPAs) in Sogod Bay in the Philippines. The research objectives involve integrating equity dimensions in SCP planning, assessing the impact of recognition and procedural equity on MPA design, and comparing SCP-designed MPAs with conventional approaches. Challenges in implementing SCP in developing nations are identified, including biased concepts, data limitations, and oversimplified socioeconomics. Findings demonstrate the effectiveness of SCP in achieving representative and equitable MPA plans, crucial for meeting Aichi Target 11 objectives (Kockel, 2018).

Salinas-Rodriguez et al., (2018) examined the efficacy of existing 73 protected areas in the Sierra Madre Oriental (SMOr), an important hotspot of vascular plant endemism in Eastern Mexico. In order to improve the representation of endemic species, new locations were suggested by Marxan, and endemism hotspots were discovered using MaxEnt and information from herbaria. The findings indicated that 66% of endemic species—those considered acceptable but not those that might be threatened—are currently covered by protected areas. To better conserve the remaining 34% of indigenous plants in SMOr, the study suggests identifying 10 more sites. This emphasizes how considering vascular plant endemism hotspots could significantly improve Mexico's conservation efforts (Salinas-Rodríguez, Sajama, Gutierrez-Ortega, Ortega-Baes, & Estrada-Castillón,2018).

Alwelaie, (1994) reviewed Saudi Arabia's conservation movement, focused on establishing protected areas and the philosophy of natural resource management. It analyzes the representation of biophysical diversity in case study areas: Harrat Al-Harrah, Urug Bani Mu'arid, and Raydah Escarpment. Saudi Arabia has established 10 protected areas, intending to expand in the future. These regions focus on biodiversity conservation, flood management, aquifer recharge, and grazing land preservation. Currently, just 10% of the proposed sites have been designated, emphasizing early conservation efforts, but the future focus will be on sustainable usage and benefits to local people (Alwelaie, 1994).

1.2. Rationale

Biodiversity conservation is of paramount importance globally because it maintains ecological balance, sustains ecosystem services crucial for human well-being, and promotes ecosystem resilience in the face of environmental challenges such as climate change and habitat loss. Alula, located in a historically rich environment with ancient archaeological sites and different ecosystems, is a priority region for the preservation of biodiversity. Preserving these natural habitats not only preserves unique species and maintains biological balance, but it also supports vital ecosystem functions like water filtering and climate regulation. The Arabian gazelle (Gazella arabica) is one example of a species that has threatened extinction because of exploitation in Saudi Arabia. The Arabian gazelle was formerly common throughout the Arabian Peninsula, including areas around Alula, and was heavily hunted for meat and hide. Withered with habitat degradation, this exploitation resulted in a severe drop in numbers, eventually leading to extinction in the wild (Mallon & Kingswood, 2019). Saudi Arabia can preserve the long-term health of Alula's ecosystems by implementing conservation plans that prioritize habitat restoration, sustainable land use practices, and community participation, as well as boosting tourist and research activities. These activities highlight the necessity of taking proactive conservation actions to protect biodiversity and ecosystem services in Alula and elsewhere.

1.3. Scope of the study

The main objective of this study is to provide useful information for the biodiversity protection planning process by identifying priority conservation sites that are less affected by human activity. This research has the potential to strategically identify and prioritize habitats that are crucial for the survival and recovery of endangered species. Systematic conservation planning enables you to effectively utilize the geographical layout of protected areas, ensuring that these species have adequate habitat and connection to grow sustainable populations. Its phases include pre-processing data, analyzing spatial prioritizing, developing an ecologically based model of conservation value, and interpreting the findings to guide conservation action. By analyzing the species distribution and their hotspot areas, the model will generate the best solution options for where the area needs to be extended for endangered species where they are less likely to experience human exploitation. This approach will identify locations with high biodiversity value where endangered species are concentrated. Focusing conservation efforts on these hotspots allows you to maximize the impact of limited resources while successfully mitigating concerns like habitat loss and fragmentation.

1.4. Objectives

This study focuses on two main objectives.

1. To identify biodiversity hotspots for conservation initiatives throughout Alula using a hotspot analysis.

2. Establish an effective network of protected zones for species representation and ecological connection using Marxan.

Chapter 2

MATERIALS AND METHODS

2.1 STUDY AREA

The study area is a county located in Saudi Arabia, 26°36'59.99" towards North and 37°54'59.99" towards East. AlUla, 1,100 km from Riyadh in northwestern Saudi Arabia, is a site of outstanding natural and historical legacy. The region is 22,561km² and has an ecologically diverse valley, high sandstone mountains, and old cultural heritage sites from thousands of years. One of the seven counties that make up the province of Medina is the Governorate of Al'Ula, which includes the city of Al-'Ula. The city has a population of 5,426m. The region is also recognized for its dramatic environment of rocks, gorges, and wadis and the contrast between these arid environs and the lush, palm-filled oasis near the city center.

Alula County is part of a complex ecosystem in northwestern Saudi Arabia, with deserts and rock formations that sustain a range of species (Alsharhan et al., 2001). Alula has an arid desert environment, with summer temperatures reaching 45°C (113°F) and winter temperatures ranging from 8°C to 20°C (46°F-68°F). Annual rainfall is modest, averaging around 50 mm (2 inches).

Among its many species are exotic ones that have adapted to dry weather. Alula hosts about 500 plant species, including endemics, 90 bird species and 20 mammal species, including the endangered Arabian Oryx and Nubian ibex (Al-Johany et al., 2012; Aldosari et al., 2020). Its distinct arid environment contributes to the vast biodiversity.

The region endures shortcomings such as habitat degradation due to urbanization and overgrazing (Al-Hemaid et al. 2002). These stresses endanger native flora and fauna. Species such as the Arabian Oryx (Oryx leucoryx) and Nubian ibex (Addax nasomaculatus) are highly endangered and under intense conservation efforts (Aldosari et al., 2020). Restoration activities include the development of protected areas and wildlife corridors. The Royal Commission for Alula is leading efforts to restore habitats and safeguard endangered animals. Several programs seek to restore degraded habitats and reintroduce animals to their natural ranges (El-Hadidi et al., 2019). These programs are critical to maintaining ecological balance. Monitoring programs track wildlife populations and habitat conditions to determine the efficacy of conservation efforts (Al-Harbi et al., 2022).

The primary goal of this research facility is to help improve the protected area design in Al'ula by identifying major conservation priorities and reconciling ecological needs with socioeconomic factors. It helps establish effective protected area networks, improves habitat connectivity, and promotes adaptive management. This strategy ensures effective resource allocation and informed decision-making for long term conservation success in the region.

Figure 2.1. displays the study area map which contains Three data frames. In one frame is the shapefile of Saudia Arabia, other has the shapefile of Madinah with district boundaries and the main frame displays Alula County.

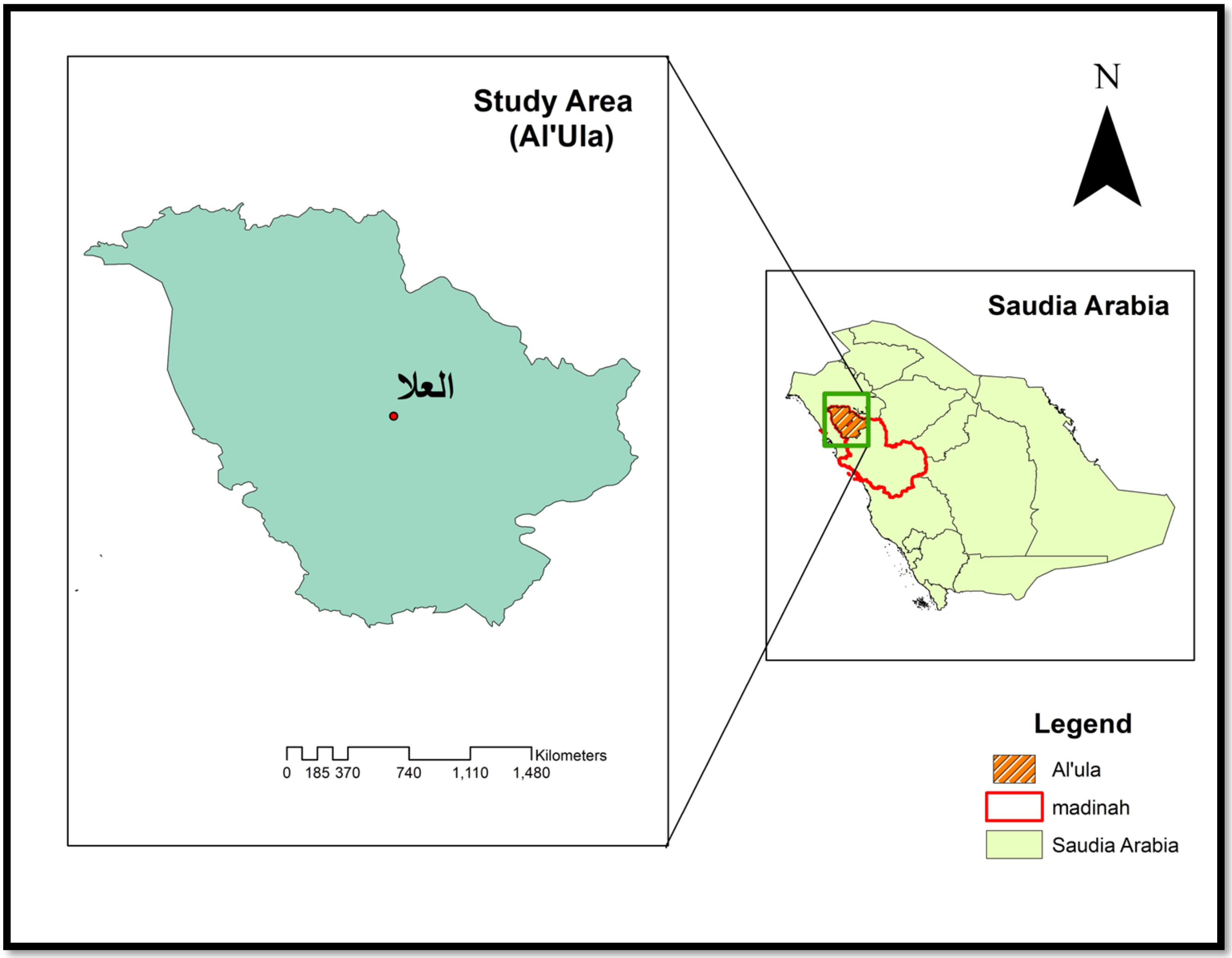

Figure.2.1. Study area map displaying the alula, county.

Because of its distinct combination of endemic species and uncommon habitats in an arid climate, alula is a priority for biodiversity conservation. According to the Royal Commission for Alula (2021), targeted conservation activities are warranted due to the area's unique geological features and cultural significance. This amalgamation of ecological and cultural significance might not exist in other areas.

2.2 Data Sources, Quality and Limitation

Table.2.1. described the various data sets which were used in the study.

Alula's native species occurrence data was obtained from Global biodiversity information facility (GBIF) in the form of vector data along with coordinates, and scientific details. Road network data was obtained from Earth works in the form of polylines. Erath work provides comprehensive geographic data about road infrastructure, including road kinds, locations and connections. Protected area boundaries were sourced from existing literature, providing documented delineations of conservation zones. Terrain analysis and environmental modeling utilize detailed elevation data from the Digital Elevation Model (DEM) sourced from USGS Explorer with a resolution of 30 meters to 1 arc-second (approximately 30 meters).

For land use land cover classification sentinel 2 images for 2020 were retrieved on Google Earth Engine and processed. The resolution of sentinel 2 is 10 meters as shown in Table.2.2.

2.3 Analytical Frameworks

The study was executed by following a set of processes in a sequence. Figure 2.2. is the graphical representation of the methodology which was followed throughout the research.

Data Processing:

The Specie Occurrence coordinates were displayed as X, Y data in ArcGIS and a shapefile of these coordinates were clipped on study area.

In ArcGIS the protected areas were georectified from reference image and then digitized. The occurrence data was overlayed on alula boundary shapefile to perform hotspot analysis. Land use landcover imagery was retrieved from the cloud on Google Earth engine to perform land use land cover classification.

Topographic Maps:

To analyze ecological study area terrain features, I began with downloading a digital elevation model (DEM) with a 30*30-meter resolution from USGS Earth Explorer. The DEM was imported in ArcMap, where it was reprojected to alula's coordinate system and clipped to the area of interest. Using analytical tools, we computed the slope to determine the steepness of the terrain, the aspect was calculated to identify the compass direction of slopes, hill shade was created to simulate the terrain illumination and enhance visualization. The maps were generated from this analysis and their results. Their analysis provides a robust understanding on terrain's characteristics which is important for land use planning or ecological zonation.

Drainage Network:

Drainage Network is crucial for ecological land use planning as it influences the water distribution, presence of soil moisture and habitat connectivity, which is mandatory for determining the plant and animal distribution across a land. The water movement and availability help the stakeholder identify and restore critical habitats and effectively manage the ecosystem services. Hydrology from spatial analyst tools was used to analyze the drainage network, and DEM was utilized again to calculate the flow direction to determine the direction as to where the water is moving across the study area. We then used the flow accumulation tool to find locations where water converges, and by using a threshold on the flow accumulation raster, we could extract the stream network. The final data is utilized to define basins. The whole stream network has been projected onto topographic maps to explain hydrological movement across the terrain.

Land Use Land Cover:

A comprehensive understanding of how the Earth's surface is utilized, and changes can be gained from basic concepts like land use and land cover. "Land use" describes how people use a particular plot of land. It is applicable to a wide range of applications, such as residential, commercial, industrial, agricultural, and recreational. It reflects the interconnections between human cultures and the environment, illuminating the dynamic interdependence between persons and their environments. What an economic activity, cultural norms, and societal demands determine land use patterns is a key factor in defining how various regions are organized spatially and function.

To identify land use and land cover using Sentinel-2 imagery on Google Earth Engine, I first imported the required Sentinel-2 datasets then selected images based on the area and time range. I preprocessed the data using atmospheric correction and cloud masking to guarantee clear and accurate images. I used a supervised classification system like Random Forest or Support Vector Machine with pre-defined training data to identify different land cover categories. Finally, I checked the classification findings' correctness by comparing them to ground truth data or reference datasets to ensure the precision of the land cover map.

Table.2.1. Datasets used for hotspot and marxan analysis.

Dataset	Specification	Data Source
Protected Areas	Name, Coordinates	Literature https://doi.org/10.1007/BF00813133
Native Species Data	Species occurrence, coordinates, scientific names and IUCN status	GBIF.org https://doi.org/10.15468/dl.gq7rj6
Road Network Data	Polyline Road Network, Coordinates, Road Names & Type.	Earth Works
Digital Elevation Model	30 * 30 meters Resolution	USGS Earth Explorer

Table.2.2. Dataset used for land use land cover classification.

Satellite	Date	Resolution
Sentinel 2	2020	10 meters

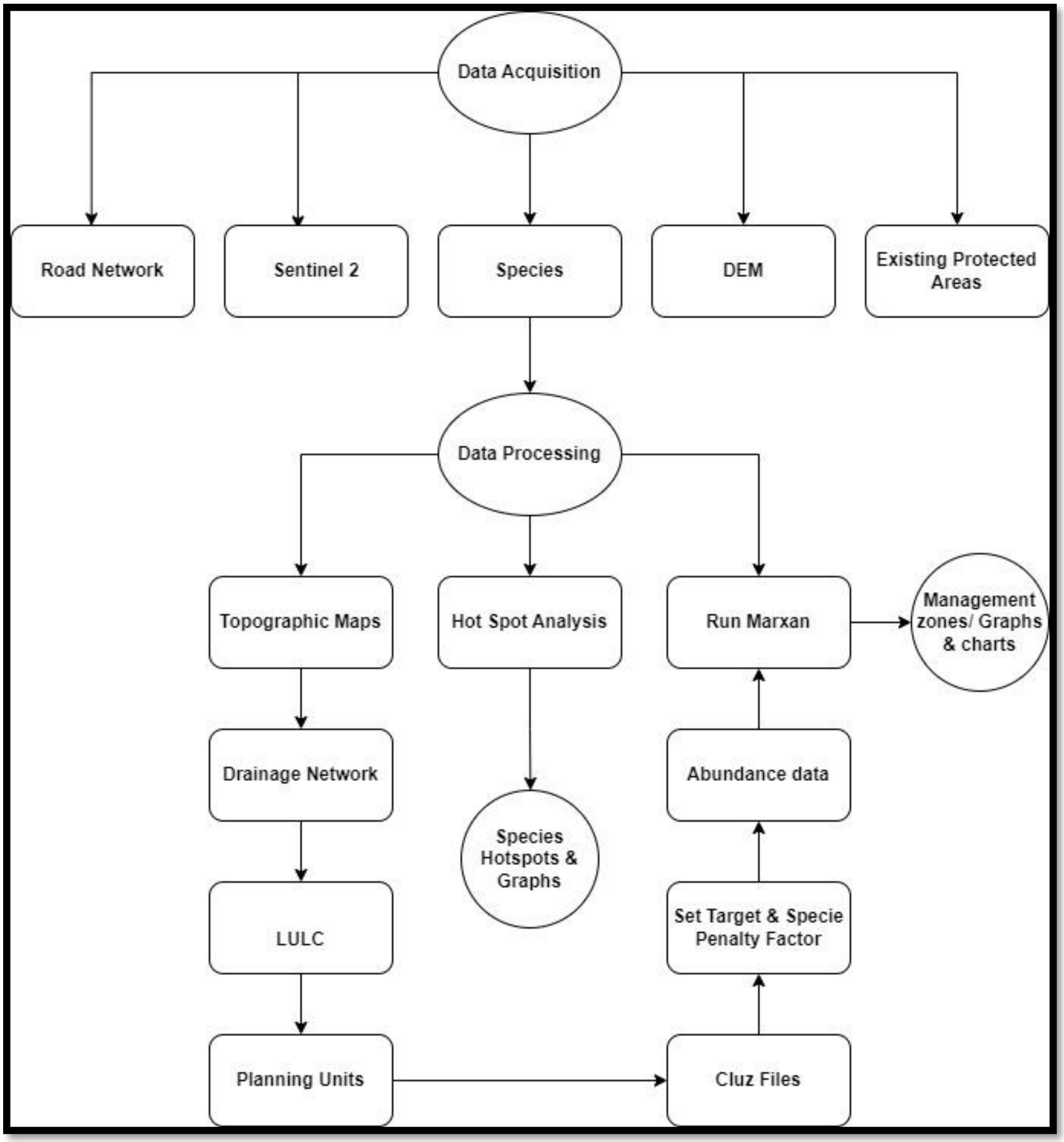

Figure 2.2. Methodological framework showing processing stages from data acquisition to conclusion.

On the other hand, land cover refers to the physical characteristics and natural features found on the Earth's surface, such as bodies of water, bare soil, flora, and man-made structures. It depicts the physical distribution of different elements within a specific area. Land cover categorization can help identify and characterize surface features based on their spectral, textural, and spatial aspects. Differentiating between different forms of land cover allows researchers to detect changes, better understand ecosystems, and assess the long-term effects of human activity on the environment. Analyzing land use and land cover combined provides a comprehensive knowledge of the complex interplay between human activities and the environmental systems that shape our planet's surface.

Hot Spot Analysis:

To find clusters of high or low values in geographic data and identify geographical hotspots and coldspots, spatial analysts employ the Getis-Ord G* statistic. It provides information on the concentration of events within a research area by measuring the degree of spatial association between a variable and its nearby values (Getis & Ord, 1992). To find trends and guide decision-making, this approach is frequently utilized in disciplines including epidemiology, criminal research, and urban studies (Getis & Ord, 1995).

We first imported the geographic dataset into ArcMap for hotspot analysis and ensured it is projected to an appropriate coordinate system before doing Getis-Ord G* Hotspot Analysis. Next up, we designated the input feature class and the field to be analyzed using the Hot Spot Analysis (Getis-Ord G) * tool (Spatial Statistics Tools > Mapping Clusters > Hot Spot Analysis). To find statistically significant spatial groupings of high or low values—which indicate hotspots or coldspots—this program results in Getis-Ord G* statistic for each feature. The output layer showed the regions with significant clustering frequency. Maps were created out of results.

Spatial zoning:

The practice of balancing ecological, economic, and social goals through the designation of certain areas for certain land uses or conservation purposes is known as spatial zoning. Maximizing the spatial distribution of activities and protection efforts supports efficient resource management (Moilanen et al., 2009).

Marxan is a spatial planning tool that balances cost constraints with biodiversity and aims to maximize the selection of conservation areas. Watts et al. (2009) state that the Marxan model identifies the most cost-effective and efficient planning units to achieve conservation objectives. To achieve this goal, Marxan minimizes the formula as follows:

$$\text{Objective Function} = \sum \text{Cost} + (\text{BLM} * \sum \text{Boundary}) + \sum (\text{SPF} * \text{Penalty})$$

In this equation, Cost represents the conservation cost of each planning unit (PU), Boundary represents the length of the reserve system boundary, and Boundary Length Modifier (BLM) determines the reserve system's aggregation. The penalty for not meeting conservation targets is determined based on the conservation cost of planning units. The conservation feature penalty factor (CFPF) is used to prioritize different conservation features. The objective formula includes three components: (1) total conservation costs for all planning units (PUs), (2) total modified length of the reserve system boundary, and (3) compensation value for underachieving conservation targets for different features (Watts et al. 2009; Levin et al. 2013). Figure 2.3 is the graphical representation of the methodology for systematic conservation zoning of the region.

Marxan Solutions:

Following an analysis, MARXAN produces two outputs: the 'best' run solution (i.e., the one with the lowest objective function value) and a summed solution that shows the number of times each planning unit was used in a run solution. The cumulative solution will contain values that span 0 (not represented in a run's solution) to 100 (included in all 100 runs' solutions) if the number of runs is set to 100. A cumulative solution broken down into three categories—high, medium, and low. High relevance planning units have a high aggregate value and are essential to accomplishing goals. These places can be thought of as hot spots. It is important to emphasize that high value units may or may not be included in the "best" solution. The absence of planning units from the "best" solution does not mean that they are of no worth. The summed solution differs from the 'best' solution in that it assigns a value to each planning unit to indicate their relative importance.

Planning Units:

Planning units are crucial components in the construction of priority areas. MARXAN evaluates and selects these units to create the best solutions. They can be defined based to natural landscapes, administrative zones, or other arbitrary criteria (Pressey & Logan, 1998) and come in several shapes and sizes. Reserve planning often involves squares (Airamé et al., 2003) and hexagons (Ardron et al., 2002), but irregular polygonal shapes have also been employed (Lewis et al., 2003). Groves (2003) recommends using a regular grid for complex planning situations or missing data.

Target:

Targets refer to the number of species to be included in the solution, which might include physical features, ecosystems, organisms, economic data, and public opinion. While Lieberknecht et al. (2004) concentrated on objectives between 10% and 40%, Airamé et al. (2003) examined targets of 30%, 40%, and 50%. Stakeholders were able to view solution sizes and configurations depending on desired values due to these ranges. Rare or susceptible features are prioritized for conservation efforts due to their high concentration. The ability of a solution to achieve its targets impacts penalties and the total expense. Lieberknecht et al. (2004) included a penalty for species that did not meet the solution's goal.

Cost:

Individual planning unit costs are utilized to calculate the overall solution, known as the objective function. Planning unit area, economic or social cost, or a mix of these, can be used to calculate cost (Lieberknecht et al., 2004). Because the objective is to reduce the overall cost of the solution, the more expensive a planning unit is, the less likely it is to be included in the final solution (Ball & Possingham, 2000). Several studies (Airamé et al., 2003; Leslie et al., 2003; Oetting and Knight, 2005) use the area of planning units to determine cost value.

Boundary Length Modifier:

The boundary length modifier (BLM) in MARXAN limits a solution's perimeter when set to a value larger than zero. The objective function's value increases with the BLM. The solution will progressively attempt to lower border length by clustering planning units because the goal is to minimize the value of the objective function (Meerman et al., 2005). Clustered (compact) solutions are more manageable than extremely fragmented areas. According to Lieberknecht et al. (2004), decreasing the perimeter (boundary length) leads to an increase in solution area due to additional planning units' need to form contiguous clusters.

Penalty Factor:

When a feature's target is not fulfilled, penalties are imposed on the objective function. A penalty is the amount of boundary length and cost required to accurately depict a missing target (Ball and Possingham, 2000). The SPF is a multiplicative factor that considers the relevance of each conservation characteristic or species. Setting a high SPF increases the likelihood of meeting a feature's target while minimizing the cost of the objective function (Smith, 2005).

Visual Representation:

The results were further processed to create maps and tables according to standard scale and shape. Figure 2.3. is a graphical representation of each factor's process (spatial zoning).

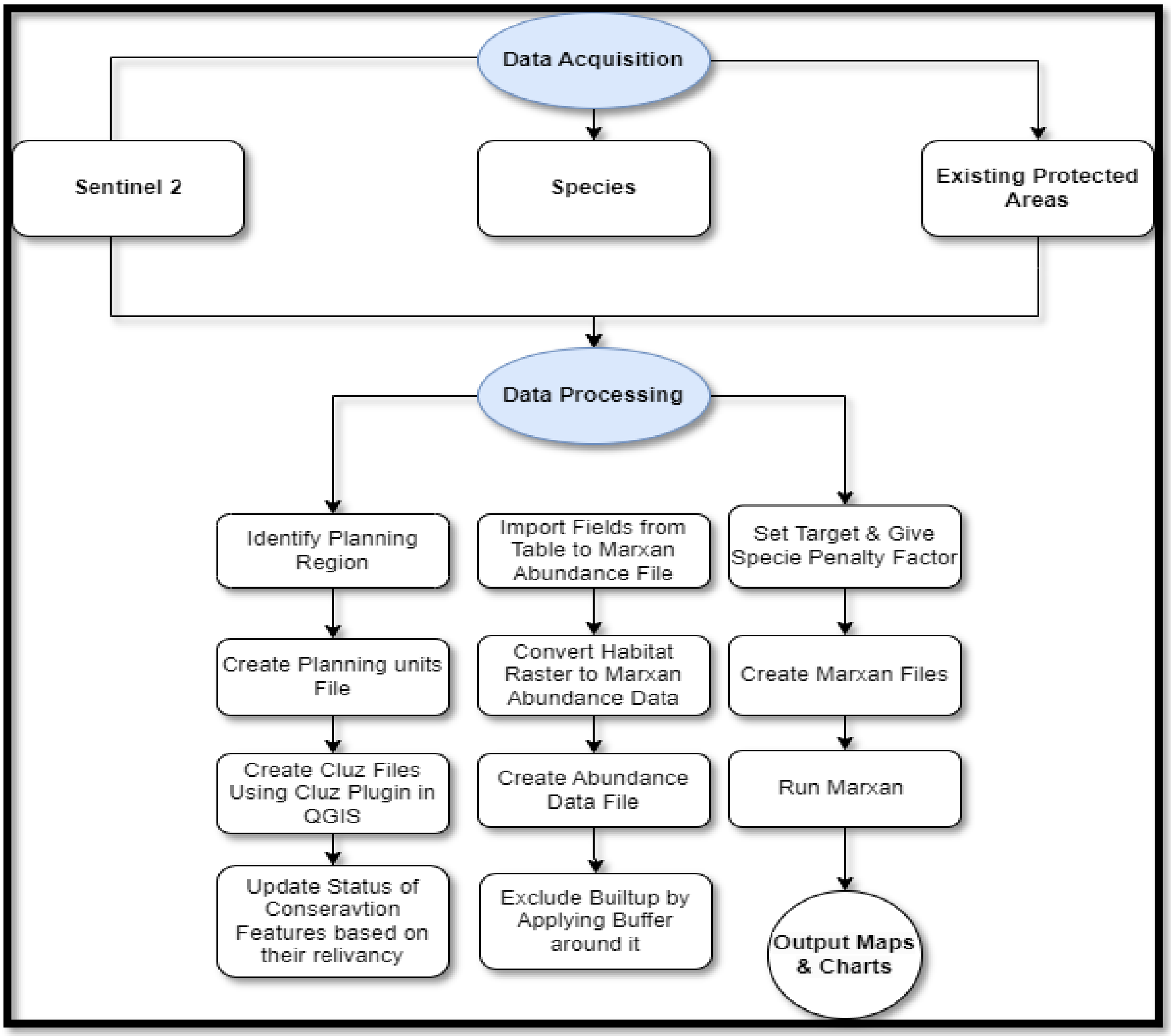

Figure 2.3. Methodology for systematic spatial zoning using marxan.

RESULTS AND DISCUSSIONS

This part provides insight into the analysis and interpretation of the study's findings. Data obtained from thorough research and a comprehensive assessment of the literature give a basis for critical analysis and investigation. The following discussion covers both the anticipated outcomes and any unanticipated conclusions or trends, as well as the significance of these findings in relation to the study goals.

3.1. Topographical Analysis:

A topographical analysis of Alula was done to visualize and understand land's areal topography and characteristics. Thorough knowledge of land before planning any land use is essential. The study area was clipped from digital elevation model of 30*30 m resolution. Further analysis was performed to observe features of the terrain.

Topographical maps are critical for systematic conservation planning because they give extensive information on terrain characteristics such as elevation, slope, and aspect. This information aids in understanding the geographical distribution of habitats, identifying regions with high biodiversity value, and measuring connections across ecological zones. Conservation planners can prioritize sites for protection by visualizing the physical aspects of the landscape based on its ecological relevance and capacity to support varied species. Topographical maps also help to create conservation networks and corridors, ensuring that conservation efforts are effective and efficient in preserving biological processes and resilience. Figure 3.1 displays the topographic maps of alula in the form of contour, hill shade, slope and aspect to explain the terrain features and characteristics of the study area.

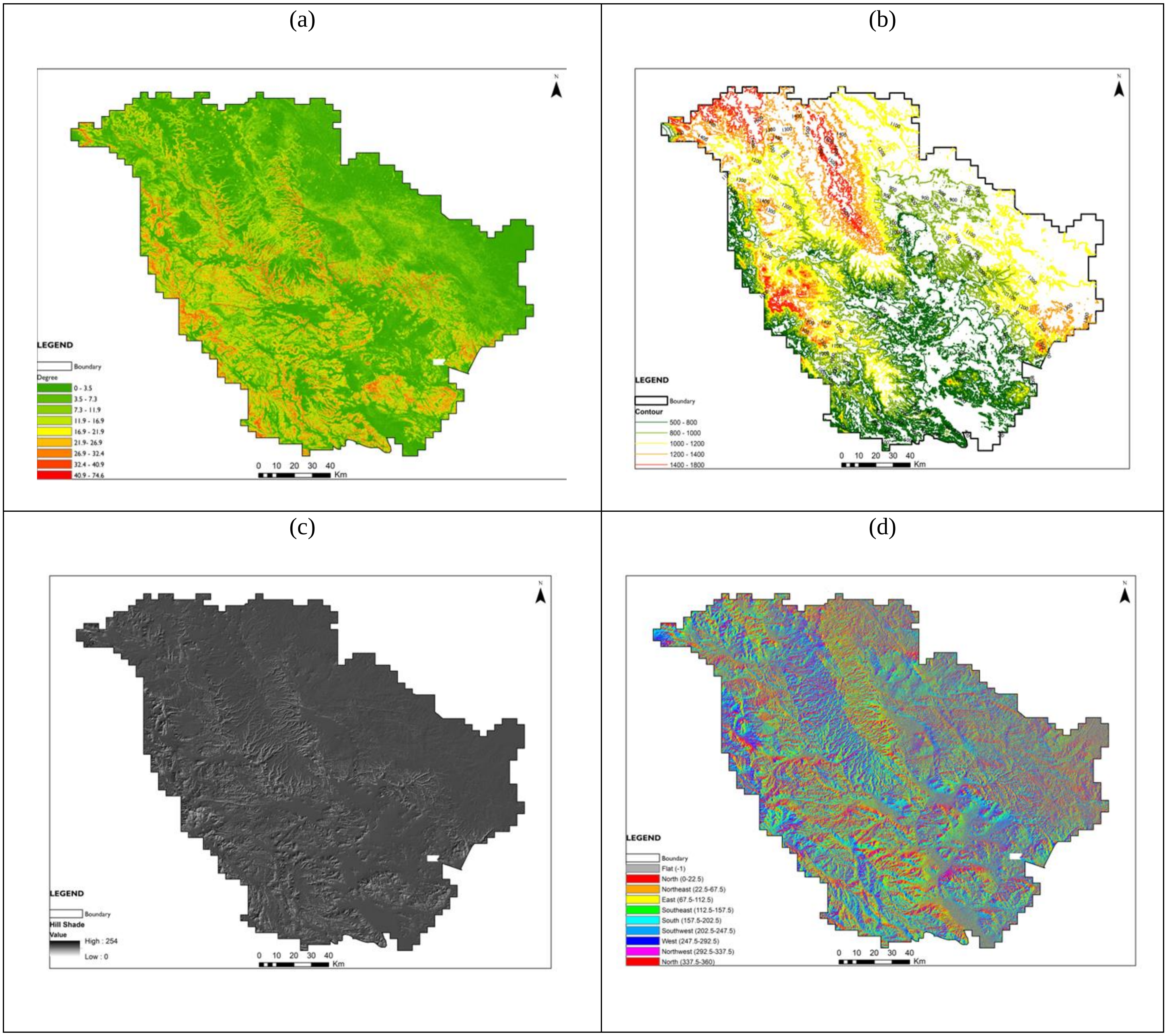

Figure 3.1. Displaying topographical maps of (a) slope, (b) contour, (c) hill shade & (c) aspect.

Drainage Network:

Observing how water moves throughout the environment allows for better managing of flood hazards and land use. It is critical for developing effective infrastructure and sustaining natural habitats. Digital elevation model was manipulated using hydrology tools from spatial analysts. The dem was filled first. And then flow direction was computed followed by flow accumulation. This analysis determines the direction in which water would flow from each grid cell, expressed in degrees relative to north. The flow direction is represented as a raster layer, with each pixel representing the compass direction of the sharpest decline. Meanwhile, flow accumulation estimates the cumulative contribution from upstream cells to determine how much water collects at each site.

This metric is shown as a raster layer, with higher values indicating places with more water accumulation. The stream network obtained from DEM through hydrological analysis of watershed was also overlayed over drainage network better to explain the hydrological condition and movement across the terrain. Flow accumulation thresholds are frequently used to create stream networks. The blue node with highest value acts as a main tributary here. The rest pours into it.

This research identifies areas of high-water flow, probable flood zones, and sediment deposition, all of which are critical for managing water resources and minimizing soil erosion. Understanding basin flow aids in the identification of crucial conservation areas, such as riparian zones and wetlands, which are critical for water quality and the survival of various wildlife. Furthermore, this knowledge helps to construct land use plans that consider natural hydrological processes, guaranteeing sustainable development and limiting the dangers of water-related disasters. Integrating drainage and flow data into spatial zoning techniques ensures that land management approaches are environmentally sound and adaptable to changing conditions.

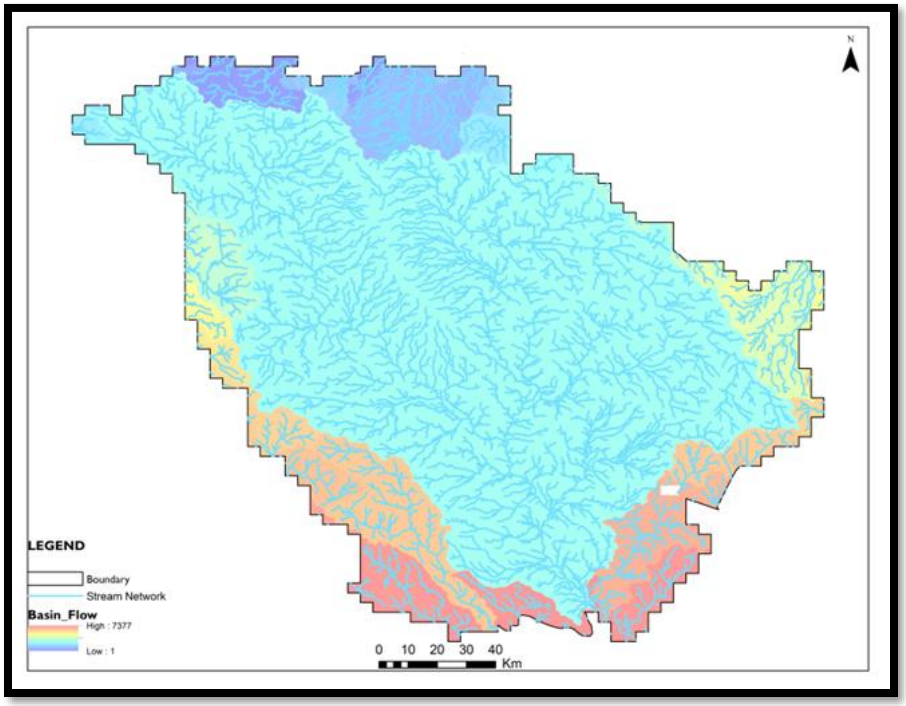

Figure 3.2. Basin flow map of alula

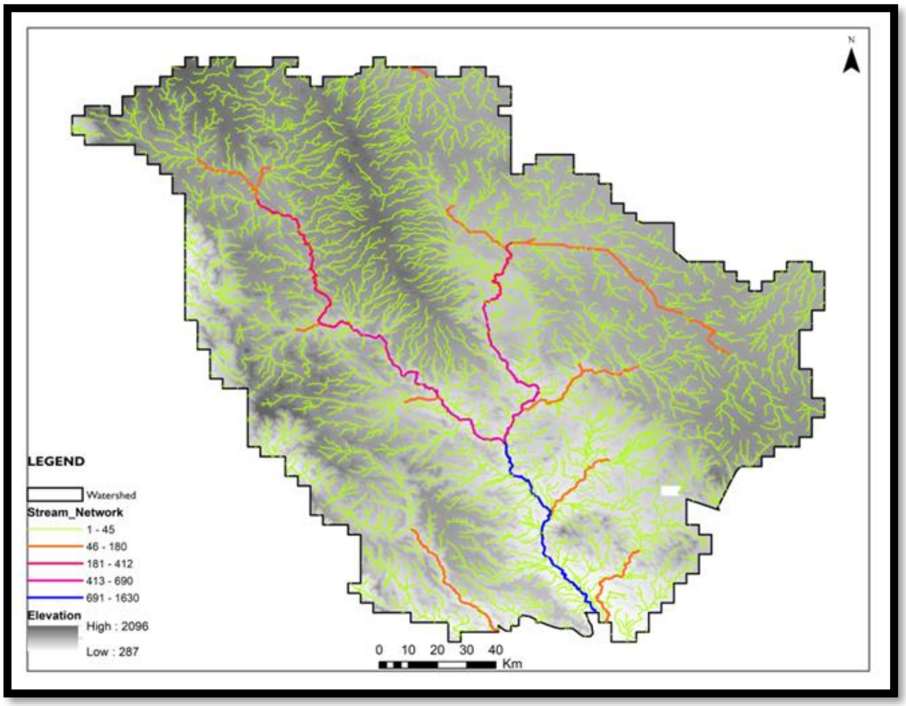

Figure 3.3. Drainage density map of alula.

Land use Land Cover Analysis:

Land use Land cover was performed on google earth engine using sentinel 2 imagery of year 2020. Cloud cover was kept under 5%. Training samples were selected at 265 different locations for most of the classes. Four classes were sampled: built up, plantation, mountains and rangeland. The classified results and its accuracy assessment report were then exported to drive. Land use land cover was then exploited to extract built up area. Marxan excludes built up from analysis and gives it a status of excluded as this area is already in human-use.

The results in figure 3.1(a) displayed 4 classified classes (built up, plantation, Rangeland and mountains/hills) in 2020. The polygons overlayed on land use cover classes are the designated protected areas.

3.2 Hotspot Analysis:

I employed Getis Ord G* Hotspot analysis to visualize the species abundance to identify spatial clusters with high and low values in the dataset. The approach began with data preparation, in which I cleaned and modified the dataset to make it suitable for analysis. I then transformed the data into a geographical format, specifying the geographic scope and size of the research. Using the Getis-Ord G* statistic, I evaluated spatial clustering by computing the local Gi* index for each feature, which quantifies how substantially high or low values cluster relative to their neighbors. This necessitated creating a spatial weight matrix to establish neighbor connections based on distance or proximity. Next, I did statistical significance tests to check that the observed grouping was not caused by chance. The findings revealed clusters of high values (hotspots) and low values (cold spots), offering insight into geographical distribution patterns.

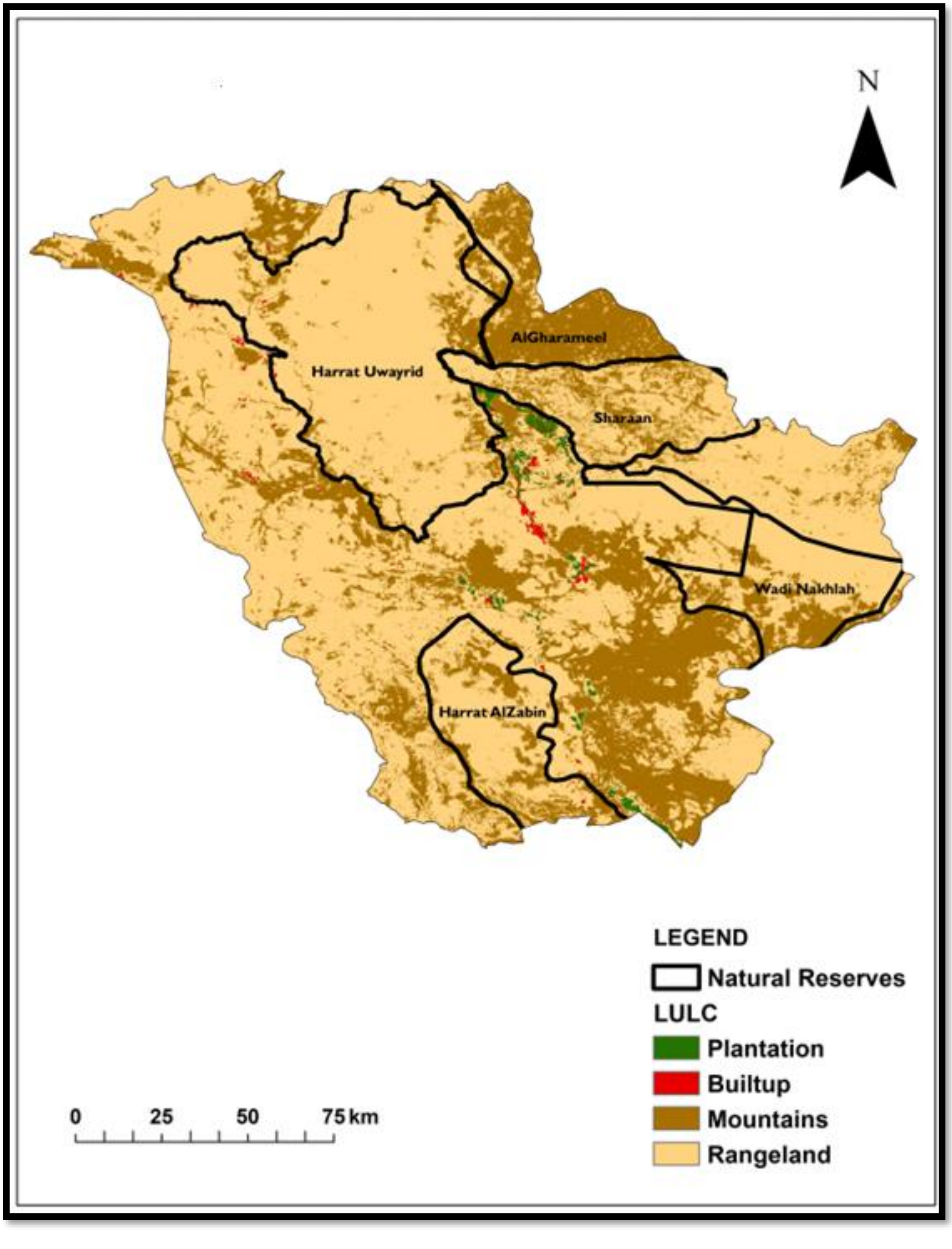

Figure 3.4. Land-use land cover map of alula for year 2020.

Figure 3.5 explains the results of Getis Ord G* hotspot analysis in the form of high and low values with confidence levels. A hotspot is a region where high values are clustered together, suggesting a concentration of increased values relative to the surrounding areas. A cold spot is a region with clusters of low values, indicating a concentration of lower values in comparison to its surrounds. Hotspots and cold spots are identified with strong certainty at the **99% confidence level ($p < 0.01$) **, indicating only a 1% chance of random variation causing the clustering. Clusters are statistically significant at the **95% confidence level ($p < 0.05$) ** if they have a chance of occurring randomly by 5% or less. The **90% confidence level ($p < 0.10$) ** suggests that clusters are significant with a 10% or less possibility of being random. Higher confidence levels (99% and 95%) provide more proof of actual clustering, whilst 90% provides relatively less comfort.

The G* Bin Report of hot spot analysis explains the areal distribution and percentage. Most of the endangered species lie under already designated protected areas. Arabian Ibex and leopard were found in Uwayrid and Alzabbin natural reserve.

The point density analysis map was generated to explain the concentration of endangered species Panthera (Arabian Leopard) and Capra nubiana (Arabian Ibex) in respective protected areas. Capra nubiana is classified as an endangered species (EN C2a) on the IUCN Red List of Threatened Species. EN denotes endangered, while C2a indicates that the population estimate is less than 2,500 mature individuals, with no subpopulations larger than 250 mature individuals and an overall deteriorating population trend. The Arabian leopard is also a critically endangered species of leopard, known for its diminutive stature and pale coat. There are believed to be less than 200 Arabian leopards alive in the wild. The Arabian Peninsula has just three additional cat species: the sand cat, the caracal, and the wild cat.

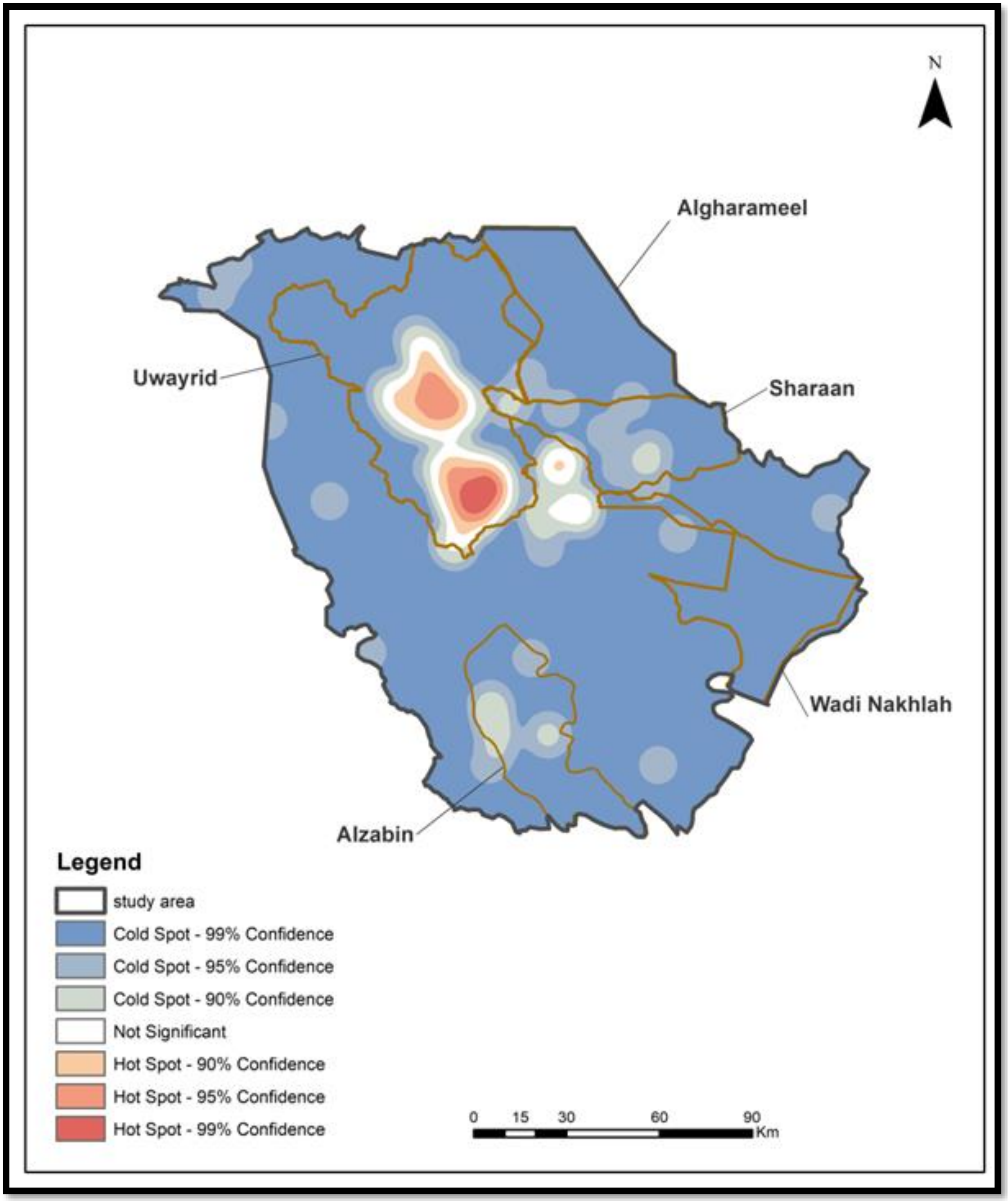

Figure 3.5. Hotspots map of species across alula.

Table 3.1: Getis-ord hot spot analysis statistics displaying bin values.

Getis Ord (Gi-Bin)	**Area (km^2)**	**Percent (%)**
Cold Spots**	20586.7	78.3
Cold Spot*	3133.4	11.9
Cold Spot	1119.2	4.3
Not Significant	664.4	2.5
Hot Spot	387.6	1.5
Hot Spot*	298.1	1.1
Hot Spot**	112.5	0.4

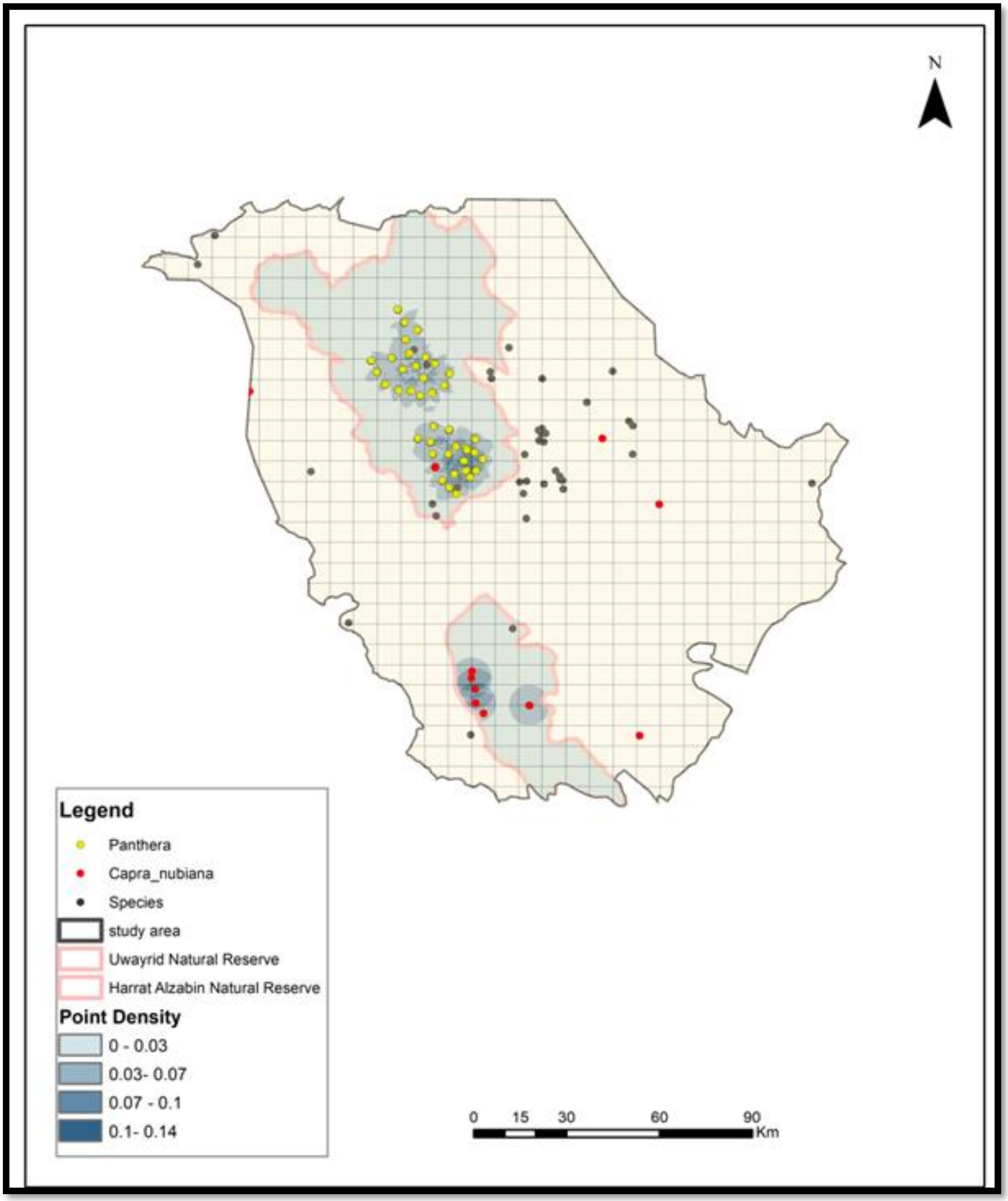

Figure 3.6. Point density analysis map of panthera & capra nubiana.

3.3 Systematic Conservation Planning:

Systematic conservation planning is an intricate method for conserving biodiversity and managing natural resources that involves carefully determining and assigning priority areas for protection based on substantial data analysis and ecological objectives. This strategy combines spatial and ecological data to improve conservation results and resource allocation (Margules & Pressey, 2000; Possingham et al., 2006). This research used systematic conservation planning to increase the Corridor limits for endangered species of alula. The method was done by intensively reviewing data on distributions of species and habitat types to identify and prioritize critical conservation areas.

Data were collected through detailed habitat mapping for endangered species and assessment of the state of existing protected areas. We then applied Geographic Information Systems to spatial data to determine the specific conservation objectives according to biological requirements and processes. Such information-based planning could further clarify which regions were of high priority and could most effectively conserve species, while considering practical restrictions on land use and resource limitations.

Spatial Allocation of Management zones:

Three scenarios were created using cluz extension with marxan in QGIS to address the management needs of protected areas. We used this approach to determine the appropriate allocation of different management zones, ensuring that resources were used effectively. I used distinctive targets and penalty factors for habitats and endangered species to establish a balanced conservation plan. mainly I chose 500 species penalty factors (SPFs) for endangered species based on values gathered from recent studies. I gave 1,000 penalty factors to habitats, classifying them as less critical than species. This distinction highlights the prioritized focus on threatened species and the urgency of habitat protection.

Scenario - 01:

For the first conservation planning exercise scenario, I established a goal to preserve 30% of a species' total population inside a 26,907 km^2 study area. This led to the creation of three management zones, with 55% designated for human use, 39% designated for completely protected areas, and 5% designated for mixed use or ecologically sustainable zones. The first scenario failed to meet the goals for species and vegetation class conservation, even though the rest of the representation units succeeded in reaching the 30% conservation aim. This shows how difficult it is to balance the need for ecological variety and conservation goals. The model selected specific areas through rigorous iterations and simulations, the model identified regions, providing an efficient approach to finding the best conservation options. It would be feasible to get a more perfect result by modifying the conservation aim, wherein the required percentage of population conservation and the appropriate representation of species and vegetation types are both fulfilled. Effective biodiversity conservation and sustainable land management practices in the investigated region depend on this iterative process of fine-tuning conservation methods through modelling and empirical validation.

The map below explains the frequency of the planning unit was the planning unit being selected in each run for 10 times for 10000000 iterations. The highest frequency identifies priority areas of significant value. Similarly, zones with frequencies from 0 to 5 are considered lower priority areas. Grey areas, with frequencies between 0 and 0.1, denote regions where the model detected no traces of the species.

The second output of the model, the best solution map, categorizes the area into four distinct sections. These include sections already under protection, zones excluded because of existing commercial development or built-up regions unsuitable for conversion, and areas eligible for future conservation initiatives. High-priority zones with notable mobility or signs of biodiversity are designated as earmarked areas, underscoring their vital role in conservation efforts.

The result is automatically updated in the target table by the outcomes to show if the representation targets for biodiversity conservation have been achieved. This clearly shows that the goal for the species class and vegetation was not met.

Table 3.2: Target table for scenario-01.

ID	Name	Target	Spf	Ear+Cons	Total	PC Target
1	Waterbody	5.97	500	19	19.9	326.5
2	Cropland	7.88	500	8	26.3	102.3
5	Vegetation	7188.59	500	569	23962.0	7.92
8	Mountains	223916.61	500	266896	746388.7	119.2
11	Rangeland	572469.79	500	786535	1908232.6	137.4
102	Species	0.01	1000	0	0.04	0

Marxan's target table demonstrates how certain conservation aims are reached within planned conservation areas. It thoroughly breaks down the area and percentage of each target's representation in the chosen planning units. Table 3.2 can be used to determine if the proposed network appropriately addresses conservation goals such as safeguarding certain species or ecosystems. Planners can assess the efficacy of their spatial conservation techniques and make necessary changes by comparing objectives to their actual representation. Overall, the goal table is critical to ensure conservation priorities are effectively integrated into the final plan.

Figure 3.7. Displays the result of scenario 1, where target was set for 30% and output was in the form of best solution & frequency map.

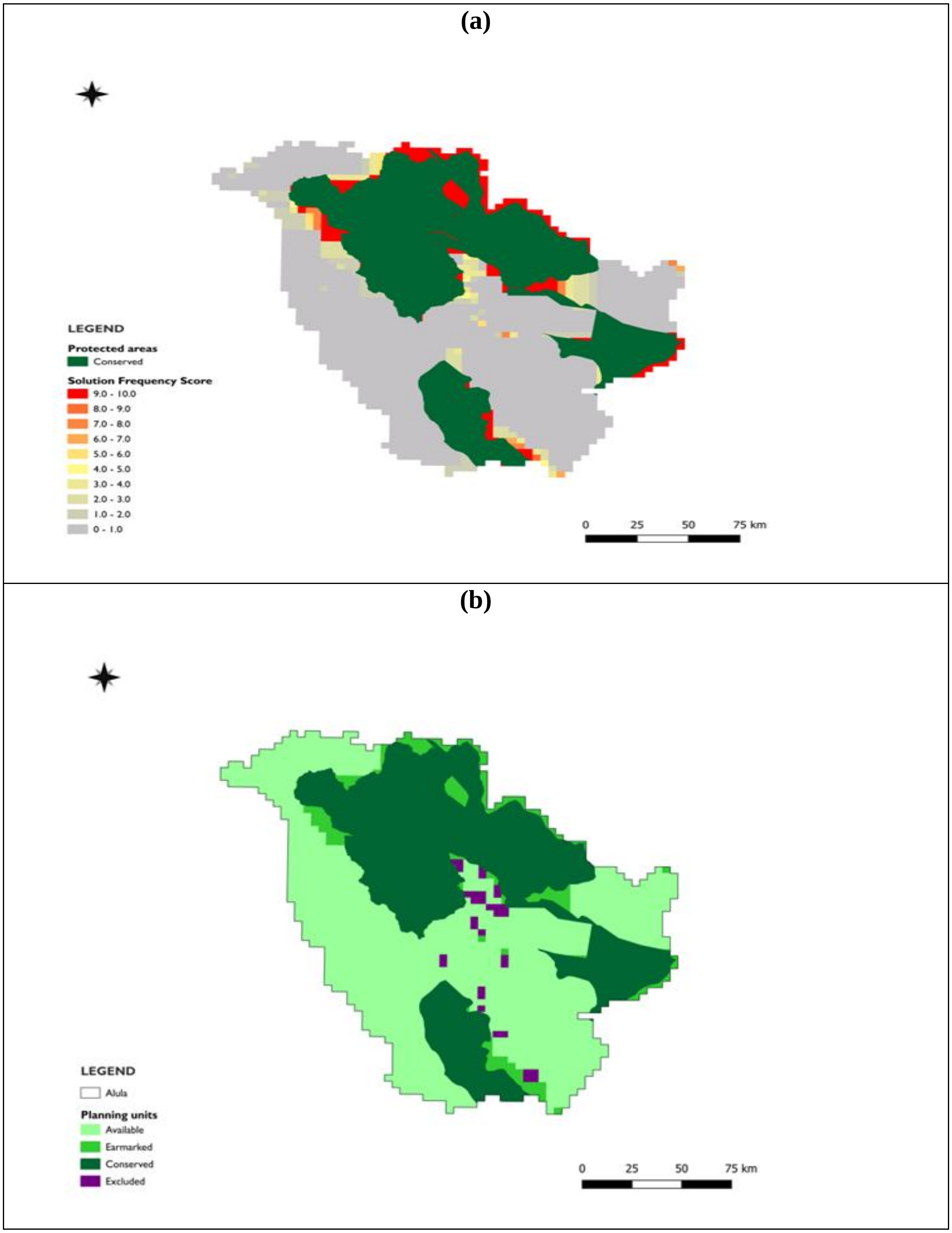

Figure 3.7. Displaying (a) specie frequency map for 30% target & (b) best solution map.

Scenario - 02:

In the second scenario of conservation planning, my goal was to preserve half of a species' entire population within a study area of 26,907 square kilometers. This strategic goal created Three separate management zones: 49% were set aside for human use, 39% were declared fully protected areas, and 12% were set aside for mixed-use or environmentally sustainable zones. This scenario ensures thorough coverage of species and Habitat classes by effectively meeting all representation objective criteria. The model was able to distribute zones more effectively and achieve optimal outcomes in biodiversity protection and sustainable land use by establishing a higher goal percentage. The frequency of selection for each planning unit across ten runs is depicted in this map. Areas with the highest frequency indicate priority sites with great conservation importance. Zones with frequencies less than five are given less importance. Grey areas, which have frequencies between 0 and 0.1, show places where the model was unable to locate the species.

The best solution map categorizes the area into four distinct sections. These include sections already designated for protection, zones excluded due to existing commercial development or built-up areas unsuitable for conservation, and areas identified for future conservation initiatives. High-priority zones exhibiting significant biodiversity or movement are earmarked, showing their critical importance in achieving the 50% conservation target. The outcomes reflect the 50% conservation target's achievement in striking a balance between habitat protection and biodiversity preservation within the studied region by showing that it successfully met all conservation goals for both species and habitat. Figure 3.8. Displays the result of scenario 2, where target was set for 50% and output was in the form of best solution & frequency map.

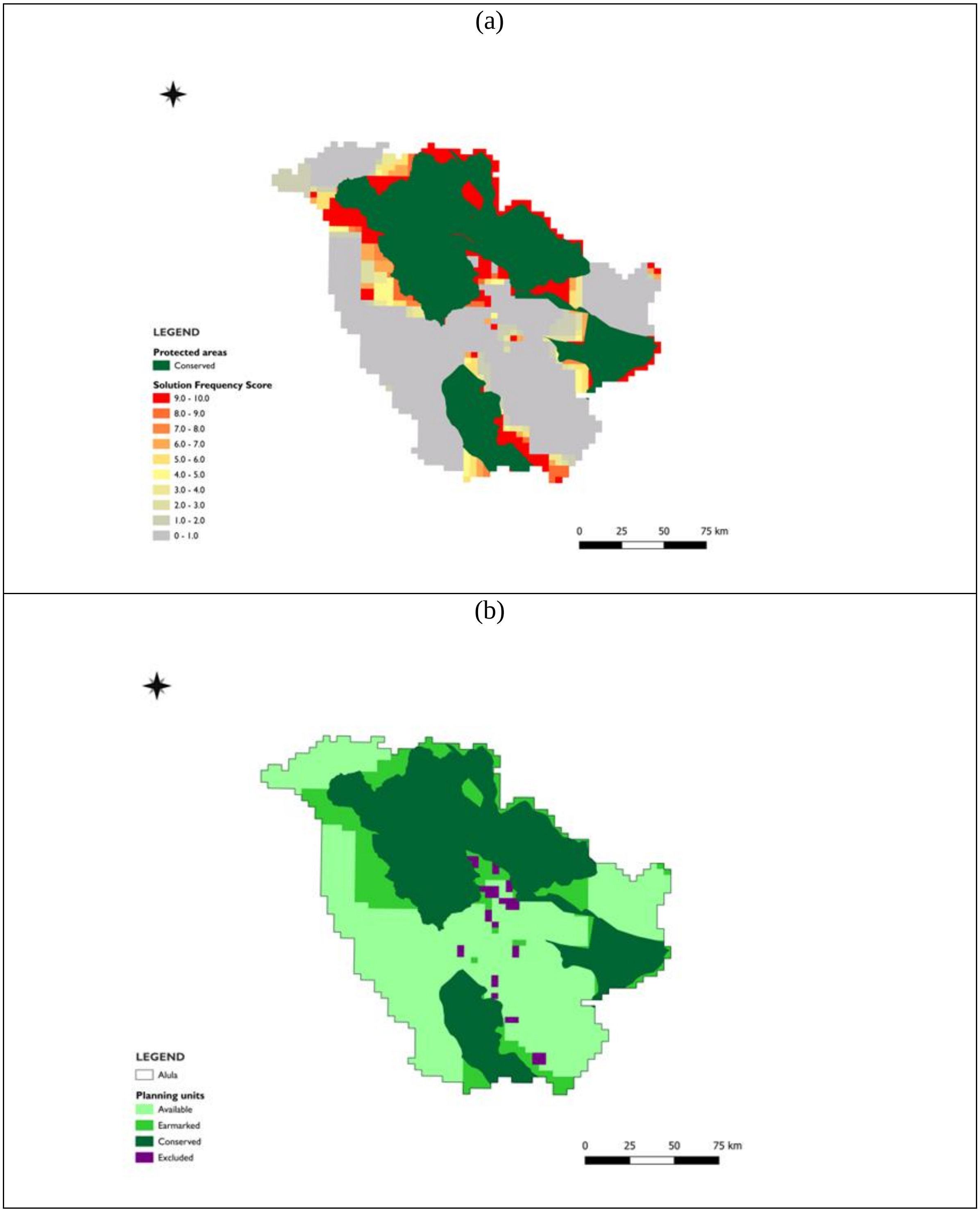

Figure 3.8. Displaying (a) specie frequency map for 50% target & (b) best solution map.

Table 3.3: Target table for scenario-02

ID	Name	Target	Spf	Ear+Cons	Total	PC Target
1	Waterbody	10	500	20	19.9	199.9
2	Cropland	13	500	19	26.3	143.91
5	Vegetation	11981	500	13009	23962.0	108.58
8	Mountains	373194	500	373214	746388.7	100.01
11	Rangeland	954116	500	1097752	1908232.6	115.05
102	Species	0.02	1000	0.02	0.04	100

Scenario - 03:

My goal in the third conservation planning scenario was to preserve 70% of the total population of a species within a research area that spanned 26,907 square kilometers. Three separate management zones were thus established: 23% for human use, 39% as entirely protected regions, and 38% as mixed-use or ecologically sustainable zones. However, this scenario did not meet goals for rangeland, agricultural, and mountain habitat conservation. This underlines how crucial it is to establish specific goals to direct conservation efforts, yet raising goals alone does not ensure the intended results. Involving stakeholders in the target-setting process is essential to avoiding misalignment and efficiently allocating resources. The best solution map divides the region into four distinct sections. High-priority zones with substantial biodiversity or mobility are given prominence, highlighting their importance in efficiently meeting the 70% conservation objective. The findings are automatically updated in the target table based on the outcomes, indicating if the biodiversity conservation representation objectives have been achieved. The targets for cropland, mountain, and rangeland species were clearly not met. Figure 3.9. Displays the result of scenario 3, where target was set for 70% and output was in the form of best solution & frequency map.

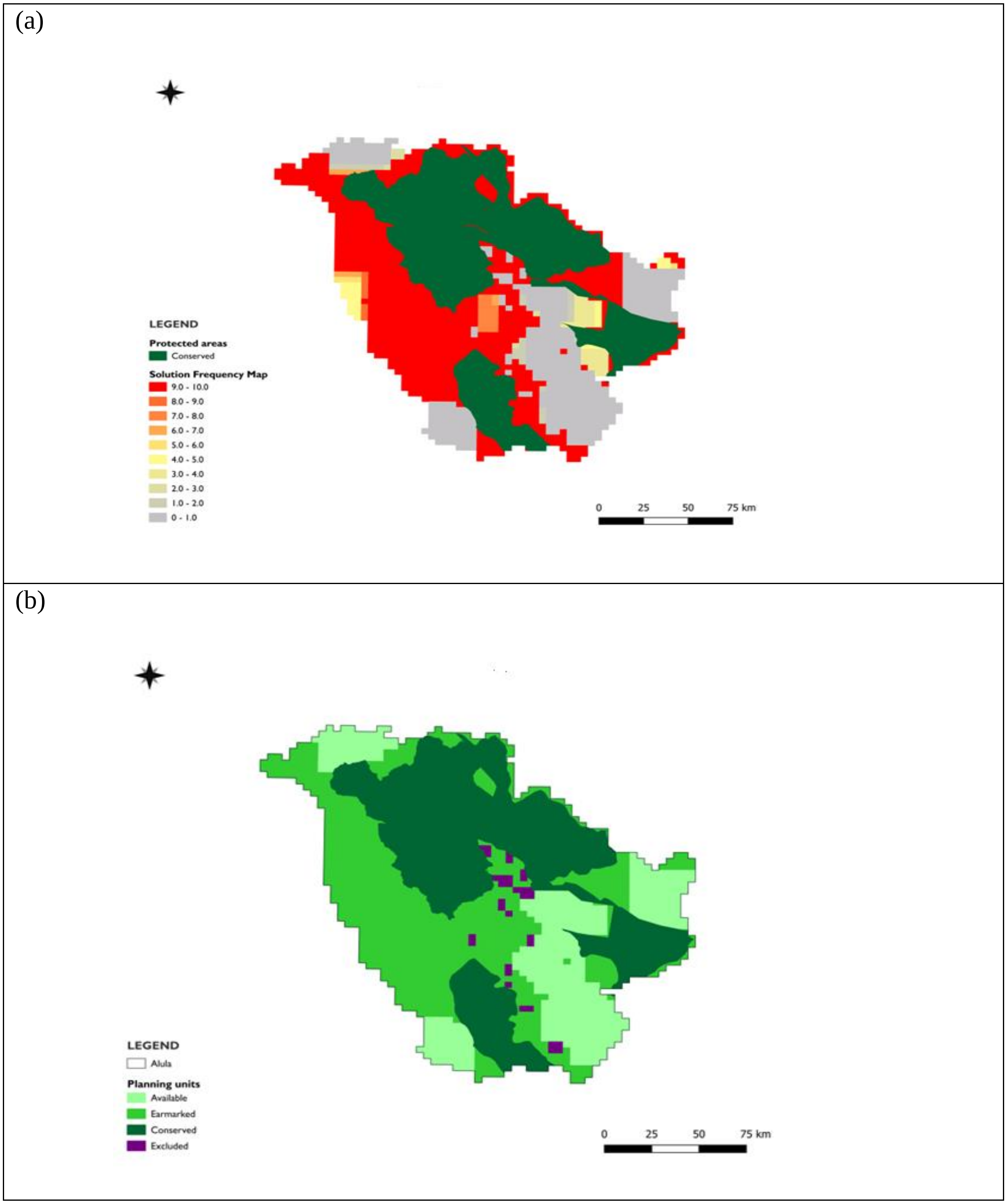

Figure 3.9. Displaying (a) specie frequency map for 70% target & (b) best solution map.

Table 3.4: Target table for scenario-03

ID	Name	Target	Spf	Ear+Cons	Total	PC Target
1	Waterbody	14	500	20	19.9	142.83
2	Cropland	18	500	18	26.3	97.88
5	Vegetation	16773	500	7342	23962.0	140.86
8	Mountains	522472	500	376439	746388.7	72.05
11	Rangeland	1335763	500	1090814	1908232.6	81.66
102	Species	0.03	1000	0.03	0.04	100

Target selection and species penalty variables considerably influence spatial zoning in terms of optimizing conservation outcomes. Target selection ensures that specified conservation goals, such as safeguarding certain species or ecosystems, are satisfied by prioritizing areas critical to these objectives. Species penalty factors, which account for species scarcity or vulnerability, help to improve zoning by emphasizing locations where these species are more at danger. Integrating these elements into spatial zoning leads to more effective biodiversity hotspot preservation and resource allocation. Areas chosen using these criteria frequently have higher conservation value and better support for target species. For example, integrating penalty considerations results in identifying essential habitats that could otherwise go unnoticed, improving the overall effectiveness of conservation programs (Margules & Pressey, 2000). This method assures that spatial zoning not only fulfils broad conservation aims but also reduces the hazards encountered by species, resulting in more robust and resilient conservation networks. By balancing target selection and species penalty variables, conservation efforts become more flexible and sensitive to the difficulties of sustaining biodiversity in dynamic settings.

Management zones:

As a result of achieving representation goals, the conservation planning output classified the area into three management zones: strictly protected areas for biodiversity preservation, multi-use zones for sustainable human activities, and exclusion zones unsuitable for conservation due to existing land uses such as urban development or intensive agriculture. This zoning system efficiently balances environmental goals and socioeconomic issues.

1. Human Use Zone:

   In Marxan output, the "Human Use Zone" refers to locations allocated for human activity such as agriculture, infrastructure, and recreation while balancing conservation strives with socioeconomic demands.

2. Strictly Protected Zone:

   These zones are designated for conservation without human intervention to maintain biodiversity and environmental integrity.

3. Mixed-Use Zone:

   These zones allow for restricted human activities that are in accordance with conservation objectives, such as sustainable agriculture or eco-tourism.

Figure 3.10 shows the division of three management zones for three different representation target goals. The strictly prohibited area is the conserved one that remains the same in all scenarios. The other two kept changing in three scenarios, making the second one most suitable for prioritization.

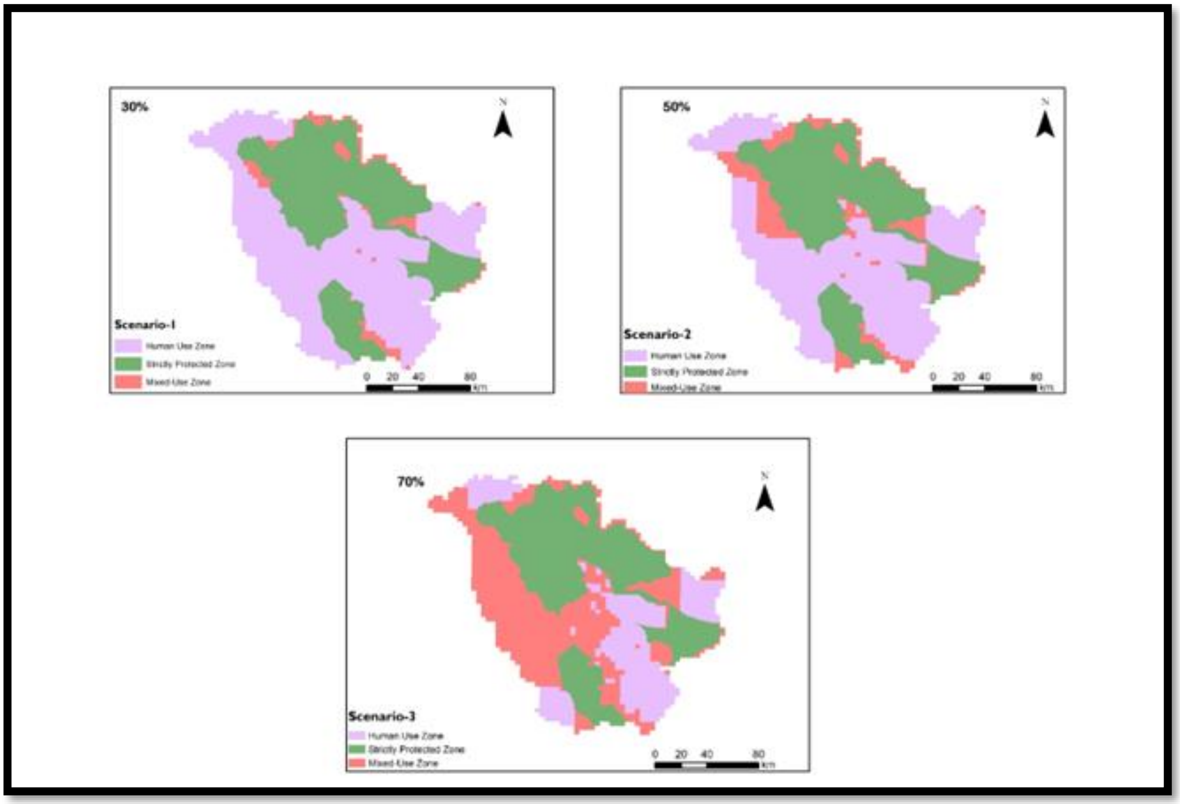

Figure 3.10. Allocation of management zones.

Table 3.5: Allocation of management zones.

Scenario (30%)	Area (km^2)	Percentage
Human Use Zone	14928	55
Strictly Protected Zone	10550	39
Mixed-Use Zone	1429	5
	26907	100

Scenario (50%)	Area (km^2)	Percentage
Human Use Zone	13070	49
Strictly Protected Zone	10550	39
Mixed-Use Zone	3287	12
	26907	100

Scenario (70%)	Area (km^2)	Percentage
Human Use Zone	6184	23
Strictly Protected Zone	10550	39
Mixed-Use Zone	10173	38
	26907	100

Tables illustrating the area and percentage for three separate zones with three unique aims show how spatial resources are divided among conservation priorities. The area allotted and % coverage for each aim indicate the relative importance of different conservation goals in each zone. These findings demonstrate the usefulness of zoning in achieving specific goals, such as habitat conservation or species preservation. Variations in area and percentage between zones show how zoning policies may be adapted to fulfill different conservation goals. Overall, the tables show the balance struck between various conservation goals and the geographical allocation needed to fulfil them.

Chapter 4

CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSIONS

In my research, systematic conservation planning was used to expand the corridor limits for endangered species in Alula. The study used Marxan and Geographic Information Systems (GIS) to analyze species distributions and habitat data to identify and prioritize priority conservation sites. This technique entailed extensive habitat mapping and assessment of protected areas, guiding spatial decision-making to achieve specified conservation goals based on biological requirements and ecological processes.

I used systematic conservation planning across three scenarios within a 26,907 square kilometer study area to evaluate the efficacy of various conservation goals and zoning systems. Each scenario, which conserved 30%, 50%, and 70% of the representation target, respectively, demonstrated various degrees of effectiveness in meeting representation requirements for habitat and endangered species. These findings highlight the complexities of conservation planning, in which greater conservation aims might improve biodiversity outcomes but need careful consideration of biological variety and stakeholder participation (Margules & Pressey, 2000; Possingham et al., 2006).

The second scenario, with the objective of 50% conservation, proved that higher conservation goals may efficiently satisfy biodiversity representation aims. This scenario's success in meeting all conservation goals emphasizes the necessity of setting ambitious but achievable goals and fine-tuning spatial prioritization techniques (Margules & Pressey, 2000). In contrast, the third scenario, which aimed for 70% protection, struggled to reach specified habitat conservation targets despite significant funding for severely protected and mixed-use zones. This scenario explains the need for precise objective formulation and stakeholder involvement to solve conservation difficulties and optimize resource allocation (Possingham et al., 2006).

The frequency and best solution maps revealed useful insights into priority conservation regions and gaps, which informed adaptive management plans for long-term biodiversity conservation. Combining spatial data analytics, ecological evaluations, and stakeholder viewpoints will be critical for improving conservation policies and successfully addressing socioeconomic concerns (Possingham et al., 2006). This thesis helps to advance conservation planning approaches by arguing for iterative procedures that improve ecological resilience and promote sustainable land management practices in a dynamic setting. Target selection significantly impacts conservation goal prioritization because it directs resources and efforts to regions with the most significant ecological relevance. When goals are established, such as endangered species or vital ecosystems, conservation methods are tailored to safeguard this priority. This targeted strategy ensures that conservation initiatives are focused on the most pressing requirements, increasing the efficacy of resource allocation. Conservation strategies can address critical ecological challenges and minimize risks more effectively if they prioritize places that satisfy certain criteria. Targets can also assist in detecting gaps in coverage and ensure that crucial regions are not neglected. As a result, conservation aims are prioritized more strategically and effectively, resulting in greater biodiversity preservation outcomes. Overall, the setting provides clarity and attention.

Targets narrow conservation priorities by concentrating efforts on specific ecological demands, improving the accuracy of conservation plans. This emphasis enables the identification of high-value areas that might otherwise be overlooked, resulting in a more efficient use of resources. By methodically addressing these goals, conservation strategies become more sensitive to the complexities of biodiversity protection. Finally, target-driven prioritization promotes a more strategic approach, resulting in better conservation outcomes and a stronger influence on saving vulnerable ecosystems.

4.1 RECOMMENDATIONS

Considering the recent status of wildlife species of flora and fauna around the globe, specifically in arid regions, given by IUCN, priority areas need to be set as ecological corridors for efficient movement and breeding of endangered species. Some suggestions/recommendations may be considered in this regard. Create reserve networks that accurately represent various ecosystems and protect crucial sites critical to the survival of endangered species. Ensure that the spatial zoning balances the representation of diverse species while addressing regions with high conservation significance, as identified by Hotspot analysis. Consider regions that provide critical ecological services, such as water management, soil fertility, and species conservation priority.

Observe the possible climate change implications when creating reserves to ensure that protected areas are robust and can adapt to modifying species distributions. Collaborate with local people, stakeholders, and conservationists to include practical factors while increasing the viability and support for the proposed zones. Implement a rigorous monitoring program to assess the success of the zoning plan, utilizing field data and updated studies to fine-tune and change the reserve network as needed. Use adaptive management techniques to continuously update and enhance spatial zoning in response to new data, changing conditions, and developing conservation aims. Establish multi-use zones that balance human activity and conservation by incorporating sustainable land management approaches to maintain ecosystems while enabling appropriate human uses.

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