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Habitat Quality Assessment in Relation to Urban Development Using the InVEST Model and GIS: A Case Study of Qamsar City

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Abstract

Given the rapid pace of urban growth and urbanization—manifested in increasing population and human demand for residential land—there is an urgent need for scientifically sound and well-structured development planning. Among the key principles of urban planning and land-use management are the assessment of natural habitat quality, land potential, and optimal site selection, all aimed at minimizing environmental degradation while maximizing urban efficiency. Accordingly, evaluating the quality and degree of degradation of natural habitats is essential for guiding urban development in Qamsar, a region characterized by sensitive environmental conditions, unique geography, and economic dependence on natural resources. This study employed the Habitat Quality model from the InVEST software suite to assess habitat quality in the context of urban development. Unlike traditional methods such as AHP and fuzzy logic, the InVEST model accounts for anthropogenic threats and quantifies habitat degradation and quality loss due to urban infrastructure. Input data included a classified land use/land cover (LULC) map and spatial layers of proximity to roads, rivers, and service centers, all developed within ArcGIS Pro. Sensitivity to threats and habitat status were determined for each land use class based on authoritative InVEST documentation and scientific literature. Results revealed that low-quality habitats are predominantly located in the northwest and areas adjacent to human settlements, suggesting these zones as suitable priorities for future urban expansion. Conversely, regions with high ecological value and habitat quality should be excluded from urban growth to preserve their

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environmental integrity. The InVEST model thus serves as a robust and practical ecological analysis tool, enabling environmentally informed and sustainable urban development decisions.

Keywords: Urban development, InVEST model, Habitat quality, Ecological analysis, Anthropogenic threats

1. Introduction

The establishment and emergence of a city is fundamentally influenced by its geographical setting, as natural phenomena play a vital role in urban site selection, sphere of influence, urban morphology, and physical expansion (Ganja yean, 2021). Currently, urban populations in developing countries are growing at a much faster rate than in developed nations. It is anticipated that rural communities will become a relatively small portion of the overall population structure in the future (Pour Mohammadi et al., 2009).

Today, the global agenda focuses on the preservation of natural resources and the pursuit of sustainability—an objective that requires the implementation of principles and criteria to guide urban development accordingly (Jome pour et al., 2018). Protected areas are essential for conserving biodiversity. The fate of many endangered species, the protection of healthy ecosystems with high species diversity and ecological richness, and the provision of ecosystem services from natural habitats heavily depend on the design and management of these protected zones (Saura et al., 2017). The emergence of environmental problems at various scales is often rooted in the disregard for ecological criteria in the site selection of new cities. Although improper urban configurations may stem from economic, social, historical, and political factors, they have also been a primary cause of environmental crises (Shanavar et al., 2016).

Globally, approximately 15 million hectares of farmland are converted to urban areas or decertified annually due to mismanagement. This alarming trend is also evident in Iran, where nearly 1.5 billion tons of soil are eroded each year, largely due to unsustainable and improper exploitation of natural resources (Makhdoom, 1991). Future habitat modeling enables us to recognize existing relationships and prevent disruption of ecological balance (Nelson et al., 2008). Geographic Information Systems (GIS), with their advanced capabilities in data management and spatial analysis, are regarded as effective tools in environmental planning (Karam, 2005).

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InVEST is a suite of GIS-based models that predict the value of ecosystem services and habitat resources using land cover/land use (LC/LU) maps (Polasky, 2011). Given the importance of understanding the sensitivity of habitats to various threats, studies have shown that the InVEST modeling framework is highly capable of delivering such insights (Mohammad Sarbaz et al., 2017).

The Habitat Quality model within the InVEST toolbox provides a robust analytical approach to assess habitat quality under human-induced threats such as roads, urban expansion, and high-risk land uses. Unlike traditional methods based on subjective scoring, this model integrates land use maps, threat factors, and ecological sensitivity classes to produce quantitative and reliable assessments of habitat quality (Sharp et al., 2018).

2. Literature review

In recent years, many studies have employed this model to evaluate ecological quality and the potential for urban development. For instance, Jeong et al. (2024) utilized the Habitat Quality model in South Korea to identify conservation priority zones, revealing that high-threat areas experienced severe habitat degradation. Similarly, Wang et al. (2022) applied statistical techniques such as principal component analysis to structurally determine the sensitivity of land-use classes to threats, which were then integrated into the InVEST framework. Zhao et al. (2023), in a study on the Yellow River Basin in China, demonstrated that urban expansion patterns had a significant impact on habitat quality, and their findings were directly applied in spatial policymaking.

In Thailand, Bamrungkhul and Tanaka (2023) evaluated land suitability for urban development in Nong Khai city. Their results showed that approximately 25% of the area was deemed suitable for physical expansion.

In Iran, Asadi et al. (2020) applied the Habitat Quality model to assess habitat vulnerability in Chaharmahal and Bakhtiari province, confirming the model's effectiveness in ecological evaluations.

Qamsar city, located in Isfahan province, is a prominent example of a region where urban development must be approached with heightened environmental sensitivity due to its unique geographical location, native vegetation, and economic dependence on natural resources. Given

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the mounting anthropogenic pressures, identifying areas that are environmentally suitable for development is of paramount importance. In this context, employing the Habitat Quality model in such an ecologically sensitive area as Qamsar offers a valuable approach for urban decision-making with minimal environmental repercussions. Since no comprehensive assessment of habitat quality has been previously conducted in Qamsar, this study aims to fill that gap and propose an environmentally informed urban site selection model to support sustainable development.

3. Methodology

3.1. Study Area

Qamsar is located approximately 27 kilometers south of Kashan County, forming a valley with an estimated dimension of 9 by 5 kilometers. Administratively, Qamsar belongs to Isfahan Province and is considered a sub-region of Kashan County (Figure 1). Positioned as the urban and administrative center of the Qamsar District, this city lies along the southern mountainous slopes of Kashan.

The Qamsar District consists of 25 inhabited settlements, including two towns—Qamsar and Joshqan-Kamoo—and several rural districts such as Ghahrood, Moslemabad, Hoseinabad, Ghaza'an, Alzag, and Kalukh. The distance from Qamsar to the provincial capital (Isfahan) is approximately 180 kilometers via the Tehran–Kashan–Isfahan highway and about 155 kilometers via the Ghahrood–Meymeh–Isfahan route.

Geographically, this garden city is situated at 33°45' N latitude and 51°26' E longitude, covering an area of 4,200,542 hectares. According to the national census data, the population of Qamsar was reported as 3,667 in 2006 and increased to 3,877 in 2016, indicating a slight upward trend.

The elevation of the city ranges from a minimum of 1,788 meters to a maximum of 2,004 meters above sea level. Due to its relatively high altitude, surrounding mountains, and abundant orchards, Qamsar enjoys a moderate climate. However, the dominant climate is classified as cold semi-arid in winter and dry-moderate in summer. The average annual minimum temperature is approximately 5.5°C, while the average maximum temperature is 21°C. The recorded absolute maximum temperature is 37°C, and the absolute minimum is –19°C.

Based on data from the Natanz meteorological station over a seven-year period, the annual average precipitation is 418 mm, and the estimated evapotranspiration is approximately 700 mm.

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Qamsar's main river originates from an altitude of about 3,000 meters in the southern highlands of Jowrah. It flows through the center of Qamsar at 1,100 meters, traverses toward the Kashan plain, and ultimately discharges into the Qom salt marsh (Mesileh).

According to Iran's geological structural classification, Qamsar lies within the volcanic-sedimentary belt of the Central Iranian Zone. This region is primarily composed of Eocene volcanic-sedimentary rocks from the Cenozoic era, which rest atop older folded formations. Numerous intrusive igneous bodies, both large and small, have penetrated the mountain system during the Tertiary period.

The rosewater (golab) industry holds remarkable significance in Qamsar due to the superior quality of its Damask roses. A substantial portion of local agricultural land is dedicated to rose cultivation, making Qamsar widely known as the Capital of Rosewater in Iran. Thanks to its unique environmental conditions and traditional extraction techniques, Qamsar produces one of the finest types of rosewater in terms of essential oil concentration and aroma (Qamsar Municipality, 2025).

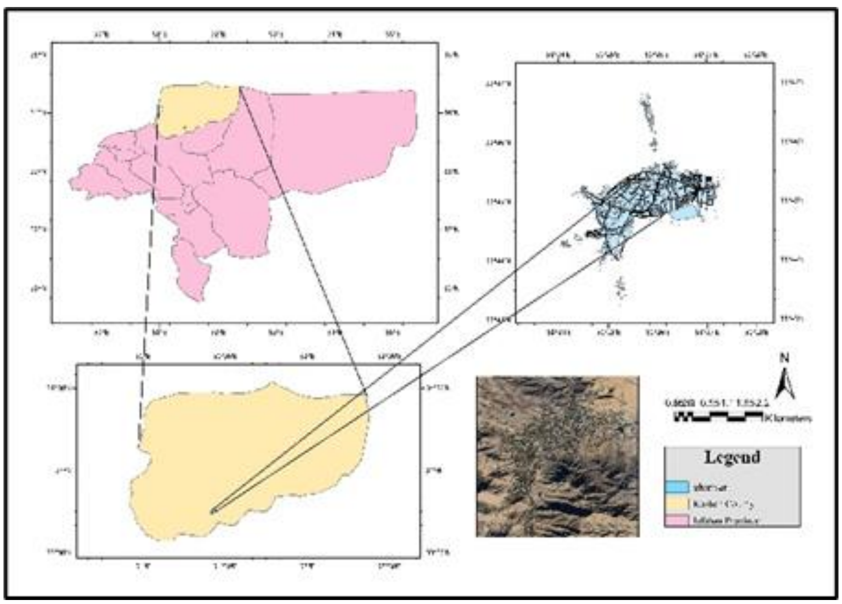

Figure 1. Geographical Location of Qamsar City

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3.2. Materials and Methods

In this study, the Habitat Quality model from the InVEST software suite (version 3.15.1) was used to assess the ecological quality of natural habitats within the boundaries of Qamsar city. This model utilizes spatial and ecological data to quantify habitat quality by incorporating human-induced threats, aiming to identify areas with potential for urban development that would cause minimal environmental degradation. Additionally, ArcGIS Pro version 3.1 was employed for the preparation of input layers and spatial data processing.

3.2.1. Spatial Data Preparation

Land use/land cover (LULC) maps of the study area were developed using Sentinel-2 imagery and the Supervised Classification method in the ArcGIS Pro environment. Six primary land cover classes were identified in this classification: (1) water bodies and rivers, (2) highlands and rangelands, (3) orchards and agricultural lands, (4) barren lands, (5) rocky terrains, and (6) urban areas. Each class was assigned a specific land use code (lucode) to ensure proper compatibility with the InVEST model input requirements. (Figure2)

To extract human-induced threats, three distance-based raster layers were generated in ArcGIS Pro using the Euclidean Distance tool. These layers included: distance from roads (roads.tif) (Figure3), distance from rivers (rivers.tif) (Figure4), and distance from service centers (services.tif) (Figure5). These rasters served as spatial indicators of anthropogenic pressure in the habitat quality assessment.

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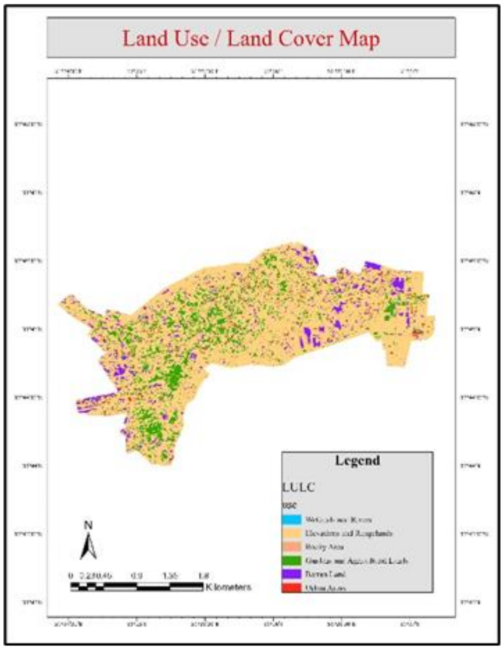

Figure 2. Land Use/Land Cover Map

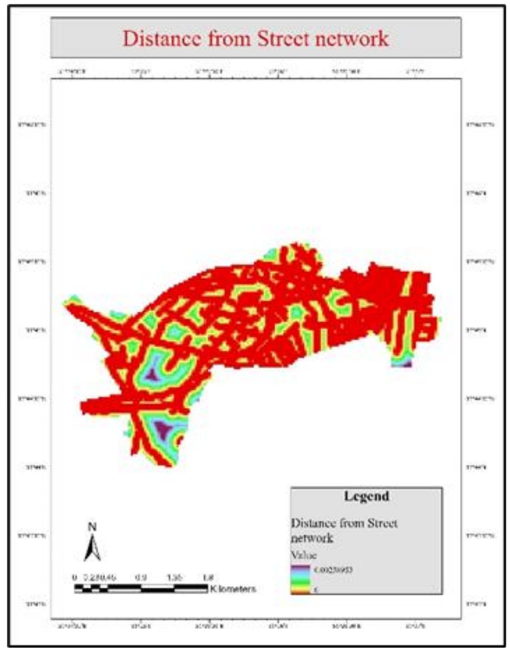

Figure 3. Distance from Roads

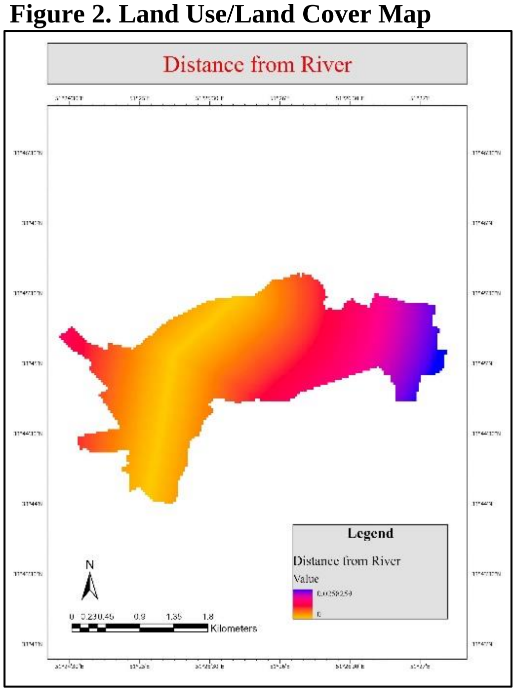

Figure 4. Distance from Rivers

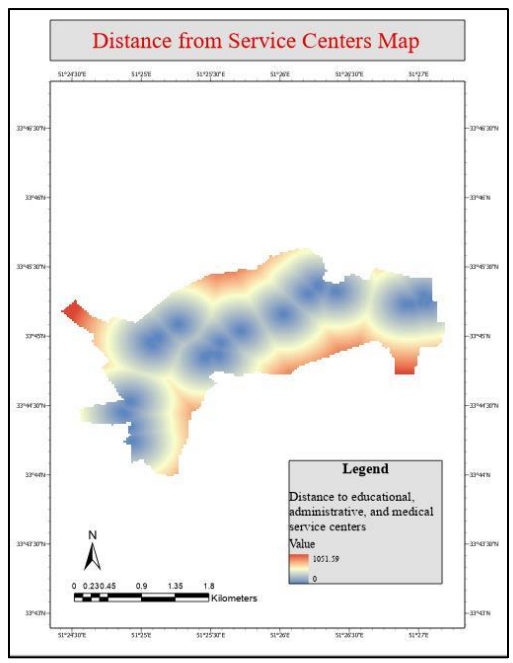

Figure 5. Distance from Services

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3.2.2. Model Table Configuration

To ensure the successful execution of the Habitat Quality model in the InVEST software, two fundamental input tables were developed in CSV format in accordance with the official model documentation. These tables play a critical role in defining how land cover types interact with anthropogenic threats and form the foundation of the model's computational framework.

3.2.2.1. Habitat Sensitivity Table (habitat_sensitivity_table.csv)

The habitat sensitivity table defines whether each land use/land cover (LULC) class is considered a natural habitat. This is expressed as a binary value—1 for habitat and 0 for non-habitat. Beyond this classification, the table specifies the degree to which each LULC class is sensitive to various anthropogenic threats that may degrade habitat quality. In this study, three primary threats were considered: proximity to roads, rivers, and service centers.

Sensitivity values range from 0 (not sensitive) to 1 (highly sensitive). These values are assigned independently for each threat and land cover class combination, based on expert knowledge, literature review, and local environmental conditions. For instance, agricultural land may be highly sensitive to road proximity but less so to rivers, while barren lands might exhibit minimal sensitivity to all threats. This table was formatted and labeled according to InVEST's model input specifications and corresponds to Table 1 in the results section.

3.2.2.2. Threats Table (threats_table.csv)

The threats table contains detailed parameters for each defined threat that may negatively impact habitat quality. Each row in this table includes the following key components:

• Maximum Effective Distance (max_distance): The furthest extent (in meters) to which the threat can influence surrounding land.

• Weight: A relative indicator of the threat's intensity or importance compared to other threats.

• Decay Function (decay): Defines how the impact of the threat decreases with distance. Two types are supported: linear, in which the threat decreases evenly, and exponential, where the threat drops off more sharply.

• Affected LULC Classes: A list of land cover classes that are sensitive to this particular

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threat, indicating where its influence should be calculated. For example, the "roads" threat may have a maximum influence distance of 5000 meters, a weight of 1.0, and a linear decay function, whereas the "rivers" threat may exert its effect over 3000 meters and follow an exponential decay curve. These definitions were encoded into the threats_table.csv file and aligned with the modeling structure used in InVEST. This table is also referenced as Table 2 in the results.

Both tables were created using Microsoft Excel and saved in CSV (Comma-Separated Values) format to ensure compatibility with the InVEST software environment. All parameter values were defined according to the official model documentation and guidelines provided by the Natural Capital Project (Sharp et al., 2018), while also incorporating site-specific adaptations relevant to the Qamsar region.

Table 1. Habitat Sensitivity Table

LULC Code	Land Use Type	habitat	Sensitivity To Road	Sensitivity To Rivers	Sensitivity To Services
1	Wetlands and Rivers	0	0.5	0.4	0.4
2	Rangelands and Meadows	1	0.4	0.4	0.3
3	Farmlands and Agriculture	1	0.6	0.6	0.6
4	Barren Lands	0	0.2	0.2	0.2
5	Rock and Desert Areas	0	0.3	0.3	0.3
6	Urban Areas	0	0	0	0

Table 2. Threats Table

Threat Name	Decay Type	Threat Weight	Max Distance of Effect
Euclidean Distance Of roads	Linear	1.0	5000
Euclidean Distance Of rivers	Exponential	0.8	3000

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Euclidean Distance Of services	Linear	0.6	4000

3.2.3. Running the Habitat Quality Model

Once all required spatial layers and input tables were properly prepared, the Habitat Quality model from the InVEST software package (version 3.15.1) was executed to assess the spatial distribution of ecological integrity across Qamsar city. This model is designed to evaluate the quality of habitats by integrating land use data with anthropogenic pressures, thereby identifying zones that are either ecologically vulnerable or relatively intact.

The model execution was carried out through the InVEST Workbench interface. Input files—including the land use/land cover raster (lulc.tif), the habitat sensitivity table (habitat_sensitivity_table.csv), and the threats definition table (threats_table.csv)—were uploaded into the model form. These inputs had previously been constructed based on scientific rationale and locally adapted sensitivity and threat values, as described in earlier sections.

A key parameter in the model configuration was the half-saturation constant, which was set to 0.5. This parameter controls the shape of the response function between cumulative threats and the resulting degradation. A value of 0.5 is commonly recommended in the InVEST user documentation (Sharp et al., 2018), as it represents a balanced point where the effect of threats begins to taper off—allowing for a more realistic and stable simulation of degradation impacts.

Upon execution, the model processed the spatial data and generated a series of output layers that serve as the core analytical results of this study. These outputs included:

•hab_quality.tif, a raster map assigning habitat quality scores to each cell in the study area based on proximity to threats and the land use type. Higher values (closer to 1) indicate better habitat conditions with minimal disturbance, while lower values reflect degraded and highly threatened zones.

• hab_degradation.tif, a raster map that quantifies the cumulative impact of defined threats on each pixel, regardless of whether the cell is considered habitat or not.

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• Summary statistics, automatically generated for each land use class, reporting average habitat quality and degradation values, which can later be used for class-level comparisons and policy recommendations.

After obtaining these outputs, the results were subjected to further geospatial analysis using ArcGIS Pro. This included operations such as:

Reclassification to simplify interpretation and highlight critical zones for conservation or urban intervention.

This stage of the modeling was crucial not only for visualizing the spatial manifestation of ecological degradation but also for extracting actionable insights. The outputs serve as foundational evidence for decision making processes related to urban planning, conservation prioritization, and ecological risk mitigation in the Qamsar region.

4. Results and discussion

The results obtained from the Habitat Quality model in the InVEST software reveal a critical ecological condition in the natural habitats of the Qamsar region. The mean habitat quality index was calculated at 0.0655, which, on a scale of 0 to 1, indicates a severely degraded ecosystem. This low value clearly reflects the intense impact of anthropogenic threats such as urban expansion, mechanized agriculture, road construction, and proximity to service centers on the region's natural habitats.

The habitat quality output map (hab_quality.tif) (Figure6) showed that areas with high ecological quality are very limited, scattered, and mainly concentrated in the central and southeastern parts of the region, where there is greater distance from destructive elements such as roads, rivers, and service facilities. In contrast, the highest levels of degradation were observed in the northwestern and western zones, which spatially overlap with the densest urban infrastructure.

Meanwhile, the habitat degradation map (deg_sum_c.tif) (Figure7), which quantifies the intensity of threats, revealed a mean degradation value of 0.4179—relatively high compared to the quality index—indicating significant anthropogenic pressure over a large portion of the study area. The degradation ranged from 0 to a maximum of 0.60, with the lowest values found in remote areas

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less exposed to human activity. A simultaneous assessment of both maps demonstrated a strong inverse correlation between habitat quality and degradation intensity. Areas classified as "very poor" in the quality map corresponded closely to those with the highest degradation values. This spatial overlap confirms the accuracy of the model's threat definitions and sensitivity assignments, and supports the structural soundness of the modeling process.

Moreover, the spatial configuration of the maps revealed clear ecological gradients along the borders between high-quality and low-quality zones. Many transitional areas, especially those located between preserved natural zones and urbanized districts, displayed moderate levels of degradation—suggesting an advancing front of habitat loss. This emphasizes the need for buffer zones and preventive planning around ecologically valuable areas.

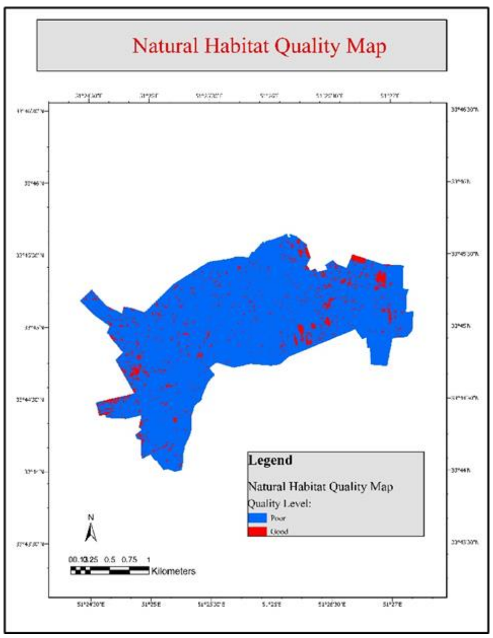

Figure 6. Natural Habitat Quality Map

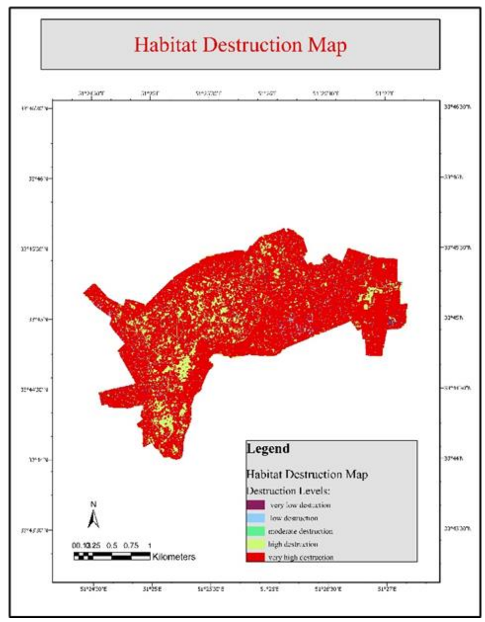

Figure 7. Habitat Destruction Map

5. Policy and Conclusion

The use of the Habitat Quality model in InVEST provided a comprehensive and spatially explicit assessment of the ecological status in the Qamsar region. The findings indicate that a significant portion of the region's natural habitats are in a critical state, facing widespread degradation. The

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extremely low mean habitat quality value (0.0655), alongside a high average degradation index (0.4179), underscores the urgent need for conservation-focused interventions and a reassessment of current development strategies.

The model's spatial outputs enabled the identification of priority zones for intervention. The northwestern and western areas, closely associated with dense infrastructure and urban sprawl, emerged as key targets for control and mitigation. Conversely, the central and southeastern parts, with relatively higher habitat quality, should be prioritized for ecological protection and continuous monitoring to prevent further encroachment.

Based on spatial analysis, areas with low habitat quality and high degradation can be considered suitable candidates for future urban development, given their low conservation value. In contrast, areas with high ecological quality must be safeguarded as ecological reserves, with all human expansion strictly avoided.

The study also demonstrates that the Habitat Quality model is not only effective for current ecological assessment but also serves as a powerful tool in urban and regional planning. By integrating spatial data on land use, threat proximity, and habitat sensitivity, the model provides critical insights for policymakers, urban planners, and sustainability professionals.

Recommendations for Future Studies:

1.Temporal analysis: Conducting multi-temporal assessments to monitor ecological dynamics and long-term habitat changes.

2.Refinement of threat layers: Incorporating additional threats such as noise pollution, heavy traffic, soil erosion, and industrial activity to enhance model precision.

3.Field validation: Comparing model outputs with field-collected ecological data or high-resolution satellite imagery to verify spatial accuracy.

4.Policy integration: Applying model results to inform land-use planning, urban zoning, permit issuance, and biodiversity conservation strategies.

In conclusion, this study underscores the value of data-driven spatial models such as InVEST in achieving sustainable and balanced development. Areas with low ecological value may be considered for controlled development, while high-value zones should be conserved as critical

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biodiversity assets. The application of such models can guide evidence-based policies that harmonize urban growth with environmental integrity.

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