Analysis of Human Disturbance and Ecological Security Evolution in Oasis in Arid Area Based on LUCC: A Case Study of Oasis in the Northern Tianshan Mountain Slope Economic Zone

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Abstract. Oases in arid areas are environmentally and economically vulnerable regions. Study on ecological security of oases in arid areas is of great significance to the stability and the economic development of oases. Based on Land Use/Land Cover data in 1965, 1980, 1995, 2005 and 2015, the study analyze the temporal and spatial changes in human disturbance and ecological security of oases in the Northern Tianshan Mountain Slope Economic Zone (NTMSEZ) in recent 50 years by establishing the ecological security index (ESI) through human disturbance index and landscape vulnerability index. The results showed that: in recent 50 years, the human disturbance of the NTMSEZ has been increased to current moderate human impacts. Urban construction, oasis expansion and farmland reclamation are the main factors of the increment. The human disturbance in Urumchi, Shihezi, Kuitun, Miquan and Changji is higher than that in other oases and that in core areas of oasis is higher than other areas. The ESI of the NTMSEZ increases firstly and then decreases. In most areas, the ESI is “relatively unsafe” and “critical”. However, there are increasingly more vulnerable areas, moving northwestwards and expanding southwards. The ESI gradually presents a “NW-SE” trend of zonal distribution pattern.

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1. Introduction
With increasingly frequent global climate changes and human activities, eco-environmental issues have been a common concern [1-2]. In China, the arid areas have abundant land, light, heat and mineral resources. However, due to an arid climate, severe drought and water resources shortage, they are also the most eco-environmentally vulnerable areas in China [3]. With oasis expansion and economy development, the ecological balance has been gradually disrupted in arid areas, causing a number of eco-environmental issues. In this case, the ecological security of oases has been a research focus in recent years [4-5]. Ecological security refers to a state where there is no threat to people’s daily life, health, safety, basic rights, living security sources, necessary resources, social order, ability to adapt to environmental changes, etc [6]. In recent years, from the landscape ecology perspective, the ecological security assessment system built based on the landscape index and the statistical data in general. However, when the high correlation between the selected landscape index and the human disturbance degree is not indicated, it might cause considerable errors in the results. With the statistical data as an index, there will be a loss in spatial information [7]. In this paper, oases in the Northern Tianshan Mountain Slope Economic Zone (NTMSEZ) is selected as a case study and the land cover type maps in 1965, 1980, 1995, 2005 and 2015 are taken as the main data source to establish the human disturbance degree and the ecological security index based on GIS technique. The aim of this paper is to analyze the temporal and spatial changes in human disturbance and ecological security in the area.

2. Data and study method

2.1. Study area
The NTMSEZ is located in the middle section of northern slope of Tianshan Mountains in Xinjiang, is a typical “mountain-basin system” in northwest arid area in China. It covers Urumchi, Changji, Miquan, Fukang, Hutubi, Manas, Shihezi, Shawan, Wusu, Kuytun and Karamay. It is the most densely populated area and the most economically developed area in Xinjiang, a key area of the western development strategy and a central area.

2.2. Data
For this study, the Land Use/Land Cover (LULC) data with a spatial resolution of 30m in 1965, 1980, 1995, 2005 and 2015 from Resources and Environmental Sciences Data Center, Chinese Academy of Sciences (http://www.resdc.cn) were selected as the data sources. Considering the practical situation of the study area, secondary land cover types of LULC data can be divided into 13 classes, including glaciers, shrubbery lands, beaches and flats, unused lands, sparsely forested woodland, medium/high coverage grasslands, lakes, sparsely coverage grasslands, irrigated land, reservoir and pond surface, dry land, residential quarters in rural areas, areas of cities and town.

2.3. Study method
In this paper, human disturbance index (U) and landscape vulnerability index (Q) were used to establish ecological security index (ESI). Based on the different proportion of landscape types area of a grid, this paper evaluate the disturbance intensities of human activity. The calculation method can be
found in the reference [8].

\[ U = \sum_{i=1}^{R} \left( \frac{A_i}{A} \times P_i \right) \]

(1)

where: \( U \) is human disturbance index of a grid; \( A \) is the total area (km\(^2\)) of the grid; \( A_i \) is the area (km\(^2\)) of the land cover type \( i \) in the grid; and \( P_i \) is the human disturbance class of the land cover type \( i \).

Following the studies of Walz [9] and Chen [10], a seven-point scale was used to classify different land cover types by degree of human disturbance (table 1).

| Class | Degree of human disturbance | Land cover type                      |
|-------|-------------------------------|--------------------------------------|
| 1     | almost no human impacts       | glaciers,                            |
| 2     | weak human impacts            | shrubbery lands, beaches and flats, unused lands |
| 3     | moderate human impacts        | sparsely forested woodland, medium/high coverage grasslands, lakes |
| 4     | moderate-strong human impacts | sparsely coverage grasslands, irrigated land, reservoir and pond surface |
| 5     | strong human impacts          | dry land                             |
| 6     | very strong human impacts     | residential quarters in rural areas  |
| 7     | excessively strong human impacts | areas of cities and town            |

Table 1. Different land cover types to degree of human disturbance.

Landscape vulnerability (Q) refers to the vulnerability of the ecosystem represented by the land cover types when suffered external disturbances. In general, the simpler the structure of the food chain, the less the species diversity index, the more fragile the ecosystem. A ten-point scale was used to classify different land cover types by degree of vulnerability (table 2).

| Degree of vulnerability | Land cover type         | Degree of vulnerability | Land cover type |
|-------------------------|-------------------------|-------------------------|----------------|
| 1                       | areas of cities and town, residential quarters in rural areas | 6                       | irrigated land |
| 2                       | shrubbery lands         | 7                       | irrigated land |
| 3                       | sparsely forested woodland, medium/high coverage grasslands      | 8                       | lakes         |
| 4                       | sparsely coverage grasslands                                    | 9                       | unused lands  |
| 5                       | dry land                                                            | 10                      | glaciers,     |

Accordingly, the ESI is introduced, which indicates the degree of ecological security of land cover type. The formula is given as follows:

\[ ESI = 1 - U \times Q / 70 \]

(2)

3. Analysis of results

3.1. Temporal and spatial changes in human disturbance degree

In recent 50 years, human disturbance of the NTMSEZ has been increased from 2.56 in 1965 to 3.19 (moderate human impacts) in 2015. Human disturbance is divided into 6 classes to calculate the area of each class in different years (table 3). A spatial distribution map is given in figure1. It can be learnt that in recent 50 years, human disturbance of the NTMSEZ mainly falls into Class 2~3, while Class 5~6 has the most obvious changes in area, followed by Class 4~5; and the area of Class 1~2, 2~3 and 3~4 tends to decrease with fluctuated changes, while that of Class 4~5, 5~6 and 6~7 presents
a significant increase trend. From the perspective of time, there were the most obvious changes in human disturbance during 1965-1980 and 2005-2015. In the NTMSEZ, there is the highest human disturbance degree along the “NW-SE” line, with gradual decrease towards both sides. With Urumchi as the boundary, both the human disturbance changes and the disturbance degree of oasis in the west are higher than those in the east. Human disturbance in each core oasis area is 5~7, higher than that in other areas. Moreover, in recent 50 years, the human disturbance has reached very strong and excessively strong human impacts. By 2015, human disturbance degree in Urumchi, Shihezi, Kuytun, Miquan and Changji has been higher than that in other oases. With increasingly intensive human activities, the areas of different human disturbance classes now have expanded from fragmentation towards integration.

### Table 3. Statistics of area of human disturbance class in different times (km²).

| Human disturbance class | 1965   | 1980   | 1995   | 2005   | 2015   | Changes in area in recent 50 years |
|-------------------------|--------|--------|--------|--------|--------|-----------------------------------|
| 1~2                     | 33316.20 | 14491.17 | 14204.79 | 13795.92 | 18813.78 | -14502.40                        |
| 2~3                     | 55967.58 | 50261.94 | 50478.93 | 50019.12 | 44029.71 | -11937.90                        |
| 3~4                     | 30502.62 | 38752.74 | 38789.64 | 38029.32 | 26447.31 | -4055.31                         |
| 4~5                     | 3326.31  | 19097.28 | 19101.33 | 20414.79 | 29788.74 | 26462.43                         |
| 5~6                     | 1.80    | 511.29  | 539.73  | 848.25  | 3551.13  | 3549.33                           |
| 6~7                     | 0.00    | 0.09    | 0.09    | 7.11    | 483.84   | 483.84                            |

### Figure 1. Spatial distribution of human disturbance of the NTMSEZ.

#### 3.2. Analysis of temporal and spatial changes in ecological security

The ESI of the NTMSEZ in different years was calculated (table 4) as per Formula (2). The ecological security of the area under study was divided into 7 levels based on natural breaks, as shown in table 5.

### Table 4. ESI in different years.

|          | 1965 | 1980 | 1995 | 2005 | 2015 |
|----------|------|------|------|------|------|
| ESI      | 0.75 | 0.76 | 0.77 | 0.77 | 0.76 |
Table 5. ESI level criterion.

| Level | 1 Level | 2 Level | 3 Level | 4 Level | 5 Level | 6 Level | 7 Level |
|-------|---------|---------|---------|---------|---------|---------|---------|
| ESI   | <0.65   | 0.65~0.70 | 0.70~0.75 | 0.75~0.80 | 0.80~0.85 | 0.85~0.90 | 0.90~0.95 |
| Criterion | Extremely unsafe | Unsafe | Relatively unsafe | Critical | Relatively safe | Safe | Ideally safe |

3.2.1. Time difference.

Statistics of areal percentage of ESI levels in different years are given in table 6. According to table 6, in recent 50 years, the mean values of the economic belt on NTMSEZ is between 0.75 and 0.8, presenting a “first increase and then decrease” trend. However, the ecological security value in 2015 is still higher than the initial value. As a whole, the ESI in most zones in the study area is “critical” and only a few zones fall into “extremely unsafe” and “unsafe”. The area of Level 3 and Level 4 decreases and that of other levels increases. This is due to land reclamation on a large scale before 2005 with the purpose of meeting local residents’ production and living demands and solving the population-land contradictions. In this case, the land cover type tend to be more abundant; the structures tend to be stable and the rises. After 2005, with further oasis expansion, urban construction and land reclamation, the ESI drops down.

Table 6. Statistics of areal percentage of ESI level in different periods.

| Level | 1965/% | 1980/% | 1995/% | 2005/% | 2015/% | Changes in area during 1965-2015 |
|-------|--------|--------|--------|--------|--------|--------------------------------|
|       | Percentage | Area/km² |        |        |        |                                 |
| 1     | 0.81   | 0.12   | 0.11   | 0.10   | 1.51   | 0.70 | 859.77 |
| 2     | 6.09   | 6.32   | 6.28   | 9.19   | 15.18  | 9.09 | 11201.40 |
| 3     | 53.74  | 46.03  | 46.08  | 44.96  | 40.16  | -13.58 | -16722.09 |
| 4     | 27.40  | 21.71  | 21.68  | 19.68  | 22.03  | -5.37 | -6575.67 |
| 5     | 7.62   | 13.82  | 13.84  | 13.45  | 8.59   | 0.97  | 1192.26 |
| 6     | 4.01   | 11.35  | 11.36  | 11.96  | 12.10  | 8.09  | 9955.26 |
| 7     | 0.36   | 0.65   | 0.65   | 0.65   | 0.43   | 0.07  | 88.65 |

3.2.2. Spatial difference.

According to the spatial distribution of ESI shown in figure 2, there have been increasingly more zones with risk in the NTMSEZ and the ecosystem shows the trend of instability in recent 50 years. From the spatial distribution, the ESI in the west is lower than that in the east, and that in the north is lower than that in the south. The zones of Level 1 and 2 move northwestwards and expand southwards in general. The greatest changes in the ESI are observed in northwest oases. In 1965, Level 3 and 4 predominated in the said zone. However, Level 1 and 2 was observed in most zones in 2015, indicating that the ESI was obviously decreased. The zone with the lowest ESI (Level 1) has moved from Qitai County to Urumchi and Changji and finally to Karamay, Shawan and Manas. The zones of different levels now have expanded tending from fragmentation towards integration. In 2015, Level 6 and 7 of oases in the economic belt on NTMSEZ had the largest area, mainly found along the “NW-SE” axis, i.e. the ESI in core oasis area is lower than that in other areas. The ESI has obvious
spatial differentiation characteristics, presenting a “NW-SE” trend of zonal distribution pattern as a whole, lying in the Relatively Unsafe Zones, Extremely Unsafe Zones, Unsafe Zones, Safe and Relatively Safe Zones and Critical Zones from north to south respectively.

![Figure 2. Spatial distribution of ESI of the NTMSEZ.](image)

### 4. Conclusions

The study analyzed the temporal and spatial changes in human disturbance and ecological security of oases in the NTMSEZ in recent 50 years. The following conclusions can be drawn:

1. From 1965 to 2015, human disturbance of the NTMSEZ was increased to a medium degree. Urban construction, oasis expansion and farmland reclamation are the main factors of the increasing trends. In 2015, human disturbance degree in Urumchi, Shihezi, Kuytun, Miquan and Changji was higher than that in other oases and that of core oasis area is higher than that in other areas.
2. From 1965 to 2015, the ESI of the NTMSEZ increases firstly and then decreases. In most areas, the ESI is “relatively unsafe” and “critical”. However, there are increasingly more areas in risk, moving northwestwards and expanding southwards. The ESI gradually presents a “NW-SE” trend of zonal distribution pattern.

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