

Desertification Analysis in the Tarim Basin Using the Raster Accumulation Method (Post-print)

Authors: Liu Chang

Date: 2021-03-03T00:00:00+00:00

Abstract

Land desertification is one of the most severe environmental issues globally today and also the primary ecological and environmental problem facing the arid regions of northwestern China. Conducting dynamic studies on land desertification contributes to desertification disaster prevention and control as well as national land spatial development. Based on monthly MODIS-NDVI 1 km data from 2000 to 2018, this study employs the raster accumulation method and transition matrix method to explore and analyze the change rate, spatial characteristics, and causes of land desertification in the Tarim Basin. The results indicate: (1) Land desertification is a dynamic process characterized by interannual fluctuations and cumulative effects; (2) The raster accumulation method possesses strong capabilities for continuous dynamic analysis, enabling accurate analysis of land desertification change rates, evolutionary trends, and spatial characteristics of changes, and can quantitatively analyze the causes of land desertification; (3) Desertification degradation in the Tarim Basin is primarily the degradation of grasslands, while desertification improvement is mainly the improvement of woodlands and cultivated lands; (4) From 2000 to 2018, land desertification in the Tarim Basin showed an overall improvement trend of extremely severe desertification gradually transitioning to non-desertification, with the transition pathway being: extremely severe desertification → severe desertification → moderate desertification → slight desertification → non-desertification. Improvement areas were mainly distributed in oasis regions, while deterioration areas were primarily located in the middle reaches of the Tarim River and the lower reaches of the Cherchen River. The causes of land desertification were mainly human activities. The research methodology of this paper provides a new approach for dynamic monitoring of land desertification, and its findings can offer theoretical foundations for national land resource development and desertification control in the Tarim Basin.

Full Text

Desertification Analysis Based on Grid Accumulation Method in the Tarim Basin

LIU Chang^{1,2}, LI Chengzhi^{1,2,3}, LI Shenghui^{1,2}, FU Xiaolei^{1,2}, SHI Qingdong^{1,2,3}

¹Institute of Arid Ecology and Environment, Xinjiang University, Urumqi, Xinjiang, China

²College of Resources and Environmental Sciences, Xinjiang University, Urumqi, Xinjiang, China

³Key Laboratory of Oasis Ecology, Ministry of Education, Xinjiang University, Urumqi, Xinjiang, China

Abstract

Land desertification represents one of the most severe environmental challenges globally and constitutes the primary ecological problem confronting China's northwestern arid regions. Investigating the dynamics of land desertification is essential for disaster prevention and spatial development of land resources. Based on monthly MODIS NDVI 1 km data, this study employs the grid accumulation method and transfer matrix approach to explore the change rate, spatial characteristics, and underlying causes of desertification in the Tarim Basin. The results demonstrate that: (1) Land desertification is a dynamic process characterized by interannual fluctuations and cumulative effects; (2) The grid accumulation method exhibits strong capability for continuous dynamic analysis, enabling accurate assessment of desertification change rates, evolution trends, and spatial patterns, while facilitating quantitative analysis of causative factors; (3) Desertification degradation in the Tarim Basin primarily involves grassland deterioration, whereas improvement mainly occurs in forestland and cultivated land; (4) From 2000 to 2018, the basin exhibits an overall improvement trend, with extremely severe desertification gradually transitioning to non-desertified land. The improvement areas are mainly distributed within oasis regions, while deterioration concentrates in the middle reaches of the Tarim River and lower reaches of the Qarqan River, with human activities identified as the primary driving force. This research methodology provides a novel approach for dynamic desertification monitoring, and its findings offer theoretical foundations for land resource development and desertification control in the Tarim Basin.

Keywords: land desertification; grid accumulation method; transfer matrix; dynamic change; desertification causes

1. Study Area Overview

The Tarim Basin is a typical inland basin characterized by scarce precipitation (<50 mm annually), high potential evaporation (up to 3400 mm), sparse vegetation, and extreme aridity. The region's predominantly sandy soils lack fine

particles and organic matter, making them highly susceptible to wind erosion. Vegetation growth depends primarily on river water and groundwater, with natural vegetation distributed mainly along river corridors. Key species include *Populus euphratica*, *Tamarix chinensis*, *Alhagi sparsifolia*, *Karelinia caspia*, and *Phragmites communis*. Major rivers include the Tarim, Aksu, Hotan, Kaidu, Kashgar, and Qarqan Rivers [Figure 1: see original paper].

With a population of 10.9596 million, human activities are increasingly intensive. Population growth has expanded cultivated land, while excessive water withdrawal has caused river channel drying and groundwater decline, leading to rapid desertification development in downstream riparian corridors. Unscientific irrigation practices have induced soil salinization, forcing large areas of farmland to be abandoned and further exacerbating desertification. Although the Tarim River water conveyance project has achieved significant results, desertification remains severe in the basin.

2. Data Sources

MODIS data, characterized by stable quality, strong periodicity, and easy accessibility, has been widely applied in desertification monitoring. This study utilized the MOD13A3 vegetation product from NASA, with 1 km spatial resolution. Based on study area requirements, data from track numbers h23v04, h23v05, h24v04, h24v05, h25v04, and h25v05 were selected, comprising 228 scenes of monthly composite data from 2000 to 2018. The MODIS Reprojection Tool was employed for image mosaicking, clipping, and projection conversion to obtain the Tarim Basin NDVI monthly dataset with a value range of [-3000, 10000].

To eliminate interference from atmospheric conditions, clouds, solar elevation angles, and seasonal factors, annual maximum value compositing was performed on the monthly data. The maximum NDVI value for each pixel across 12 months was extracted to generate annual maximum value composite datasets. Water bodies were identified as areas with NDVI values less than 0, and these pixels were assigned a value of 0 to eliminate the influence of water area changes on desertification analysis.

For analyzing desertification causes, land use maps with 30 m spatial resolution from 2000, 2005, 2010, and 2015 were obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<http://www.resdc.cn/>).

3. Research Methods

3.1 Vegetation Coverage Calculation

NDVI is a vegetation index calculated using vegetation spectral characteristics, but it lacks clear physical meaning and cannot be directly validated through

ground measurements. This study employed a linear pixel dichotomy model to convert NDVI into vegetation coverage fraction (F_c):

$$F_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where F_c represents vegetation coverage fraction; $NDVI_{veg}$ is the NDVI value for pixels with nearly 100% vegetation cover; and $NDVI_{soil}$ is the NDVI value for bare soil pixels without vegetation cover.

To ensure calculation accuracy, the same region of flowing sand dunes in the Taklamakan Desert was selected annually as the $NDVI_{soil}$ reference area. $NDVI_{veg}$ was determined from areas with dense vegetation cover. The pixel value range was linearly adjusted to $[0, 100]$ to generate annual vegetation coverage datasets.

3.2 Land Desertification Classification

Based on the desertification classification system proposed by Wang Tao and adapted to Tarim Basin conditions, the study area was classified into five categories: non-desertified, mildly desertified, moderately desertified, severely desertified, and extremely severely desertified .

3.3 Grid Accumulation Calculation

Land desertification exhibits fluctuating changes under natural and anthropogenic influences with certain cumulative effects. The grid accumulation method was applied to analyze multi-year desertification status and spatial patterns:

$$Edn = \sum_{i=1}^n (U_i - U_0)$$

where Edn represents the cumulative effect of land desertification in year n ; U_i is the desertification status in year i ; and U_0 is the baseline year desertification status.

The essence of grid accumulation is calculating the annual average change rate of vegetation coverage for each pixel across multiple years. Positive values indicate increasing vegetation coverage, while negative values indicate decreasing coverage, with magnitude representing the rate of change. Based on the desertification classification standards, field survey data, and iterative testing, the final grid accumulation rate classification standard was established .

3.4 Analysis of Land Desertification Causes

Transfer matrices were constructed using desertification grade maps from adjacent years to analyze transfer quantities and spatial distributions between different desertification grades. Combined with land use type data, desertification causes were analyzed. Previous studies indicate that desertification in the Tarim Basin primarily results from unreasonable water resource utilization and reclamation, with overgrazing, fuelwood collection, and herb digging being relatively minor factors.

Therefore, desertification changes on cultivated land and construction land were classified as direct human activity factors, while changes on grassland, forestland, water bodies, and unused land were classified as indirect human activity factors. Based on transfer matrix results, the proportions of direct and indirect factors were statistically analyzed to identify desertification drivers.

4. Results

4.1 Temporal Changes in Land Desertification

Statistical analysis of annual desertified land areas at various grades from 2000 to 2018 reveals that vegetation coverage in the Tarim Basin showed a fluctuating upward trend [Figure 2: see original paper]. Non-desertified land area increased rapidly, particularly during 2005-2010 and 2015-2018, with the fastest growth reaching 9,332.94 km² in 2010. This rapid increase likely resulted from combined effects of increased ecological water conveyance in the Tarim River basin and policies returning farmland to forest and grassland.

Extremely severe desertification area decreased substantially, with a cumulative reduction of 20,000 km². The largest decrease occurred in 2010, reaching 5,384 km². Moderate and severe desertification areas showed minimal changes, remaining relatively stable with slight increases in 2010 and 2015. Mild desertification area decreased overall, with the most significant reduction of 3,000 km² in 2010.

4.2 Spatial Changes in Land Desertification

Using 2000 as the baseline year, grid accumulation calculations show that the Tarim Basin exhibited an overall improvement trend [Figure 3: see original paper]. The improvement rate reached 44,749.80 km² · a⁻¹, far exceeding the deterioration rate of 3,000.52 km² · a⁻¹. Improvement was dominated by low-speed and medium-speed improvement, covering 20,914.3 km² · a⁻¹ and 19,196.3 km² · a⁻¹ respectively. High-speed and extremely high-speed improvement accounted for 3,560.6 km² · a⁻¹ and 53.8 km² · a⁻¹ respectively.

Improvement areas were widely distributed within and at the edges of oases, with notable improvement also observed in the lower reaches of the Tarim River. Deterioration areas concentrated in the middle reaches of the Tarim River (from

Aral to Chala Reservoir) and lower reaches of the Qarqan River. The middle Tarim River segment contained 34.79% of low-speed, 25.79% of medium-speed, and most high-speed and extremely high-speed deterioration areas in the basin.

4.3 Transfer Changes in Land Desertification

The transfer area statistics show that improvement transfers ($12,179 \text{ km}^2 \cdot \text{a}^{-1}$) significantly exceeded deterioration transfers ($8,916 \text{ km}^2 \cdot \text{a}^{-1}$), indicating an overall improving trend [Figure 4: see original paper]. Among improvement transfers, the transition from extremely severe to severe desertification had the highest annual transfer volume ($3,920 \text{ km}^2$), accounting for 32.18% of total improvement. The transition from mild to non-desertified ranked second ($3,290 \text{ km}^2 \cdot \text{a}^{-1}$), comprising 27.01% of improvement.

Among deterioration transfers, the transition from severe to extremely severe desertification had the largest volume ($3,102 \text{ km}^2 \cdot \text{a}^{-1}$), representing 21.18% of total deterioration. Transitions between adjacent desertification grades showed large interannual fluctuations, with the mild-to-non-desertified transition showing the highest amplitude ($8,000 \text{ km}^2$). The fluctuation peaks and troughs of improvement and deterioration transfers were largely opposite, with improvement peaks corresponding to deterioration troughs.

Spatially, mild-to-non-desertified and non-desertified-to-mild transitions were widespread within oasis areas. Transitions between moderate, severe, and extremely severe grades were more concentrated, primarily occurring in the middle Tarim River, lower Qarqan River, lower Weigan River, and the confluence area of the Yarkant and Kashgar Rivers [Figure 5: see original paper].

5. Discussion

5.1 Development Direction of Land Desertification

The analysis reveals frequent conversions between desertification grades. To further examine the transfer direction, the sources of each desertification grade were statistically analyzed [Figure 6: see original paper]. Non-desertified land originated primarily from mild desertification (98.2%), while extremely severe desertification came mainly from severe desertification (95.3%). Mild, moderate, and severe desertification grades derived predominantly from adjacent grades, following the path: extremely severe \rightarrow severe \rightarrow moderate \rightarrow mild \rightarrow non-desertified.

Cross-grade transfers (skipping one or more levels) were relatively small and stable, though they increased after 2010. Most cross-grade transfers involved skipping one level (e.g., extremely severe to moderate, severe to mild). Transfers skipping two or more levels were rare. This indicates that desertification in the Tarim Basin is a gradual, continuous, and slowly fluctuating process.

5.2 Causes of Land Desertification

Statistical analysis of grid accumulation results by land use type reveals that desertification changes primarily occurred in water bodies, grassland, forestland, cultivated land, and unused land [Figure 7: see original paper]. Deterioration was most prominent in grassland, followed by forestland and water bodies. Grassland is distributed along riverbanks and terminal lakes, forming communities that are highly susceptible to river water and groundwater fluctuations. When water levels decline, grassland rapidly degrades, exposing sand surfaces. The interannual fluctuation of water levels likely explains the observed desertification fluctuations.

Forestland deterioration occurred mainly in riparian forests, particularly natural forests far from river channels, with shrubs showing the most decline. Forestland responded more slowly to water level changes than grassland, resulting mainly in medium-speed deterioration. Water body deterioration appeared as ultra-high-speed changes, reflecting rapid area fluctuations due to climate change and human activities.

Cultivated land deterioration, accounting for 15.3% of high-speed deterioration, primarily resulted from salinization-induced abandonment. Construction land deterioration in low-speed categories requires further investigation. Overall, water resource variation was the key factor driving desertification changes in the Tarim Basin.

Improvement areas were dominated by forestland, cultivated land, and unused land. Ultra-high-speed improvement occurred mainly on unused land through sand control projects. High-speed and extremely high-speed improvement were concentrated in forestland due to afforestation efforts. Cultivated land improvement resulted from salinization control, drip irrigation promotion, and planting structure adjustments. The improvement was primarily driven by active human interventions with substantial financial investment, representing exogenous input-dependent improvement with questionable sustainability.

5.3 Grid Accumulation Analysis Method

The grid accumulation method offers a simple and clear principle that overcomes errors from interannual fluctuations. It provides a practical approach for analyzing evolution trends, rates, and spatial distributions of continuous long-term spatial data. By combining this method with transfer matrix analysis, we can quantitatively obtain transfer paths, quantities, and spatial distributions of desertification.

This study first quantitatively identified the desertification transfer path in the Tarim Basin: extremely severe \rightarrow severe \rightarrow moderate \rightarrow mild \rightarrow non-desertified. The largest transfer volumes occurred between mild desertification and non-desertified land within oasis areas, while transfers between other adjacent grades were smaller and more concentrated in specific river reaches. Integrating land

use types with grid accumulation provides a new approach for quantitative cause analysis, revealing that grassland degradation was the main deterioration type, while forestland and cultivated land improvement dominated the positive changes.

6. Conclusions

Based on MODIS NDVI 1 km monthly data from 2000 to 2018, this study analyzed land desertification changes in the Tarim Basin using the grid accumulation method, yielding the following conclusions:

- 1) Land desertification in the Tarim Basin from 2000 to 2018 was an inter-annually fluctuating process. Frequent conversions occurred between desertification grades, with significant fluctuations in annual transfer areas causing obvious interannual variations in desertified land area.
- 2) The grid accumulation method features simple principles and clear processes that overcome errors from interannual fluctuations. It provides a simple and practical new method for analyzing evolution trends, rates, and spatial distributions of continuous long-term spatial data.
- 3) The analysis reveals an overall improvement trend in the Tarim Basin, with an improvement rate of $44,749.80 \text{ km}^2 \cdot \text{a}^{-1}$, primarily through low-speed and medium-speed improvement distributed within and at the edges of oases. The deterioration rate was $3,000.52 \text{ km}^2 \cdot \text{a}^{-1}$, mainly low-speed deterioration concentrated in the middle Tarim River and lower Qarqan River reaches.
- 4) Combining grid accumulation with transfer matrix analysis provides a new means for quantitatively obtaining desertification transfer paths, quantities, and spatial distributions. This study first quantitatively identified the transfer path as extremely severe \rightarrow severe \rightarrow moderate \rightarrow mild \rightarrow non-desertified. The largest transfer volume occurred between mild desertification and non-desertified land within oases, while other transfers were relatively smaller and concentrated in specific river reaches.
- 5) Integrating land use types with grid accumulation provides a new attempt at quantitative cause analysis. The analysis shows that desertification degradation in the Tarim Basin was mainly grassland degradation, while improvement was dominated by forestland and cultivated land improvement. Forestland improvement focused on shelterbelts inside and outside oases, while cultivated land improvement resulted from salinization control and planting structure adjustments. The improvement was primarily driven by active human activities with substantial financial investment.

However, this study only considered the NDVI indicator and insufficiently explored climate, soil, and human activities, requiring further improvement. Additionally, the 1 km resolution data is relatively coarse, and higher-resolution data warrants future investigation.

Acknowledgments

We thank NASA (<https://search.earthdata.nasa.gov/>) for providing MODIS NDVI data and the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<http://www.resdc.cn/>) for providing land use data.

References

- [1] Meyer W B, Turner II B L. Human population growth and global land-use/cover change[J]. *Annual Review of Ecology & Systematics*, 1992, 23(23): 39-61.
- [2] Jacquin A, Sheeren D, Lacombe J P, et al. Vegetation cover degradation assessment in Madagascar savanna based on trend analysis of MODIS NDVI time series[J]. *International Journal of Applied Earth Observations & Geoinformation*, 2010, 12(13): S3-S10.
- [3] Mutti P R, Lúcio P S, Dubreuil V, et al. NDVI time series stochastic models for the forecast of vegetation dynamics over desertification hotspots[J]. *International Journal of Remote Sensing*, 2020, 41(7): 2759-2788.
- [4] Tucker C J, Newcomb W W, Dregne H E. AVHRR data sets for determination of desert spatial extent[J]. *International Journal of Remote Sensing*, 1994, 15(17): 3547-3565.
- [5] Wang Tao, Song Xiang, Yan Changzhen, et al. Remote sensing analysis on aeolian desertification trends in northern China during 1975–2010[J]. *Journal of Desert Research*, 2011, 31(6): 1351-1356.
- [6] Zhang Jianshen, Yan Zhenglong, Wang Xiaoguo, et al. Remote sensing analysis of spatial-temporal changes of desertification land in lower reaches of Tarim River[J]. *Agricultural Engineering*, 2009, 25(10): 161-165.
- [7] Zhu Zhenda. Concept, cause and control of desertification in China[J]. *Quaternary Sciences*, 1998, 18(2): 145-155.
- [8] Liu Xingwen, Jiang Xiaoguang. Extraction of the change information of land desertification from multitemporal remote sensing images by the method of combining optical false color composite with computer digital image processing[J]. *Arid Land Geography*, 1996, 19(3): 1-7.
- [9] Li Chengzhi. Study on the desertification monitoring and early warning in Xinjiang[D]. Urumqi: Xinjiang University, 2012.
- [10] Guo B, Zang W Q, Han B M, et al. Dynamic monitoring of desertification in Naiman Banner based on feature space models with typical surface parameters derived from LANDSAT images[J]. *Land Degradation & Development*, 2020, doi: 10.1002/ldr.3533.

- [11] Zhou Mengtian, Li Jun, Zhu Kangwen. Spatial-temporal dynamics of different types of vegetation NDVI and its response to climate change in Xinjiang during 1998–2012[J]. *Arid Land Geography*, 2015, 38(4): 779-787.
- [12] Liu Yang, Li Chengzhi, Liu Zihui, et al. Assessment of spatio-temporal variations in vegetation cover in Xinjiang from 1982 to 2013 based on GIMMS NDVI[J]. *Acta Ecologica Sinica*, 2016, 36(19): 6198-6208.
- [13] Zhao Mingwei, Wang Ni, Shi Huihui, et al. Spatial-temporal variation and its driving forces of vegetation coverage in China from 2001 to 2015[J]. *Quaternary Sciences*, 2019, 42(2): 104-111.
- [14] Yang Guanhua, Bao Anming, Chen Xi, et al. Study of the vegetation cover change and its driving factors over Xinjiang during 1998–2007[J]. *Journal of Glaciology and Geocryology*, 2009, 31(3): 436-445.
- [15] Wang Fei, Wu Zhaopeng, Wang Yang, et al. Dynamic monitoring of desertification in the Tarim Basin based on RS and GIS techniques[J]. *Chinese Journal of Ecology*, 2017, 36(4): 1029-1037.
- [16] Ma Jinzhu, Li Jijun. Impact of human activities on groundwater and the effect on eco-environment in southern Tarim Basin[J]. *Journal of Natural Resources*, 2001, 16(2): 134-139.
- [17] Zhang Liyun. The natural grasslands on the flowing plains along the large rivers in Tarim Basin and the affects of the mankind activities[J]. *Journal of Arid Land Resources and Environment*, 1990, 4(1): 68-76.
- [18] Shi Peijun, Yan Ping, Gao Shangyu, et al. The duststorm disaster in China and its research progress[J]. *Journal of Natural Disasters*, 2000, 9(3): 71-77.
- [19] Song Yuqin, Chen Yan. A review of desertification early warning methods[J]. *Journal of Desert Research*, 2017, 37(2): 205-213.
- [20] Deng Yulin, Jiang Hongtao, Zhang Fei, et al. NDVI at a vertical gradient in the Ebinur Lake Basin, Xinjiang, China[J]. *Journal of Desert Research*, 2015, 35(2): 508-513.
- [21] Li Jun, Zhu Hui. The reconstruction of MODIS/NDVI time series data in Chongqing[J]. *Scientia Geographica Sinica*, 2017, 37(3): 120-127.
- [22] Tang Liang, He Mingzhu, Xu Hua, et al. Validation of vegetation coverage and NDVI based on UAV remote sensing method and its response to hydrothermal gradient[J]. *Chinese Journal of Applied Ecology*, 2020, 31(1): 35-44.
- [23] Chen Yaning, Li Weihong, Chen Yapeng, et al. Water conveyance in dried river way and ecological restoration in the lower reaches of Tarim River, China[J]. *Journal of Ecology*, 2006, 27(2): 538-545.
- [24] Chen Yaning, LI Weihong, Chen Yapeng, et al. Science in supporting the ecological restoration and sustainable development of the Tarim River Basin[J]. *Arid Land Geography*, 2018, 41(5): 901-907.

- [25] Su Bingqian, Wang Yinyin, Shangguan Zhouping. Analysis on the scale of a new period of returning farmland to forestland and grassland in northwest China[J]. Research of Soil and Water Conservation, 2017, 24(4): 59-65.
- [26] Li Chengzhi, Zhang Yan, Liu Yang, et al. Residents' cognition to desertification in the lower reaches of the Tarim River[J]. Journal of Desert Research, 2016, 36(5): 1271-1277.
- [27] Li Chengzhi, Zhang Yan, Liu Zhihui, et al. Response and control mechanism of desertification to climate change in Xinjiang region[J]. Bulletin of Soil and Water Conservation, 2014, 34(4): 264-268.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv –Machine translation. Verify with original.