

## **Supplementary information for**

“A perspective on the impact of grassland degradation on ecosystem services for the purpose of sustainable management”

# Content

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**Supplementary Information S1. Functional zoning of the Xilingol Grassland National Nature Reserve**

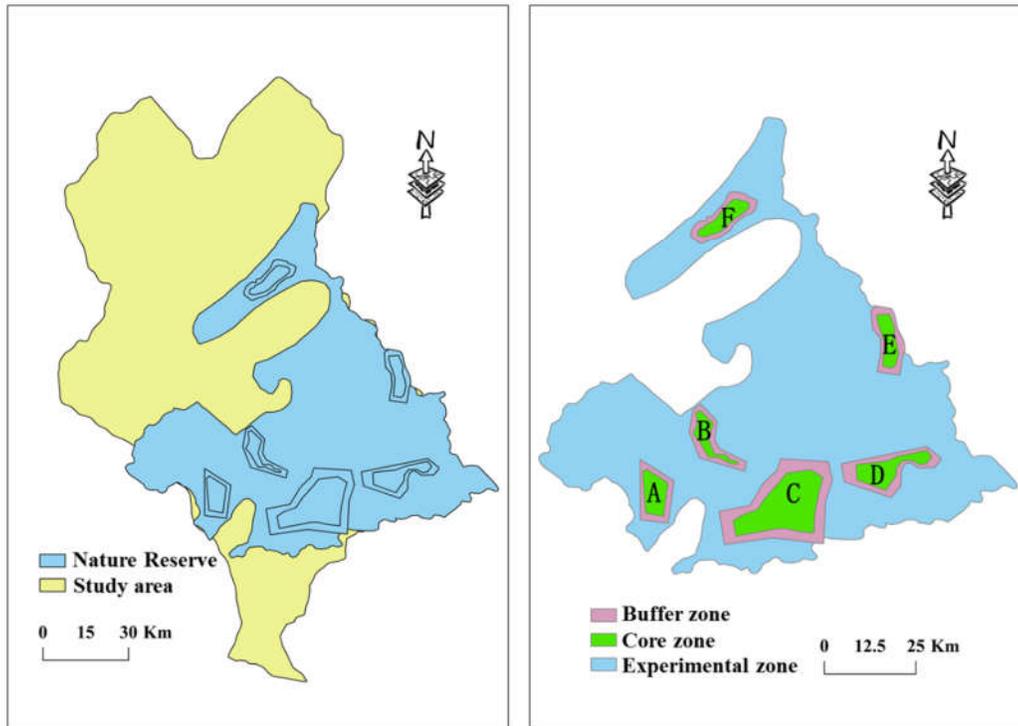


Figure S1. Functional zoning of the Xilingol Grassland National Nature Reserve

## Supplementary Information S2. Quantification of 4 ecosystem services

### 1. Net Primary Production (NPP)

Carbon sequestration was estimated by Carnegie-Ames-Stanford Approach (CASA) based on the vegetation productivity (biomass production), which can be reflected by NPP. The formula is as follows:

$$NPP(x, t) = TSOL(x, t) \times FPAR(x, t) \times r \times \xi(x, t) \quad (S1)$$

Where,  $NPP(x, t)$  is the net primary productivity at the pixel  $x$  in the month  $t$  ( $\text{gC}\cdot\text{m}^{-2}$ );  $TSOL(x, t)$  is total solar radiation ( $\text{MJ}\cdot\text{m}^{-2}$ );  $FPAR(x, t)$  is the fraction of total incoming photo synthetically active radiation absorbed by vegetation canopy ( $\text{MJ}\cdot\text{m}^{-2}$ );  $r$  is the ratio of the effective solar radiation against the total solar radiation (wave length ranges  $0.4\text{--}0.7 \mu\text{m}$ ), the value of this study was 0.5;  $\xi(x, t)$  is light use efficiency of  $FPAR(x, t)$  into organic dry matter ( $\text{gC}\cdot\text{MJ}^{-1}$ );

$$\xi(x, t) = T_{\varepsilon 1}(x, t) \times T_{\varepsilon 2}(x, t) \times W_{\varepsilon}(x, t) \times \varepsilon_{max} \quad (S2)$$

Where,  $T_{\varepsilon 1}(x, t)$  and  $T_{\varepsilon 2}(x, t)$  are temperature stress coefficients;  $W_{\varepsilon}(x, t)$  is a moisture stress coefficient;  $\varepsilon_{max}$  is the maximal light use efficiency of the specific biome under an ideal condition, which was based on the study of Zhu et al. [1].

## **2. Ecosystem Carbon Sequestration (EC)**

The improved Terrestrial Ecosystem Regional (TECO-R) model was adopted for carbon stock simulations in this study. TECO-R is often employed in carbon stock simulations of forest ecosystems [2,3], and, therefore, needs to be adjusted to grassland ecosystems in order to perform accurate analyses [4]. The adjusted structure of TECO-R model and the main parameters meanings, please refer to the study of Lyu et al. [5].

### 3. Soil Conservation (SC)

Soil retention was estimated by the Revised Universal Soil Loss Equation (RUSLE) based on potential soil retention during the process soil water erosion [6,7]. The formula is as follows:

$$SR = A_p - A_r \quad (S3)$$

Where,  $SR$  is the annual potential soil conservation ( $t \cdot ha^{-1}$ );  $A_p$  is the amount of potential soil erosion ( $t \cdot ha^{-1}$ );  $A_r$  is the amount of actual soil erosion ( $t \cdot ha^{-1}$ ).

$$A_p = R \times K \times LS \quad (S4)$$

Where,  $R$  is rainfall-runoff erosivity ( $MJ \cdot mm \cdot ha^{-2} \cdot h^{-1}$ ), which is calculated using the empirical equations for arid and semiarid lands proposed by Wischmeier and Smith [8];  $K$  is the soil erodibility factor ( $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ ), which is determined using the erosion-productivity impact calculator (EPIC) model and was corrected according to the study of Zhang et al. [9,10];  $LS$  is the slope length and steepness factor calculated according to McCool et al. and Liu et al. using the Digital Elevation Model (DEM) in ArcGIS [11,12].

$$A_r = R \times K \times LS \times C \times P \quad (S5)$$

Where,  $C$  is a dimensionless factor for vegetation cover calculated by vegetation coverage fraction [13]; and  $P$  is also a dimensionless factor referring to the support practice of soil conservation using Wener's slope-based method [14]. The ranges of the above two factors are both between 0 and 1.

### 4. Soil Loss by Wind (SL)

Soil Loss by Wind was estimated by the Revised Wind Erosion Equation (RWEQ) [15–17]. The formula is as follows:

$$Q_x = \frac{2 \times Z}{S^2} \times Q_{max} \times e^{-(x/S)^2} \quad (S6)$$

Where,  $Q_x$  is the amount of sand transported by the wind at a point  $x$  downwind ( $kg \cdot m^{-2}$ );  $Q_{max}$  is the maximum amount of sand that can be transported downwind ( $kg \cdot m^{-2}$ ); and  $S$  is the critical field length (m).

$$Q_{max} = 109.8 \times (WF \times EF \times SCF \times K' \times C) \quad (S7)$$

Where,  $WF$  is the weather factor ( $kg \cdot m^{-1}$ );  $EF$  is the soil erodibility factor;  $SCF$  is the soil crust factor;  $K'$  is the soil roughness factor; and  $C$  is the vegetation cover factor based on the study of Gong [18].

$$S = 105.71 \times (WF \times EF \times SCF \times K' \times C)^{-0.3711} \quad (S8)$$

In particular, the instruction manual for the RWEQ model specifies that the wind speed input parameter should be an average of wind speed data collected every 1 to 2 min which is difficult to achieve [19]. In this study, we converted daily mean wind speed data into minute wind speed data using a formula based on the study Guo et al. [20].

## References (Supplementary Information S2)

- [1] Zhu, W.; Pan, Y.; Zhang, J. Estimation of net primary productivity of Chinese terrestrial vegetation based on remote sensing. *J. Plant Ecol.* **2007**, *31*, 413–424.
- [2] Zhou, T.; Shi, P.; Luo, J.; Shao, Z. Estimation of soil organic carbon based on remote sensing and process model. *Frontiers of Forestry in China.* **2008**, *3*, 139–147.
- [3] Zhou, T.; Shi, P.; Jia, G.; Li, X.; Luo, Y. Spatial patterns of ecosystem carbon residence time in Chinese forests. *Sci. China Earth Sci.* **2010**, *53*, 1229–1240.
- [4] Li, G.; Li, X.; Zhou, T.; Wang, H.; Li, R.; Wang, H.; Wei, D. A model for simulating the soil organic carbon pool of steppe ecosystems. *Environ. Model. Assess.* **2016**, *21*, 339–355.
- [5] Lyu, X.; Li, X.; Dou, H.; Dang, D.; Li, S.; Li, X.; Li, M.; Liu, S. Evaluation of grassland carbon pool based on TECO-R model and climate-driving function: A case study in the Xilingol typical steppe region of Inner Mongolia, China. *Ecol. Indic.* **2020**, *117*, 106508.
- [6] Fu, B.; Liu, Y.; Lü, Y.; He, C.; Zeng, Y.; Wu, B. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. *Ecol. Complex.* **2011**, *8*, 284–293.
- [7] Lü, Y.; Fu, B.; Feng, X.; Zeng, Y.; Liu, Y.; Chang, R.; Sun, G.; Wu, B. A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the Loess Plateau of China. *PLoS ONE* **2012**, *7*, e31782.
- [8] Wischmeier, W.H., Smith, D.D. Predicting rainfall erosion losses—a guide to conservation planning. *Agriculture Handbook* **1978**, 537.
- [9] Sharpely, A.N., Williams, J.R. EPIC-erosion/productivity impact calculator: 1. Model determination. *United States Department of Agriculture Technical Bulletin* **1990**, 1768.
- [10] Zhang, K. L.; Shu, A. P.; Xu, X. L.; Yang, Q. K.; Yu, B. Soil erodibility and its estimation for agricultural soils in China. *J. Arid Environ.* **2008**, *72*, 1002–1011.
- [11] Mccool, D.K.; Foster, G.R.; Mutchler, C.K.; Meyer, L.D. Revised slope length factor for the Universal Soil Loss Equation. *T. ASABE* **1989**, *32*, 1571–1576.
- [12] Liu, B.; Nearing, M.A.; Shi, P.; Jia, Z. Slope length effects on soil loss for steep slopes. *Soil Sci. Soc. Am. J.* **1994**, *64*, 1759–1763.
- [13] Cai, C.; Ding, S.; Shi, Z.; Huang, L.; Zhang, G. Study of applying USLE and geographical information system IDRISI to predict soil erosion in small watershed. *J. Soil Water Conserv.* **2000**, *14*, 19–24.
- [14] Jia, X.; Fu, B.; Feng, X.; Hou, G.; Liu, Y.; Wang, X. The tradeoff and synergy between ecosystem services in the Grain-for-Green areas in Northern Shaanxi, China. *Ecol. Indic.* **2014**, *43*, 103–113.
- [15] Van Pelt, R. S.; Zobeck, T. M.; Potter, K. N.; Stout, J. E.; Popham, T. W. Validation of the wind erosion stochastic simulator (WESS) and the revised wind erosion equation (RWEQ) for single events. *Environ. Modell. Softw.* **2004**, *19*, 191–198.
- [16] Fu, Q.; Li, B.; Hou, Y.; Bi, X.; Zhang, X. Effects of land use and climate change on ecosystem services in Central Asia's arid regions: A case study in Altay Prefecture, China. *Sci. Total Environ.* **2017**, 607–608, 633–646.
- [17] Jiang, C.; Nath, R.; Labzovskii, L.; Wang, D. Integrating ecosystem services into effectiveness assessment of ecological restoration program in northern China's arid areas: Insights from the Beijing-Tianjin Sandstorm Source Region. *Land Use Policy* **2018**, *75*, 201–214.
- [18] Gong, G., Liu, J., Shao, Q. Wind erosion in Xilingol League, Inner Mongolia since the 1990s using the revised wind erosion equation. *Prog. Geogr.* **2014**, *33*, 825–834.
- [19] Fryrcar, D.W.; Chen, W.N.; Lester, C. Revised Wind Erosion Equation. *Ann. Arid Zone* **2001**, *40*, 265–279.
- [20] Guo, Z.; Zobeck, T.M.; Zhang, K.; Li, F. Estimating potential wind erosion of agricultural lands in northern China using the Revised Wind Erosion Equation and geographic information systems. *J. Soil Water Conserv.* **2013**, *68*, 13–21.

### Supplementary Information S3. Spatial simulation of grazing pressure

The study calculated grazing pressure by moving window method based on fractional vegetation cover, and characterized the grazing pressure of each pixel by grazing pressure index, which is calculated in Equation (S9):

$$GPI_i = \frac{(FVC_{ref} - FVC_i)}{FVC_{ref}} \quad (S9)$$

where  $GPI_i$  is grazing pressure index of pixel  $i$ ,  $FVC_{ref}$  is the average fractional vegetation cover of the reference pixel, and  $FVC_i$  is the average fractional vegetation cover of pixel  $i$ .

Plants in the Xilingol typical steppe generally return to green in early April and stop growing in September. Local herders cut grass from mid-to-late August to early September each year to stock fodder for winter. Therefore, normalized difference vegetation index (NDVI) of the Moderate Resolution Imaging Spectroradiometer (MODIS) images from early August were selected to calculate vegetation cover by pixel dichotomy. Since fractional vegetation cover monitored by remote sensing means is the result of a combination of climate, soil, topography, and grazing factors, the key to identifying grazing pressure using fractional vegetation cover is to minimize the differences in natural conditions between pixels. In order to minimize the influence of topography, all the pixels except the focal pixel in the 90–95% fractional vegetation cover range were selected as the reference pixels. When calculating the grazing pressure index by the moving window method, the size of the moving window was chosen by considering the differences in the distribution of grassland types.

**Supplementary Information S4. Spatial distribution of ecosystem services in the study area from 2000 to 2019**

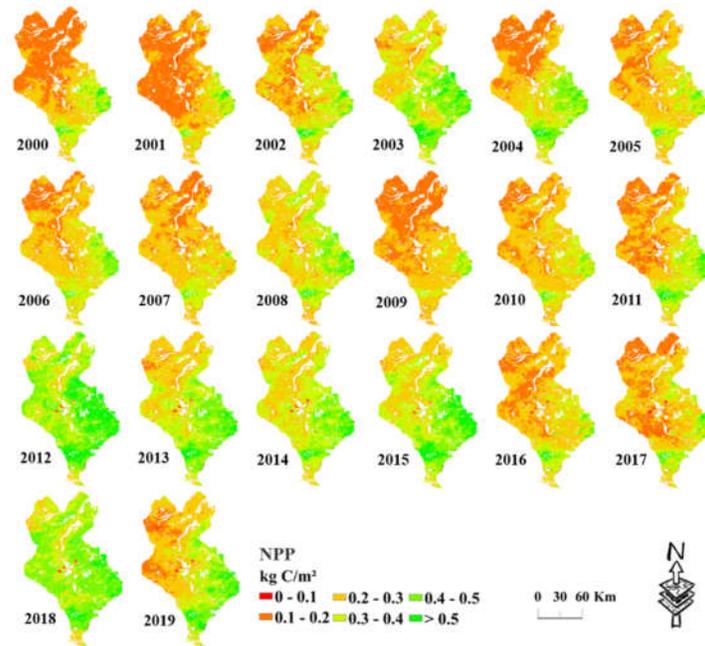


Figure S2. Spatial distribution of net primary production in the study area from 2000 to 2019

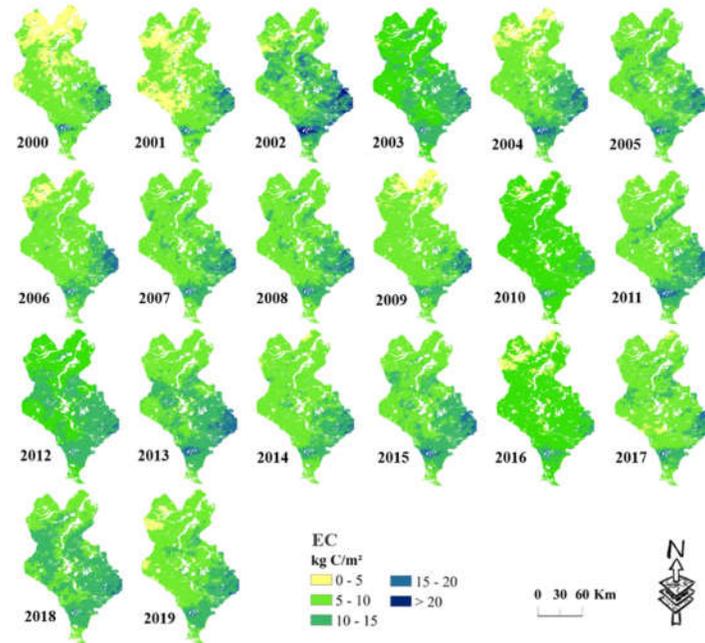


Figure S3. Spatial distribution of ecosystem carbon pool in the study area from 2000 to 2019

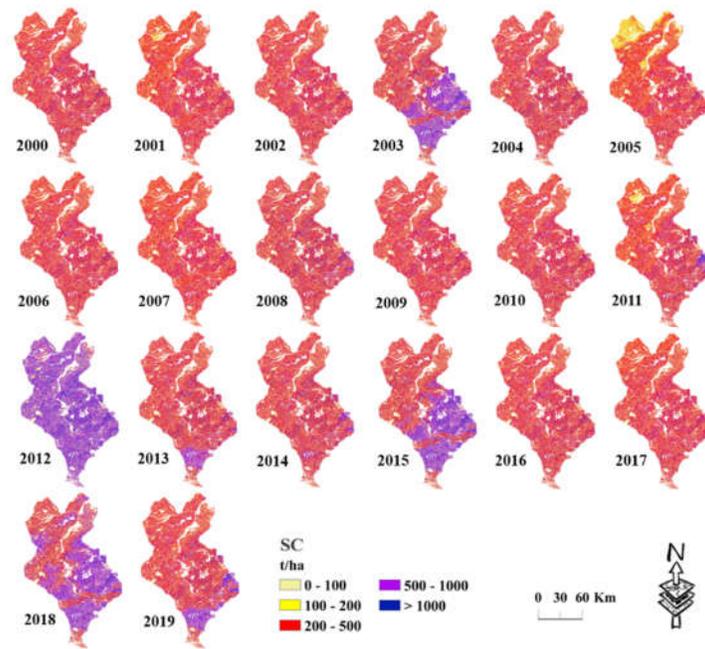


Figure S4. Spatial distribution of soil conservation in the study area from 2000 to 2019

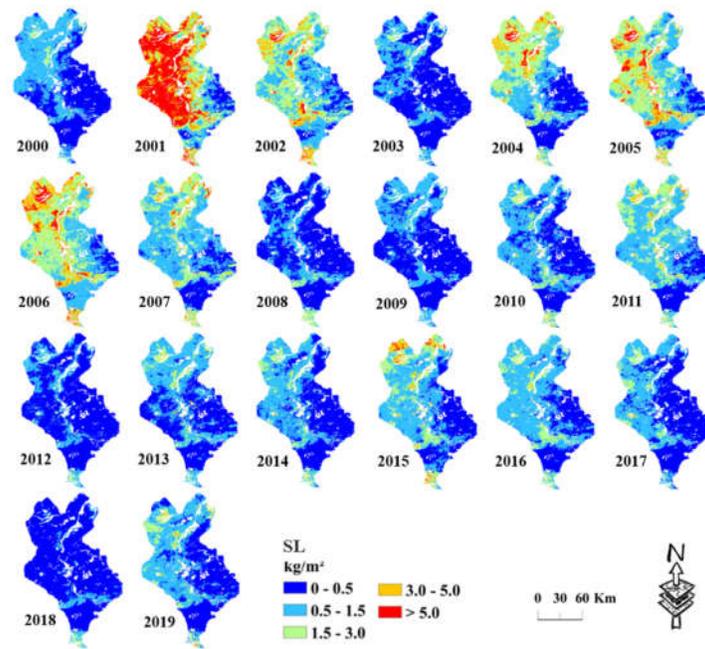


Figure S5. Spatial distribution of soil loss by wind in the study area from 2000 to 2019

**Supplementary Information S5. Temporal and spatial distribution of temperature, precipitation and grazing intensity in the study area from 2000 to 2019**

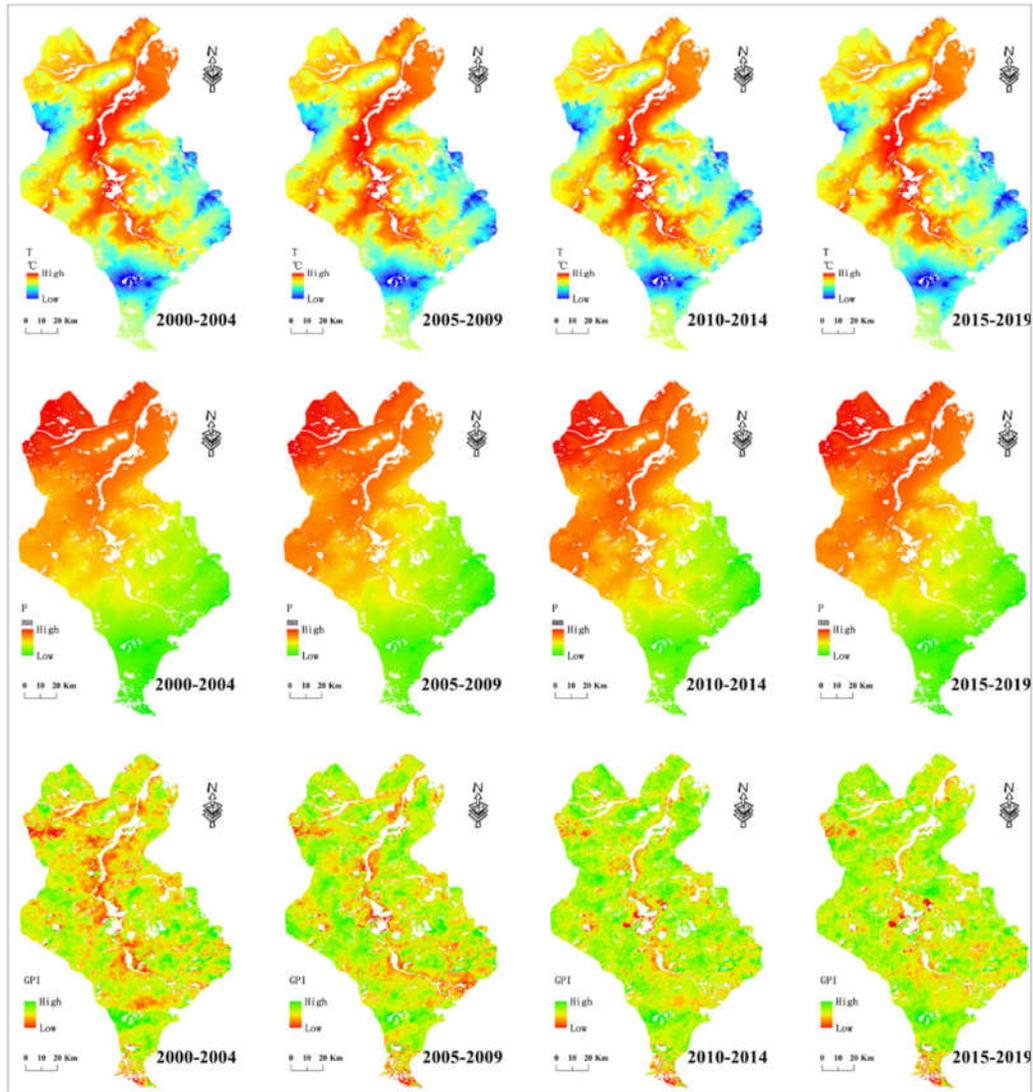


Figure S6. Spatial distribution of temperature, precipitation and grazing intensity in the study area from 2000 to 2019

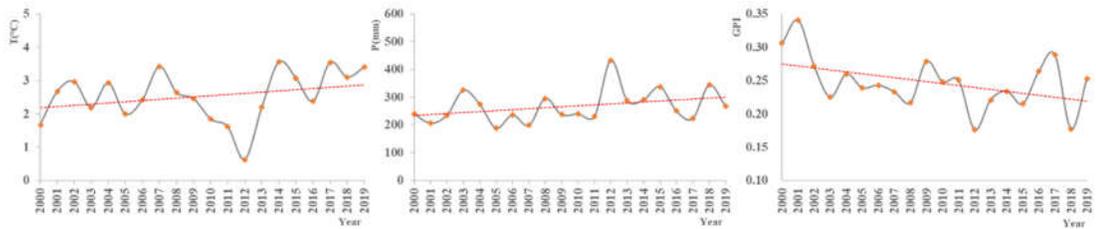


Figure S7. Temporal distribution of temperature, precipitation and grazing intensity in the study area from 2000 to 2019