Impacts of Climate Change and Human Activities on Vegetation Variation in the Sharyn Gol River Basin

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Abstract. The Sharyn Gol River Basin in the central region of Mongolia is one of the economically important areas for agriculture, animal husbandry and mining. Due to its favourable natural condition and advantageous geographical location, the Sharyn Gol River Basin is under increased pressure from human activities. The aim of this study was to analyse spatial-temporal changes in vegetation and to determine the contributions of climate change and human activities to vegetation dynamics in the Sharyn Gol River Basin. We obtained a 16-day composite MODIS NDVI data set (MOD13Q1 product) acquired from the Land Process Distribution Active Archive Centre (LP DAAC) and ERA 5 reanalysis data (monthly average air temperature and monthly total precipitation) from the European Centre for Medium Range Weather Forecasts (ECMWF) with a spatial resolution of 0.1°x 0.1° lat/long. We used Sen's slope, Mann-Kendal test, Ordinary least squares regression, and the RESTREND method to detect spatial-temporal changes in vegetation during the period 2000 to 2022 and assess the impacts of human activities and climate change on vegetation dynamics. We found that areas with significant ($p<0.05$) increases ($p <0.05$) in NDVI trends represented 35.5% of the total study area. The areas that experienced significant ($p<0.05$) decreases ($p <0.05$) in NDVI trends occupied 1.06% of the total study area. The remaining areas exhibited an insignificant increase and decrease in NDVI trends. The result of the RESTREND analysis indicated that the increasing trend in NDVI was generally driven by climate factors, while the decreasing trend in NDVI was likely driven by human activities.

Keywords: Impact of human activities, residual analysis, Sharyn Gol River Basin, Vegetation variation.

1 Introduction

As one of the main components of the ecosystem, changes in vegetation can affect global climate change, carbon balance, and hydrological cycles [1–4]. Climate-related factors and disturbance factors originated by natural or human activities are considered to be factors that influence vegetation dynamics [5]. Vegetation exhibits a more rapid reaction to land use and disturbances than to climate change. Also, vegetation responses

O. Batdelger et al. (eds.), *Proceedings of the Fourth International Conference on Environmental Science and Technology (EST 2023)*, Advances in Engineering Research 224,
https://doi.org/10.2991/978-94-6463-278-1_7

to the factors mentioned above can last for a long period [6]. Since vegetation is sensitive to climate change [7] and external environmental influences [8], it can be used as an indicator to reveal environmental changes such as changes in the physical properties of the land surface and the stability of the ecological environment [9, 10]. Thus, many scholars have highlighted that monitoring and quantifying the spatial-temporal dynamics of vegetation are crucial for understanding the interactions between ecosystems and the atmosphere, evaluating the effectiveness of ecological restoration policies, as well as planning strategies to cope with land degradation and adapting to climate change [11–13].

Remote sensing has been confirmed to be a valuable tool for identifying vegetation dynamics in vast regions [14]. Since the 1980s, the normalised difference vegetation index (NDVI) derived from satellite imagery has been widely used for studies that focused on detecting and monitoring changes in vegetation due to its sensitivity to vegetation greenness [15]. Vegetation greenness is closely related to the productivity of terrestrial vegetation, surface roughness, and albedo [16]. Numerous studies have used NDVI and meteorological datasets to analyse vegetation responses to climate variation and human activities interferences, and to monitor vegetation dynamics such as [10, 17, 18].

To assess the contributions of human activities and climate variation to vegetation dynamics, scholars have applied several methods. Among these methods, the residual trend (RESTREND) method suggested by [19] is the most commonly used method due to its simple and effective way of separating the impact of human activities on vegetation dynamics from climate variation [14, 20].

The Sharyn Gol River Basin in the central region of Mongolia is one of the economically important areas for agriculture, animal husbandry and mining. Due to its favourable natural condition and advantageous geographical location, the Sharyn Gol River Basin is under increased pressure from human activities. McIntyre et al. (2016) found that the size of the land area affected by small-scale gold mining increased approximately 4.5 times between 1999 and 2015 and the mining activity affected water quality and local water users [21]. [22] estimated that 1.4% of the total land area is severe, 6.9% is strong, 18.7% is moderate, 33% is weak, 39.9% is very weak affected by human activities in the Sharyn Gol River Basin. Therefore, determining and assessing vegetation dynamics and its driving forces in the Sharyn Gol River basin is essential not only to improve our understanding of spatio-temporal patterns of environmental change but also to formulate proper ecological restoration strategies. The aim of this study was (1) to analyse spatial-temporal changes in vegetation and (2) to determine the contributions of climate change and human activities to vegetation dynamics in the Sharyn Gol River Basin. The results of this research can be used as reference information for local land managers and decision makers to develop and implement appropriate land use planning and mitigate negative influences of human activities.

2 Methods

2.1 Study area

The Sharyn Gol River Basin is located in northern Mongolia. It covers an area of 2943.61 km^2, representing 0.19% of the total territory of Mongolia. The study area is located on the northwest side of the Khentii mountain range, and the elevation of the land surface is 800-2600 m above sea level. The climate condition of the study area is defined by harsh continental climate and the growing season lasts from May to August. The annual average temperature is 0°C, the monthly average temperature in the coldest month (in January) is -23.5°C to -27.5°C, the monthly average temperature in the warmest month (in July) is 20 ° C to 20.9°C. The average annual precipitation is about 290 mm. Approximately 90% of total precipitation falls during the warm season, of which almost 50-60% occurred in July and August [23]. In terms of administrative division, the river basin can be divided into seven soums of two provinces. Eruu, Javhlant, Bayangol, and Mandal soums of Selenge province, and Orkhon, Khongor, and Sharyn gol soum of Darkhan province.

2.2 Data sets

The 16-day-composite MODIS NDVI dataset (MOD13Q1 product) with a spatial resolution of 250 m for the period 2000-2022 acquired from the Land Processes Distribution Active Archive Centre was used to investigate changes in vegetation. The monthly NDVI values were calculated using the maximum value composite (MVC) method. The NDVI values from June to August were averaged to obtain the NDVI values for each year of the growing season. The NDVI values for the growing season were classified into 5 classes: low vegetation coverage (NDVI<0.2), slightly low vegetation coverage (0.2<NDVI<0.4), medium vegetation coverage (0.4<NDVI<0.6), slightly high vegetation coverage (0.6<NDVI<0.8), high vegetation coverage (0.8<NDVI) based on [24]. For the investigation, ERA 5 reanalysis data including monthly average air temperature and monthly total precipitation from the European Centre for Medium Range Weather Forecasts at spatial resolution of 0.1°x0.1° lat/long were used. The ERA 5 reanalysis data was chosen based on [25]. They found a high correlation (r=0.967) between the air temperature data from ERA 5 and the air temperature records of the meteorological station for the summer season (June-August).

2.3 Methods

Sen's slope estimate, Mann-Kendal test, Pearson's correlation test, Ordinary least squares regression, and RESTREND method were applied to detect spatial-temporal changes in vegetation during the period 2000-2022 and to distinguish the effect of human activities on vegetation dynamics from the effect of climate variability.

The Sen slope estimate, a nonparametric statistical method [26], was used to detect a trend (increasing or decreasing) in the NDVI time series. If slope>0, NDVI time series are on an increasing trend, and slope<0, NDVI time series are on a decreasing trend. The Mann-Kendall test, a rank-based nonparametric test [27], was applied to identify the significance of the detected NDVI trend. A confidence interval of 95% ($p<0.05$) was applied to determine whether the trend was statistically significant or insignificant. To describe the stability of the NDVI values, the coefficient of variation (CV) was calculated per pixel by the following [28]. A high CV value represents a high fluctuation in the NDVI time series, and vice versa.

The relationship between NDVI dynamics and meteorological variables was analysed using the Person's correlation test. The significance of the correlation coefficients was estimated by the t-test at the 95% confidence level.

The RESTREND method was applied to distinguish the influences of human activities and climate variability on vegetation. The basic assumption of this method is that vegetation production has a strong relationship with precipitation in dry land. Therefore, human influence can be revealed if the effect of rainfall is removed from the dynamics of vegetation [29]. To analyse the residual trend, the relationship between NDVI and the climate variables should be modelled [30]. In this study, the relationship between NDVI and climate variables (monthly average temperature and monthly total precipitation) was estimated through a multiple linear regression model per pixel. The difference between the observed NDVI and the predicted NDVI obtained from the multiple linear regression model was defined as a residual. The calculation formulas were as follows:

$$NDVIp = \beta_1 \times Tem + \beta_2 \times Pre + \varepsilon \quad (1)$$

$$NDVIr = NDVIo - NDVIp \quad (2)$$

where: *Tem* and *Pre* refer to the growing season's monthly average temperature (°C) and monthly total precipitation (mm), respectively; β_1, β_2, and ε are model parameters; *NDVIp*, *NDVIo*, and *NDVIr* denote to the predicted *NDVI*, observed *NDVI*, and residual *NDVI*, respectively.

Then, the trend and significance of the residual NDVI time series were calculated by Sen's slope estimate and Mann-Kendall test. If the residual trend is insignificant at the 95% confidence level, the changes in NDVI can be explained by climate variability, while the residual trend was significant at the 95% confidence level, the changes in NDVI could be affected by human activities [11]. The relative contributions of climate variation and human activities to vegetation dynamics were analyzed based on the method suggested by [31].

3 Result and Discussion

The spatial distribution of multi-year average NDVI values in the Sharyn Gol River Basin for the period of 2000-2022 is shown in Fig. 1a. Multi-year average NDVI values ranged from 0.882 to 0.114 with a mean value of 0.661. The multi-year average NDVI values gradually declined from the upper section to the lower section of the river basin. The areas with high vegetation cover were mainly distributed in the upper section of the river basin, where forest cover is dominant vegetation. The slightly high vegetation coverages were observed to a great extent along the riparian meadow of the Sharyn Gol River and the Khuiten River and mountain meadows near the forest. Areas with medium vegetation coverage were mostly concentrated in the broad valleys of the Sharyn Gol River and the Khuiten River and hilly uplands, while areas with low and slightly low vegetation coverage were found near the centre of Sharyn gol soum, around the Sharyn Tsagaan Lake, and along the riparian zone of the lower stream of the Sharyn Gol River. A total of 41% of the total basin area was covered with medium vegetation coverages and these areas were used primarily for livestock grazing and cropland. Furthermore, 58.5% of the total NDVI pixels had values higher than 0.6.

For the entire study area, the mean NDVI of the growing season had an increasing trend at a rate of 0.0024/year during 2000-2022, but the increasing trend was statistically insignificant (R^2=0.1318, p=0.08) (Fig. 1b). However, the changes in NDVI were spatially heterogeneous and upward and downward NDVI trends were found in the study area. The rate of change in NDVI values ranged from 0.0218 to 0.0126/year. Areas with significant ($p<0.05$) increasing NDVI trends accounted for 35.5% of the total study area. The areas experienced significant ($p<0.05$) decreasing NDVI trends detected for 1.06% of the study area, while statistically insignificant ($p>0.05$) increasing and decreasing NDVI trends were estimated for 63.4% of the study area. The increasing trend of NDVI with a rate of 0.0034/year ($p<0.01$) was mainly observed in the upper section of the river basin, while the decreasing trend with a rate of -0.0053/year ($p<0.01$) was clearly revealed along the banks of the Sharyn Gol River and the Khuiten River.

During the study period, the coefficients of variation ranged from 0.0186 to 0.3486 with a mean value of 0.0995 in the Sharyn Gol River Basin. As shown in Fig. 1c, the spatial distribution of the coefficients of variation was uneven across the study area. A total of 99% of the study area had coefficients of variation that ranged from 0.02 to 0.2, of which 0.1 to 0.2 represents 51.4% of the total area of the basin. NDVI values fluctuated higher in the lower section of the river basin and around mining sites, while forest variations were relatively stable. The coefficients of variation ranged from 0.02-0.05 in the forest.

The results of the Pearson's correlation test showed that NDVI was a statistically significant positive correlation with precipitation (r=0.609) and a statistically significant negative correlation with temperature (r=-0.684). These correlation coefficients indicated that precipitation has a significant influence on vegetation growth, while increasing temperature can inhibit plant growth in the Sharyn Gol River Basin.

Human activities in the Sharyn Gol River Basin had a significant negative impact on vegetation dynamics. A total of 2.8% of the study area or 2336 pixels exhibited a statistically significant downward trend in the residual NDVI (Fig. 1d).

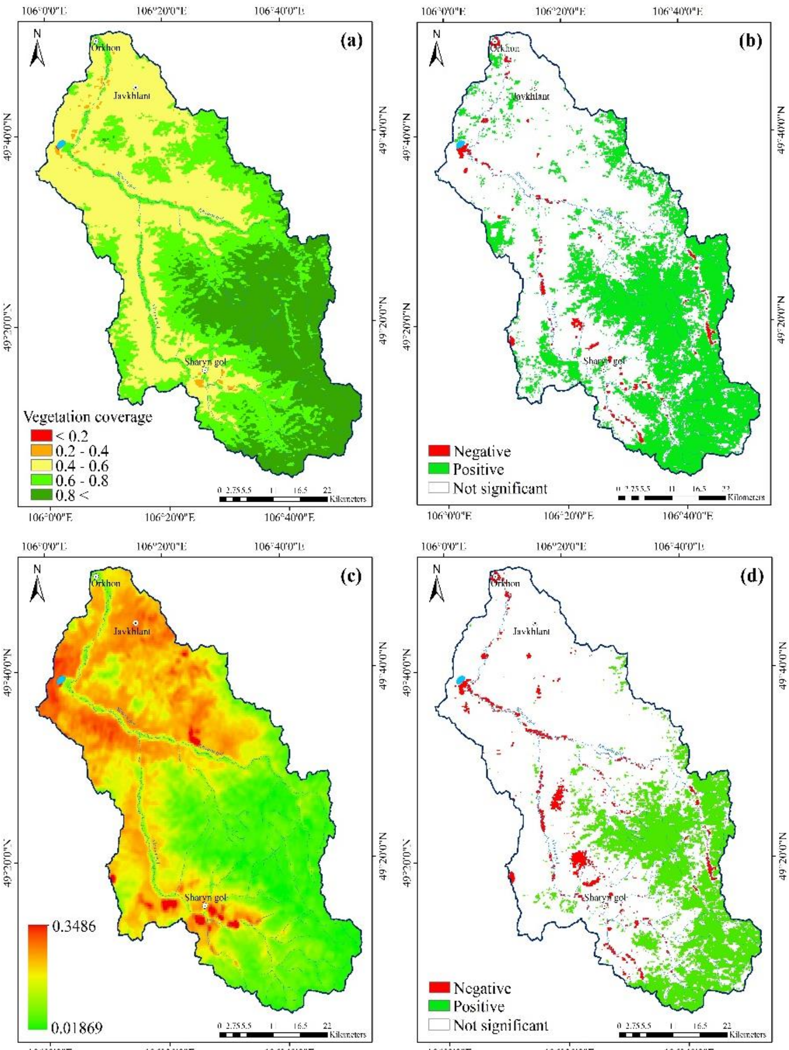

Fig. 1. Spatial distribution of (a) multi-year average growth season NDVI; (b) NDVI trends; (c) NDVI coefficient of variation; (d) NDVI residual trends

Based on the estimation of the relative contribution of human activities and climate factors to vegetation dynamics, 2043 or 87.5% of all pixels with a decreasing trend of residual NDVI was caused by human activities, while 293 or 12.5% was caused by the combination of human activities and climate factors. There was no pixel with a decreasing trend of residual NDVI caused by climate factors. Meanwhile, only 53 pixels of all pixels showed a positive contribution of human activities to the dynamics of vegetation in the entire study area. The decreasing trend of residual NDVI indicated the degradation of the river bank due to overgrazing of summer-autumn grasslands and open-pit coal mining, as well as small-scale artisanal gold mining along the riparian zones of the Sharyn Gol River and its tributaries. At the 95% confidence level, the statistically insignificant trend of the residual NDVI was observed in 75.7% of the study area. Furthermore, the statistically significant increase in the residual NDVI promoted by the combination of climate factors and human activities represented 21.5% of the river basin (Fig. 2).

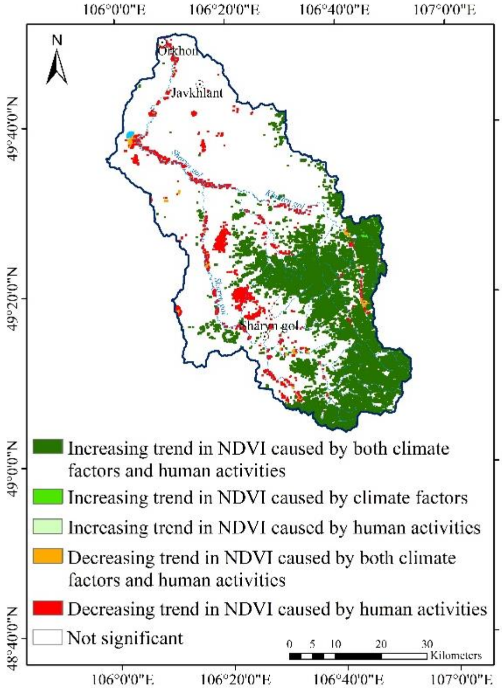

Fig. 2. Relative contribution of climate and human activities to vegetation dynamics

Munkhdulam et al., (2022) found a positive trend in vegetation dynamics in northern, central and northeast Mongolia and that determined trend was statistically insignificant in areas with dense vegetation. In the Sharyn Gol River Basin, located in northern Mongolia, the upward trend in NDVI accounted for approximately 90 % of the study area, of which 63.45% was statistically insignificant. Therefore, the general pattern of the change trend of NDVI in this study area was consistent with the changes in vegetation described by [32].

Human activities showed a negative effect on vegetation growth rather than a positive effect on vegetation growth in the Sharyn Gol River Basin. Especially, the riparian zones of the Sharyn Gol River and the Khuiten River were notably affected by human activities, including overgrazing, cultivation, and mining activities. The previous studies highlighted the result mentioned above that the river banks of the Sharyn Gol River and the Khuiten River were under high pressure of human activity from its upper stream to the downstream and human activities have a negative impact on aquatic ecosystems and water quality [23]. Gold mining activities in the upper stream of the

Sharyn Gol River have resulted in spoilt heaps, tailing dams and ponds, and a high amount of total suspended solid load to the downstream [33]. Riparian forests, willows and shrubs in the upper stream of the Khuiten River were destroyed by gold mining. Furthermore, the forest in this basin is affected by human activities and wildfires [34]. [35] found that the species composition, vegetation cover and biomass of riparian vegetation in the Sharyn Gol River had changed due to overgrazing and mining activities compared to untouched grassland. In intact grasslands and fenced areas, the average biomass was 30.6 c / ha, the dominant plant species were *Geranium pratense, Agrostis gigantea, Angelica decurrens, Halenia corniculate, Aconitum barbatum, Thalictrum simplex, Galium Verum and Achillea asiatica*, while the average biomass in the areas influenced by humans was 5.1 c / ha, the dominant plant species were *Potentilla anserine, Carex duriuscula, Cirsium esculentum, Taraxacum officinalis, Iris, and Achnatherum splendens* [35].

Those areas with an increasing trend in residual NDVI were located mainly in the upper section of the river basin and far from human settlements. According to the relative contribution analysis, the growth of vegetation in those areas was positively influenced by a combination of climate factors and human intervention. It could be explained hypothetically that the combined effect of human intervention and climate factors on vegetation tended to promote plant growth. However, there was no obvious sign that human intervention had played a positive role in helping vegetation growth in those areas. Therefore, future studies could conduct a detailed analysis to confirm whether the relative contribution analysis is suitable for assessing the driving forces of vegetation dynamics in a similar local context.

4 Conclusions

Sen's slope estimate, Mann-Kendall test, and residual trend (RESTREND) method were used to identify spatial and temporal changes in vegetation dynamics in the Sharyn Gol River Basin during 2000-2022 and calculate the impacts of climate change and human activities on vegetation. Our research findings suggested that (1) the growing season NDVI exhibited a gradually increasing trend with a mean rate of 0.0024/year during the study period. The increasing trend in NDVI occurred mainly in the upper section of the river basin, while the decreasing trend in NDVI was concentrated mainly along the river banks of the Sharyn Gol River Basin and the Khuiten River; (2) the fluctuation of NDVI values was higher in the lower section of the river basin and around the mining sites, while the variations in the forest were relatively stable; (3) human activities could lead to land degradation in the Sharyn Gol River Basin. Human activities had a notable negative impact on the riparian vegetation in not only the Sharyn Gol River, but also its tributaries. Degradation of riparian vegetation might be a diminishing of the ecosystem services provided by the riparian zone to social communities. Climate factors might have played a significant role in vegetation growth in this basin area. Therefore, more strict enforcement of existing legislation is urgently needed, in order to protect land and water resources in this basin. Decision makers, land managers, river basin authorities, and local residents should pay more attention to those classified as 'negative trends in NDVI' areas and prevent further degradation of the ecosystem. Ecosystem restoration and ensuring sustainable use of land resources are the most demanding tasks in the riparian zones of the Sharyn Gol River.

5 Acknowledgements

The author would like to acknowledge my colleagues from the Division of Water Resource and Utilization and the Division of Environmental and Natural Resource Management, Institute of Geography and Geoecology, Mongolian Academy of Sciences for their valuable and helpful comments and suggestions.

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