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Article

Research of non-equilibrium dynamic of pasture ecosystems in Mongolia

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Abstract. Wiens, DeAngelis and Waterhouse, and Ellis and Swift first introduced the concept of non-equilibrium rangelands. In 1988, Ellis and Swift further proposed that rainfall variability could degrade rangeland ecosystems, with non-equilibrium conditions arising when the rainfall coefficient of variation surpasses 33%. It means that rangeland's dynamics, particularly livestock dynamics, are governed by frequent droughts. Direct application of this statement in Mongolia shows that the drylands of Mongolia with annual precipitation of less than 175 mm exhibit non-equilibrium dynamics. These areas include the Gobi and the southern part of the dry steppe. Based on the above theoretical basis and research, the precipitation coefficient of variability in Mongolia was re-mapped using data from a total of 68 stations. Otherwise, for the above stations the analysis was done using 58 year time series, and the above stations were generated by creating a geographical distribution. One of the goals of this work was to show the results of coefficient of variation for natural zones. From the resulting map, shows an expanding area with a precipitation coefficient of variability exceeding 33%, and in terms of natural zones, a greater spread is observed towards the steppe region. This indicates that the area of unbalanced pasture ecosystems is expanding, and it shows the need for alternative management solutions at the level of livestock sector and pasture utilization in the region. Another important point is that global warming, livestock numbers, and pasture overcapacity are significantly affecting the imbalance in the above-mentioned pasture ecosystem, so further comprehensive studies are needed.

Keywords: non-balanced dynamic, biomass, pasture of ecosystem, coefficient of variation, system dynamics model.

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Introduction

One of the pillars of Mongolia's economy is the livestock sector. This sector has played and continues to play a significant role in providing food for the population, raw materials for the processing industry, and jobs for citizens. This sector employs 23.8% of Mongolia's total workforce, generates 12.8% of the country's gross domestic product (GDP), and 87.2% of total agricultural production. It is also the main source of food supply for the population and the livelihood of herders [1]. The livestock sector is based on natural pasture and is highly dependent on climate and natural factors.

In recent years, the rapidly changing climate has tremendously influenced climate-dependent pasture ecosystems. In particular, recent research on precipitation changes has shown that “Against a backdrop of global climate change, precipitation in Mongolia has tended to decline over the past 60 years” [2]. However, the changes vary seasonally, with a decreasing trend in precipitation during seasons other than winter.

This is creating a trend towards increasing the risk of dzud. However, the intensity of summer rainfall is increasing, as evidenced by the increase in the maximum daily rainfall observed in many years [2]. This will lead to an increase in the risk of flooding and soil erosion. Another change in precipitation patterns is the increase in the coefficient of variability of total annual precipitation in most regions.

The precipitation coefficient of variability for 1991-2020 compared to 1961-1990 are shown in Fig. 1. [2].

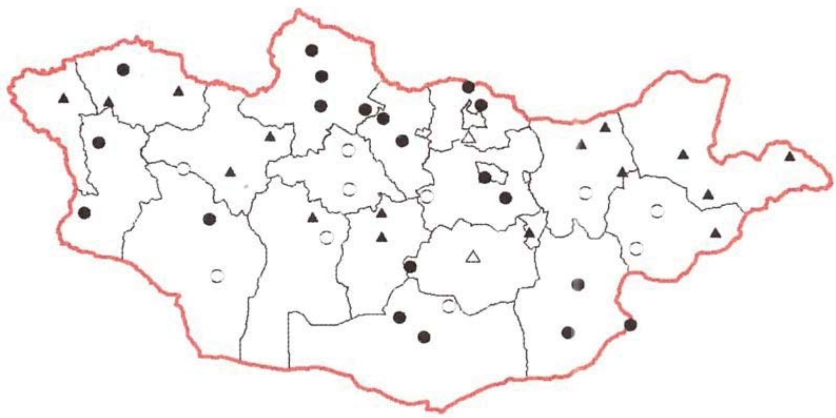

Figure 1. Change of precipitation coefficient of variability in warm season (1991-2020 average compared to 1961-1990 average)

Note: unshaded triangle - coefficient of variation (CV) unchanged, highlighted triangle - CV increased from 0.32 to above this threshold, closed black circle - CV value decreased, circle - CV value increased.

Over the past 70 years, Mongolia's air temperature has increased by 2.1°C, making our country one of the most affected by climate change. Precipitation is one of the driving factors of any ecosystem, and fluctuations in precipitation express its characteristic of non-equilibrium dynamics [3].

Currently, the prevailing view among rangeland ecologists is that where the coefficient of variation of inter-annual precipitation is >0.33, ecosystem dynamics are controlled predominantly by abiotic factors, not biotic ones (whether livestock or other organisms) [4].

Fig. 1. shows that Khuvsgul, Bulgan, and Selenge provinces, the northern part of Tuv province, and the Gobi Desert region, precipitation variability has generally decreased or has shown little change, but from the Dornod steppe through the Govisumber region to the Uvurkhangai region, Khangai-Gobi intertidal zone, the eastern part of Uvs, Zavkhan region, and the northern part of the Gobi-Altai it has increased. In this case, even in areas where the variability coefficient was less than 0.30, it has increased to more than 0.32. Looking at this picture on a larger scale, it seems that precipitation variability between the Gobi desert region and the Khangai region (which can be considered an ecotone zone of the landscape) may be increasing, and the pastural ecosystem may be shifting to an unstable state [2].

As mentioned in the previous section, studies that considered the precipitation variability of coefficient is a key measure of the equilibrium of pasture ecosystems have been conducted since the mid-1980s, with researchers Wiens [5], DeAngelis and Waterhouse [6], and Ellis and Swift [7]. As research continues, regions where the global precipitation variability of coefficient value exceeds 33 were mapped.

Researchers Ellis and Ramankutty [8] used the University of Delaware global gridded monthly precipitation dataset to map the proportions of rangeland anthromes where the CV of inter-annual precipitation is >0.33.

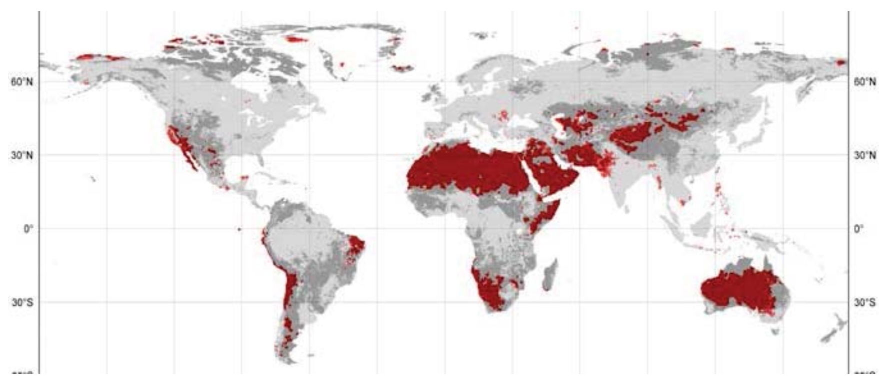

Figure 2. Map of global land area with an inter-annual precipitation coefficient of variation >33% (red), based on data from 1970 through 1999[1].

[1] (University of Delaware global gridded monthly precipitation dataset (http://www.esrl.noaa.gov/psd/)

Greyed background indicates rangeland and non-forested wildland anthromes (residential, populated, and remote rangelands, inhabited treeless and barren lands, and wild treeless and barren lands).

As the map above shows, most of Central Asia, North Africa, and Australia fall into the unbalanced region. Therefore, previous studies have shown that areas with a precipitation variability of coefficient exceeding 33 were observed in Central Asia, especially in the southern Gobi region of Mongolia. However, recent results of studies that conducted by L.Natsagdorj, G.Sarantuya, and B.Munkhbat highlight that steppe regions, in particular, are also expanding into areas with a precipitation variability of coefficient exceeding 33 [2].

Therefore, a detailed study of the regions in Mongolia where the pasture ecosystem is unbalanced, or where the precipitation variability of coefficient exceeds 33, will make a significant contribution to the development, planning, and research of the pasture sector of Mongolian economy.

Research methodology

This study utilized monthly average air temperature (°C) and monthly precipitation (mm) data from 68 meteorological stations across Mongolia's 21 aimag (provinces) and 68 soums (districts), spanning diverse ecological zones. The data series varied in duration, with the longest spanning 83 years and the shortest covering 16 years. As Mongolia's pasture sector relies heavily on natural pastures for livestock feed, pasture biomass data from unfenced areas (measured annually on August 25 by Agricultural Meteorological Stations) were sourced from the National Agency for Meteorology and Environmental Monitoring. Livestock population data were obtained from the National Statistics Office of Mongolia and standardized to sheep unit equivalents for comparability.

The analysis employed the framework proposed at the previous study [7], which defines non-equilibrium rangeland conditions as occurring when the CV of rainfall exceeds 33%. This threshold signifies substantial climatic variability relative to the mean, a critical factor in arid and semi-arid ecosystems.

Variance linear coefficient: a relative measure that compares the variance of the linear mean to the mean

$$V_k = \frac{\theta}{\bar{\bar{X}}} \cdot 100 \tag{1}$$

Relative indicators of variation are indicators for evaluating the arithmetic mean calculated for the original population.

Considering the coefficient of evolution (variation) of rainfall, CV >33% during drought, this method disturbs the interaction between plants and livestock and leads to unbalanced conditions. The longer the drought or lack of rainfall, the lower the yield of plants will grow, creating a poor region. In this way, the number of livestock living in this area will increase, turning it into a region of high deviation.

This method considers the CV in precipitation, and a CV>33% reduces the relationship between plants and livestock and leads to an unbalanced state. The longer this drought or lack of precipitation lasts, the lower the crop yield will be, creating some weak zones. As a result, the number of livestock living in the area will increase, transforming it into a volatile region.

Calculated Baseline Conditions and Reports

Mongolia is divided into 6 natural zones: High mountain zone, Mountain taiga zone, Forest steppe zone, Steppe zone, Desert steppe zone, and Desert zone (Fig. 3).

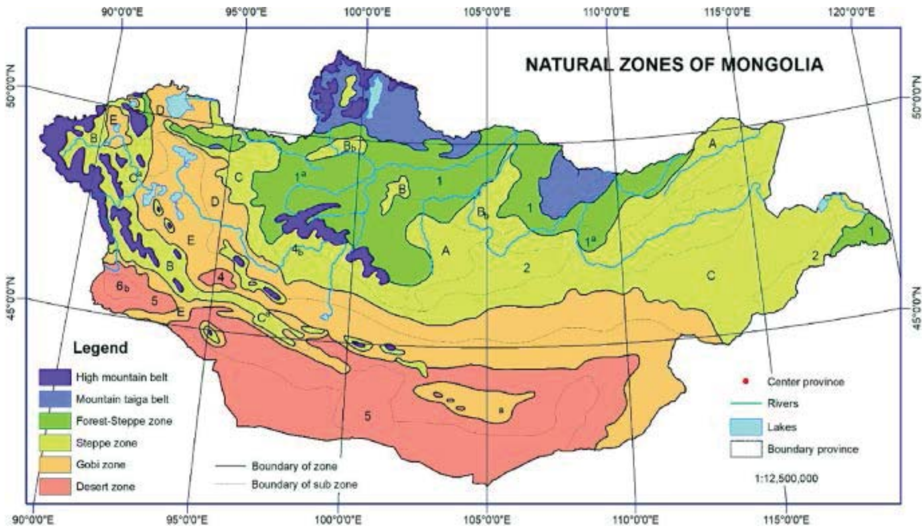

Figure 3. Classification of natural zones and belts [9].

The annual air temperature and precipitation data recorded at the soums' meteorological stations, along with the corresponding monthly trends for spring and summer, standard deviation, and CV, are presented below. The CV was calculated using annual and May–August precipitation data from 68 soums across 21 provinces in Mongolia, based on a multi-year dataset. The average length of the time series for the stations is 58 years.

Results

According to the calculations, the of annual precipitation exceeded 33 percent for 28 stations, while the CV of precipitation during the growing season (May – August) exceeded 33 percent at 38 stations (Fig. 4-5). The CV was calculated separately for total annual precipitation and May–August precipitation. In Mongolia, approximately

80 percent of total precipitation occurs between May and August, which is the key period for plant growth. Therefore, the study aims to examine relationship between pasture yield and CV of precipitation during the May–August period.

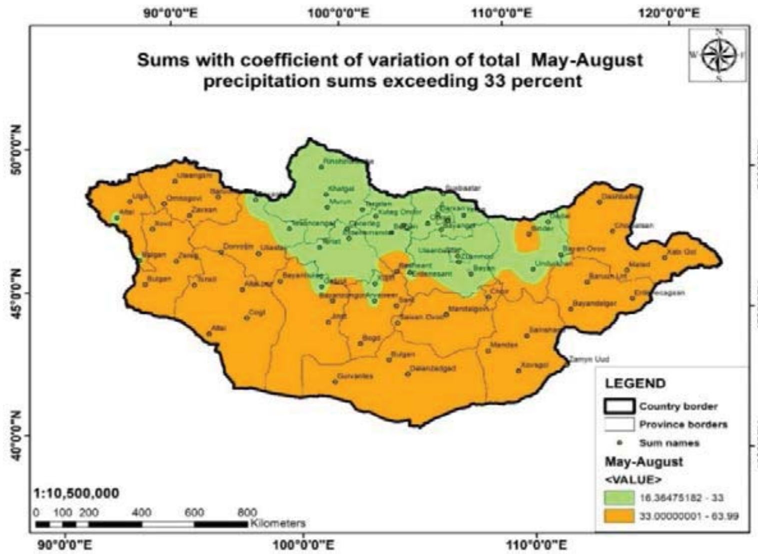

Figure 4. Soums where the coefficient of variation for May–August precipitation exceeds 33%

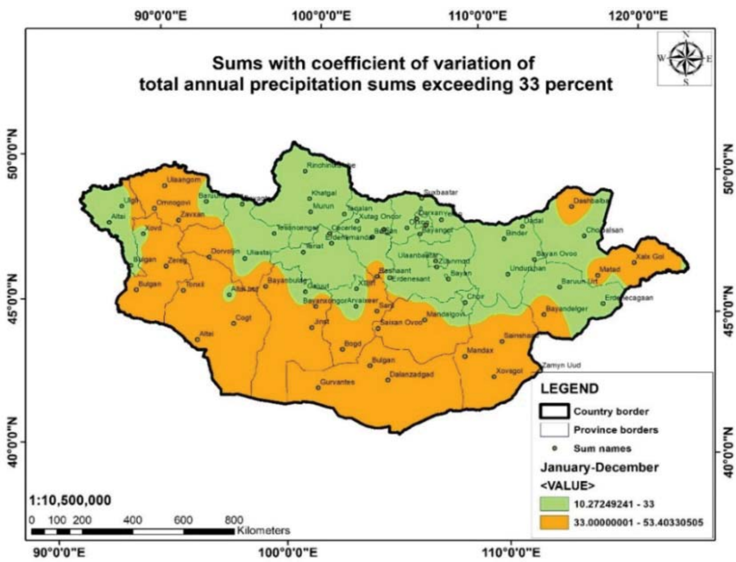

Figure 5. Soums where the coefficient of variation for annual precipitation exceeding 33 percent.

Comparing the results of the above maps with the results of (Fig. 3) published in 2003, the land area with unbalanced conditions has increased, including some soums belonging to the steppe and forest-steppe zones. Previously, non-equilibrium conditions were observed only in the Gobi and desert regions regarding natural zonation. However, these conditions have expanded in recent years and are now present in the steppe and forest-steppe regions. In other words, an increase in precipitation variability indicates ongoing changes in precipitation's temporal and spatial distribution. For example, this means that the frequency of heavy rainfall events, intense precipitation, and the number of days with no precipitation is increasing.

Also, the results of previous study [2] suggested that the pasture ecosystem may be shifting to an unstable state due to increased precipitation variability between the Gobi desert region and the Khangai region (which can be considered an ecotone region of the landscape), are consistent with the results presented in (Fig. 4-5).

The table below shows the results for any natural girdle (Table 1).

Table 1. Natural zones with a coefficient of variation in precipitation exceeding 33%.

№	**Zone**	**Total for the year**	**05-08 months**	**Soum**
1	Desert steppe	13	13	26
2	Steppe	8	15	23
3	Desert	6	7	13
4	Forest steppe	1	3	4
Total		**28**	**38**	

From the above results, 34.2-46.4 percent belong to the desert steppe zone, 28.5-39.4 percent to the steppe zone, 18.4-21.4 percent to the desert zone, and 3.5-7.8 percent to the forest-steppe zone. Of these results, most of the population is in the desert and steppe zones, and the percentage of the steppe zone has increased. At the same time, the increasing variability in precipitation in the forested areas suggests a tendency to destabilize the ecosystem further. One soum was selected from each of the natural zones with a precipitation variation coefficient exceeding 33 percent. A correlation study was conducted with pasture yield and livestock population data for that period. Gurvantes soum of Umnugovi province from the desert zone, Bogd soum of Uvurkhangai province from the desert steppe zone, Erdenetsagaan soum of Sukhbaatar province from the steppe zone, and Bayangol soum of Selenge province from the forest-steppe zone were selected and used in the study.

For the desert zone, as shown in the table above, the number of livestock is most closely related to the soum of precipitation during the warming season. The lowest correlation is found between biomass and the total precipitation value during the warm season, May to August. Pasture yields in the desert steppe region are most correlated with precipitation values, ranging from 0.43 to 0.46. In particular, considering the relationship between the total precipitation during the vegetation period, i.e. from May to August, and pasture yield, for example, all 4 regional stations had a positive correlation, with the highest correlation being in the Bogd soum, or desert steppe region of Uvurkhangai province.

Table 2. Correlation coefficient between pasture yield, livestock number, and precipitation values in natural zone.

	Number of livestock	**Total annual precipitation**	**Precipitation from May to August**
Desert zone, Gurvantes of Umnugovi			
Biomass of pasture yield	0.058	0.11	0.05
Number of livestock	-	0.21	0.22
Desert steppe zone, Bogd of Uvurkhangai			
Biomass of pasture yield	-0.08	0.43	0.46
Number of livestock	-	0.20	0.16
Steppe zone, Erdenetsagaan of Sukhbaatar			
Biomass of pasture yield	0.19	0.30	0.21
Number of livestock	-	-0.032	-0.33
Forest steppe zone, Bayangol of Selenge			
Biomass of pasture yield	0.40	-0.02	0.08
Number of livestock	-	0.07	0.09

It makes a direct logical sense that yields depend on precipitation. The lowest value is -0.08 for biomass, suggesting that the lower number of livestock is grazing. In the steppe zone, the highest correlation was found between biomass and total precipitation, while livestock numbers were negatively correlated with precipitation. The highest correlation was found for the forest-steppe zone when biomass was between 2 and the number of livestock, while biomass was negatively correlated with total annual precipitation.

Discussion

The rangelands of the Mongolian Plateau are dynamic social-ecological systems influenced by a complex network of drivers, including climate, social institutions, market forces, and broad-scale policies affecting land tenure. These factors are linked via feedback and often exhibit non-linear relationships [10].

According to the theory of non-equilibrium dynamic of pasture, when the precipitation variability of coefficient exceeds 33 percent, non-equilibrium conditions are created, and the area of pastures with such conditions tends to expand. This is seen from the results of previous studies [2] and our own calculations. In other words, pastures, which are the basis of livestock, are highly dependent on the conditions of precipitation variability, which means that will increase the impact on livestock production and the economic situation of Mongolia. At present, this only refers to the results of theoretical studies based on the conditions of precipitation variability, which is a meteorological indicator. But in the future, it will be more important to conduct systematic research, including factors such as pasture conditions, livestock numbers, climate change trends, and natural disasters such as drought and dzud, to determine future trends. A finding of rangelands with non-equilibrium dynamics in Mongolia has important policy implications. In order to cope with climate change, especially uncertainty, it is necessary to maintain traditional livestock migration in pastures with unbalanced dynamics, and to coordinate flexible economic development.

Flexible economic development means that variable livestock production should be installed. For example, we may have to harvest more meat during drought in non-equilibrium rangelands in anticipation of dzud and keep the meat in freezing systems, selling the meat in the springtime when the meat price is higher. Renewable energy and satellite communication systems must be used for the sustainable development of these nomadic communities.

Conclusion

Based on the observed results, the following conclusions are drawn:

1. Non-equilibrium conditions prevail in the rangelands of Mongolia's Gobi and steppe regions. The area of non-equilibrium rangelands increases (from 28 to 38 stations) in the steppe region if we account for warm-season climate variability. It may indicate that warm-season climate variability is a more critical driver in the desert-steppe zone than the steppe zone because warm-season precipitation in the desert-steppe region correlates better with plant productivity than the steppe zone. The number of livestock was especially inversely related to biomass only in the desert steppe zone. It is -0.08.
2. The coefficient of variability for the annual total precipitation calculated from our 68 meteorological stations is 33 percent to point 28 or 41.17 percent of the total stations calculated. For the total precipitation from May to August, where most of the precipitation occurs, the CV is from 33 percent to point 38, or 55.8 percent of the total stations calculated.
3. In Erdenetsagaan soum (a representative steppe region studied here), livestock population growth showed an inverse relationship with precipitation levels, indicating that pasture biomass alone does not dictate livestock dynamics in Mongolia. While higher precipitation intuitively enhances pasture productivity and supports livestock growth, prolonged hot/dry periods followed by short-term heavy rainfall (1–2 days) did not significantly alter monthly precipitation averages. However, such extreme events may distinctly influence pasture quality and regeneration, highlighting the complexity of climatic drivers in arid systems. Further research should investigate how short-term extreme rainfall affects pasture resilience and livestock sustainability.
4. In the forest-steppe sum, biomass is inversely related to total annual precipitation, but a direct relationship is evident for total precipitation from May to August.
5. The practical result of the work is that it can be used for natural regions by properly defining the relevant parameters of the above model.
6. Our results are consistent with the findings of researchers L.Natsagdorj, G.Sarantuya, and B.Munkhbat, who suggested that the pasture ecosystem may be shifting to an unstable state due to the increasing a precipitation variability in the steppe region. 28.5 percent of the total values that the annual total precipitation coefficient of variability exceeding 33 percent, and 39.4 percent of the total values

of May-August precipitation coefficient of variability exceeding 33 percent, belong to the steppe region.

7. The results of previous researchers, who found that the average annual precipitation between 1960 and 1995 was less than 250 mm, or in the Gobi and desert regions, have expanded geographically, and in some cases, there are unbalanced conditions in the forest-steppe.

References

1. A.Bakei, R.Samiya, J.Jargal, Yu.Altanbagana, Guidelines, Implementation recommendations for livestock development policy reform, 2023.
2. L.Natsagdorj, G.Sarantuya, B.Munkhbat, The most recent climate change in Mongolia: Drought, Ulaanbaatar, 2024.
3. Ministry of Food, Agriculture and Light Industry, Improving the climate change adaptation capacity and risk management of rural Mongolian communities, Ulaanbaatar, 2023.
4. F. S. Nathan, K. D. Diana, B. Brandon and C. W. Jeb, Rangelands: Where anthromes meet their limits, MDPI, no. land6020031, May 2017.
5. J. Wiens, On understanding a non-equilibrium world: myth and reality in community patterns and processes, Ecological Communities, 1984.
6. D. L. DeAngelis and J. C. Waterhouse., Equilibrium and nonequilibrium concepts in ecological models, Ecological Monographs, pp. 1-21, 1987.
7. J. E. Ellis and D. M. Swift, Stability of African pastoral Ecosystems: Alternate Paradigms and Implications for Development., Journal of Range Management, vol. 41, pp. 450-459.
8. Ellis, E. C. Ramankutty, N., Putting people in the map: Anthropogenic biomes of the world., Frontiers in Ecology and the Environment, vol. 6, pp. 439-447, 2008.
9. Y. Batchuluun, The Physical Geography of Mongolia, Switzerland: Springer Cham, 2021.
10. G. R. Allington, L. Wei and D. G. Brown, Modeling System Dynamics in Rangelands of the Mongolian Plateau, Building Resilience of Mongolian Rangelands, pp. 216-221, 2015.