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CHANGES OF ARIDITY INDICES IN MONGOLIA

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Aridity is one of the major indicators to delineate territories prone to desertification, thus the present paper discusses spatial and temporal variability of aridity in the past over the Mongolia. The aridity were calculated using four temperature and precipitation based indices: 1) de Martonne aridity index (IDM); 2) Thornthwaite aridity index (AI); 3) moisture coefficient by V.I. Mezentsev (MI) and 4) Hydrothermal coefficient by Selyaninov (HTC). The basic meteorological data from 70 stations in Mongolia for the period of 1961-2015 are used in present paper. The area of drylands (hyper-arid, arid, semi-arid and subhumid regions) is different depending on used index. According to the results drylands delineated by IDM, MI, AI and HTC is 64.1%, 70.7%, 85%, and 98%, respectively. Out of 4 aridity indices, AI and MI showed high correlation with NDVI derived dryland regions. According to the temporal analysis of AI and MI around 66% of a time series had a decreasing tendency during observed period of time. The central and northeastern regions of the country have the significant decreasing trends of the aridity indices. The relative changes of the aridity indices vary between 14%-74% for stations with significant decreasing trend.

Keywords: aridity index; Mongolia; trend; relative change.

1. Introduction

Aridity is a phenomenon which defined by a shortage of moisture based on average climatic conditions over a region [1]. On the onset of XXI century the climatic aridity, dryness, and drought are becoming a significant socio-environmental problem, due to affecting the both ecosystems and livelihood of the population in many regions, especially in developing countries. The increase of the aridity or dryness level beyond a certain point negatively affects the resilience to the climate change. To understand the various climate mechanisms and describe the state of the climate the climatic indices are used as diagnostic tools [2]. The aridity index is a numeric climatic indicator which can be used for monitoring and prediction of the degree of dryness in a region [3]. Its changes would affecting the hydrological cycle, water resources and its management [4], and may induce desertification.

The temperature and precipitation measurements are usually used to derive primary climatic indices, due to 1) temperature and precipitation are the main climate indicators; 2) comparing to other climatic variables records of temperature and precipitation are longer. The changes expected to accompany climate warming, thus are well approximated by these two variables than for the other variables such as cloud cover, winds, and humidity [5], [3]. Although the temperature and precipitation are useful parameters to study the overall tendency of the climatic change, the aridity or humidity index is better expresses the climate change and its significance regarding bioclimatic conditions [6].

Numerous studies have been conducted to determine spatial distribution and spatio-temporal changes in aridity using aridity equations derived from temperature and precipitation data [7], [8], [9]. Besides using the global indices, some regions of the world use own climate indices to define dry/wet regions [10], [11].

The aim of this study is to characterize and determine changes in climate aridity using temperature and precipitation based indices for the regions where full meteorological data is not available to define ETo estimation.

2 Materials and methods

2.1 Dataset

The monthly records of temperature and precipitation data provided by the National Agency for Meteorology and Environmental Monitoring (http://namem.gov.mn) used in this study. Totally 70 weather stations with a minimum record length of 40 years were considered. The spatial distributions of the selected stations illustrated in Fig. 1.

2.2 Aridity indices

Aridity is the degree to which a climate lacks sufficient, life-promoting moisture; the opposite of humidity, in the climate sense of the term [12]. The higher the aridity indices of a region, the greater water resources variability [3]. The increasing aridity represents a higher frequency of dry years over an area [2]. In this study, the De Martonne aridity index (I_{DM}), UNEP aridity index (AI), Selyaninov's hydrothermal coefficient (HTC) and Mezentsev's (MI) moisture ratio calculated for Mongolia based on temperature and precipitation data for the period 1961-2015.

2.3 Methods of trend analysis

Mann-Kendall test:

Mann-Kendall test is a statistical test widely used for the analysis of trend in climatologic [13], [14] and in hydrologic time series analysis [15]. In the present study, the Mann-Kendall test was used to detect temporal trends in four different aridity index time series. The test statistic (Z_{MK}) is given as:

$$Z_{MK} = \begin{cases} \dfrac{S\text{-}1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \tag{1}$$

In which, $$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \operatorname{sgn}(x_k - x_i) \tag{2}$$

$$Var(S) = \frac{\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(t_i + 5) \right]}{18} \tag{3}$$

Where the x_k and x_i are the sequential data values, *m* is the number of tied groups (a set of sample data having the same value), t_i is the number of data points in the *i*th group, n is the length of the data set, and $\operatorname{sgn}(\theta)$ is equal to 1, 0, — 1 if θ is greater than, equal to, or less than zero, respectively [16],[3]. The positive (negative) values of Z indicate increasing (decreasing) trends, and the value $Z_{1-\alpha/2}$ denotes a quantile of the standard normal cumulative distribution. The null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \le Z_{MK} \le Z_{1-\alpha/2}$ [3].

The significance of trends found in this study evaluated at the 5% significance level.

Pettitt's test: The approach after Pettitt (1979) is widely used to detect a single change-point in hydrological and climate series for continuous data [17]. It tests the null hypotheses (H_0) that the T variables follow one or more distributions having the same location parameter (no change), against the alternative: a change point exists.

$$K_T = \max |U_{t,T}| \tag{4}$$

where
$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}(x_i - x_j) \tag{5}$$

The change-point of the series located at K_T, provided that the statistic is significant. The significance probability of K_T is approximated [17] for $p \le 0.05$ with

$$p = 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \tag{6}$$

Relative change: The relative change (RC) of the aridity index [3] determined as:

$$RC = \frac{n \times \beta}{|\bar{x}|} \times 100 \tag{7}$$

Where n is the length of the dataset record, β is a trend magnitude observed in the series and $|\bar{x}|$ is the absolute average of the series. The non-parametric Theil-Sen's estimator [18],[19] was used to obtain the magnitude of the trends as follows:

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i - j}\right) \tag{8}$$

where $1 < j < i < n$.

3 Results and discussion

3.1 Spatial distribution of aridity index

The IDM index spatial distribution over the Mongolia illustrated in Fig. 1a. The IDM values account the entire range of the climate classification categories. At 21 from the total 69 stations, the IDM has lower than 10.0, indicating the arid climate. In opposite, the highest values of the IDM, entailing humid, very humid, and extremely humid climates, are distributed to the stations located in the northern parts of the country. About 25.5% of the country was arid, 17.0% was semi-arid, 7.6% was Mediterranean, 7.0% was semi-humid, 12.8% was humid, 21.3% was very humid, and 8.7% was extremely humid. The IDM values ranged from about 2.5 at Ehiingol station in the south to about 79 at Renchinlhumbe station in the north.

According to the AI values, about 22.7% of the entire area is classified as hyper-arid and arid climates (Fig. 1b). At 17 out of the 69 stations, the values of the AI were less than 0.2, implying a dry climate. The semi-arid climate with formal steppe vegetation found in the middle regions of the country. Only the regions located on the north and east of the country had AI values higher than 0.5.

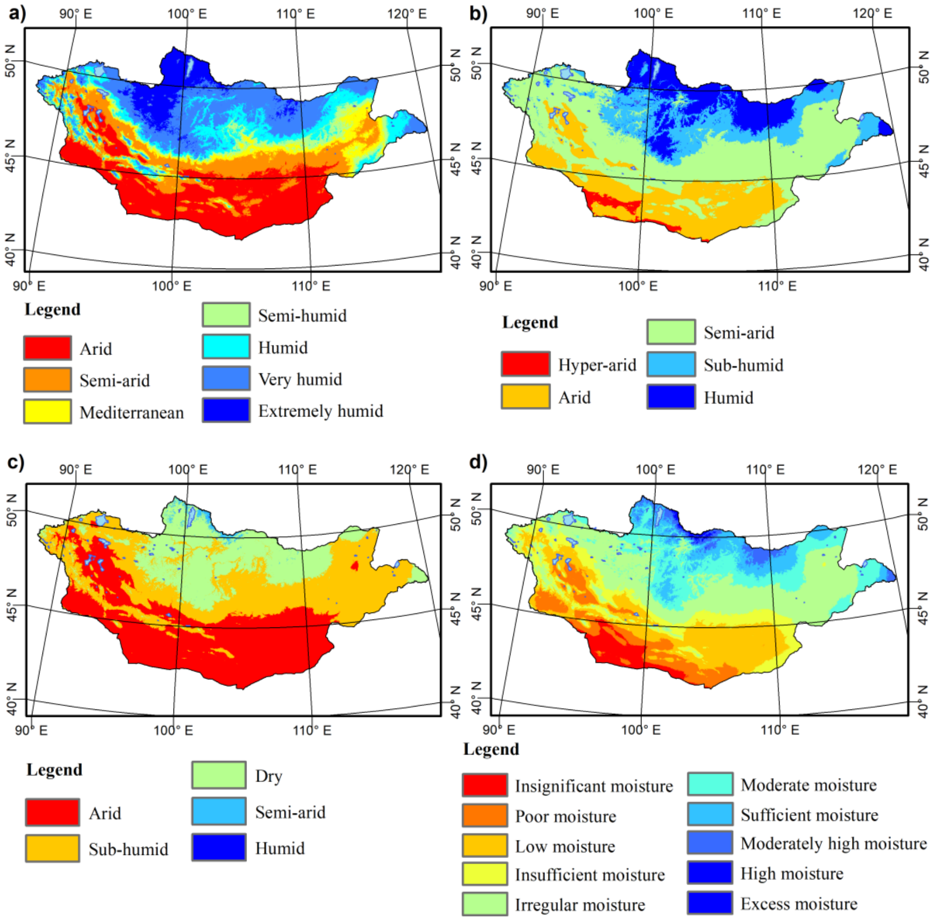

Fig. 1 Climate type map of Mongolia (1961–1991): a) IDM; b) AI; c) HTC; d) MI.

The spatial distribution of the HTC value (Fig. 1c) shows that 35.6% of the country was extra arid, 37.9% was arid, 25.5% was semi-arid, and only 1.0% was subhumid. At 26 out of the 69 stations, the HTC value was lower than 0.4, indicating arid climate. The lowest values of HTC range from 0.03 to 0.09 at the station to be found in the south of the country.

The map of MI values (Fig. 1d) indicate that the area of insignificant and poor moisture occupy 12.8% of total territory of Mongolia, which coincides with the arid land. The semi-arid and dry climate is found on 29.1% of total area. The area of land with humid climate is about 3% of the total territory.

The extra-arid area identified by the AI is smaller than that found by the other methods, but the semi-arid area obtained by the AI is biggest. Overall, the spatial distribution of the AI and MI are similar, while climatic zones defined by IDM and HTC are different. To evaluate how the selected indices represent climatic classification we compared the results of the four methods with average NDVI for the country (Table 1). According to the results of the correlation analysis, it can be concludedd that AI and MI are more appropriate for climate classification since it with their climate categories defines the vegetation cover condition more precisely.

Table 1

The matrix of Pearson's correlation coefficients for aridity indices

	NDVI	IDM	HTC	MI
IDM	0.46**			
HTC	0.61**	0.75*		
MI	0.78***	0.52**	0.71***	
AI	0.79***	0.60**	0.79**	0.98***

Note: Significance level is associated to a symbol: "***" — 0.001, "**" — 0.01, "*" — 0,05.

The AI and MI are highly correlated in the study stations. The coefficient of determination (r^2) equals to 1 found in the arid and semi-arid regions and 0.98 for all locations. In the humid climate (Renchinlhumbe and Hatgal stations), the r^2 value of 0.60 is obtained between the IDM and AI. The r^2 values of the AI with IDM and HTC for the stations were between 0.60 and 0.79.

3.2 Trend of aridity

The Mann-Kendall is illustrated in Fig. 2. The arrow markers in the maps show the temporal trends detected by the Mann-Kendall test for the IDM, AI, HTC, and MI series. The decreasing trend of the aridity indices means the arid climatic conditions exist. Around 84% of the IDM series showed a decreasing tendency. In a context of human well-being, especially in drylands, the increase of aridity will diminish the livelihood sources for human in general and increase risks for the production of livestock.

Significant decreasing trends in the IDM series at the 5% level were found at 36 stations. The relative changes of the IDM at the stations mentioned above were between 13% and 57%.

Similar to the IDM variations, around 85.5% of the HTC series showed a decreasing tendency. Significant decreasing trends in the HTC series at the 5% level were observed at 28 stations. The relative changes of the HTC at the mentioned stations ranged between 18% and 72%. The stations located in central parts of Mongolia have the relative changes higher than 50% (Fig. 2).

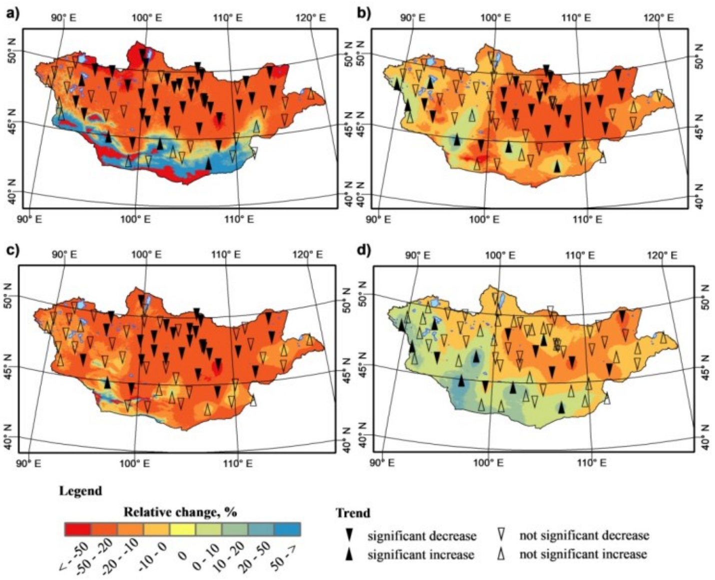

Fig. 2 Relative change (%) of the aridity indices over 1961–2015 (arrow markers show the trends detected by the modified Mann-Kendall test): a) IDM; b) AI; c) HTC; d) MI.

A different picture observed for MI and AI indices, where around 52% of MI and 80% of AI showed decreasing tendency. The number of stations with the significant decreasing trend at the 5% level observed at only eight locations for MI index and 21 stations for AI index. The number of stations with relative change over the 50% identified only at two stations for AI and MI indices.

The significant increase of aridity was observed mainly in the middle and northern parts of the country, which largely occupied by steppe and dry steppe ecosystems. With increasing aridity in the regions, the water deficiency increases significantly, this impacts on agriculture and livestock as the largest water user. Compared to humid regions the arid and semi-arid regions are more sensitive to water resource variability and availability [20]. Furthermore, the impacts of changes in aridity, especially its increase, can exacerbate the extent and level of desertification [3].

Pettitt's test was used to determine the position of change points in the time series of the selected 4 aridity indices with significant trends. In general, the change point years obtained for the series of aridity indices are consistent with each other and for the greater part of stations with significant changes the change point is 1994.

5. Conclusions

Annual de Martonne, UNEP, Mezentsev and Selyaninov aridity indices series of Mongolia investigated with respect to spatiotemporal variations for the period 1961-2015. According to the results of the spatial assessment the total area hyper-arid, arid, semi-arid and subhumid regions by IDM, MI, AI, and HTC are 64.1%, 70.7%, 85% and 98%, respectively.

The trend analysis showed that around 66% of the stations are defined by a decreasing trend of aridity index. Mostly in the central, southwest and western regions of Mongolia, the aridity indices showed the significant decreasing trends.

At the stations with significant decreasing trends, the relative changes of the aridity indices varied between 14% and 74% for the period 1961-2015. According to the results of the Pettitt's test, there was a change point around 1994 at the greater part of the stations with significant changes of the aridity indices.

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References

1. Agnew C, Anderson W. 1992. Water in the Arid Realm. Routledge, London.
2. Deniz A, Toros H, Incecik S. 2011. Spatial variations of climate indices in Turkey. International Journal of Climatology, 31: 394-403
3. Tabari H, Talaee P H, Nadoushani S S M, et al. 2014. A survey of temperature and precipitation based aridity indices in Iran. Quaternary International, 345: 158-166.
4. Liu X, Zhang D, Luo Y, et al. 2012. Spatial and temporal changes in aridity index in northwest China: 1960 to 2010. Theoretical and Applied Climatology, 112: 307-316.
5. Toros H, Deniz A, Incecik S. 2008. Continentality and Oceanity Indices in Turkey. In: Twenty-First Annual Conference, PACON 2008, Energy and Climate Change, Innovative Approaches to Solving Today's Problems, Ala Moana Hotel, Honolulu, Hawaii, USA.
6. Kafle H K, Bruins H J. 2009. Climatic trends in Israel 1970-2002: warmer and increasing aridity inland. Climatic Change, 96: 63-77.
7. Baltas E. 2007. Spatial distribution of climatic indices in northern Greece. Meteorological Applications, 14: 69-78.
8. Paltineanu C, Tanasescu N, Chitu E, et al. 2007. Relationships between the De Martonne aridity index and water requirements of some representative crops: a case study from Romania. International Agrophysics, 21: 81-93.
9. Wu S H, Yin Y, Zheng D, et al. 2006. Moisture conditions and climate trends in China during the period 1971–2000. International Journal of Climatology, 26: 193–206.
10. Perevedentsev Yu P, Sharipova R B, Vajnova N A. 2012. Agriclimatic resources of Uliyanovsk region and their impacts on agriculture productivity. Vestnik Udmurtskogo Universiteta, 2: 120-126 (in Russian).
11. Mezentsev V S, Karnatsevich I V. 1969. Humidity of Western Siberian plain. Leningrad: Gydrometizdat (in Russian).
12. American Meteorological Society. 2006. Glossary of Meteorology. http://amsglossary.allenpress.com/glossary.
13. Zhang Q, Xu C Y, Zhang Z, et al. 2009. Changes in temperature extremes for 1960-2004 in Far-West China. Stochastic Environmental Research and Risk Assessment, 23: 721-735.
14. Chen Y, Deng H, Li B, et al. 2014. Abrupt change of temperature and precipitation extremes in the arid region of Northwest China. Quaternary International, 336: 35-43.
15. Yue S, Wang C. 2004. The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. Water Resources Management, 18: 201–218.
16. Tabari H, Marofi S. 2011. Changes of pan evaporation in the west of Iran. Water Resources Management, 25: 97-111.
17. Pohlert T. 2016. trend: Non-Parametric Trend Tests and Change-Point Detection. R package version 0.2.0. https://CRAN.R-project.org/package=trend

18. Theil H. 1950. A rank-invariant method of linear and polynomial regression analysis. Proceedings of Koninalijke Nederlandse Akademie van Weinenschatpen A, 53: 1397-1412.

19. Sen P K. 1968. Estimates of the regression coefficient based on Kendall’s tau. Journal of American Statistical Association, 63: 1379-1389.

20. Zhang Q, Xu C Y, Tao H, et al. 2010. Climate changes and their impacts on water resources in the arid regions: a case study of the Tarim River basin, China. Stochastic Environmental Research and Risk Assessment, 24: 349-358.

ИЗМЕНЕНИЯ ИНДЕКСОВ АРИДНОСТИ В МОНГОЛИИ

Работа выполнена при реализации проекта фундаментальных исследовании 201500053.

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Аридность является одним из основных показателей для определения территорий, подверженных опустыниванию. Цель данной работы выявление изменения степени засушливости климата на территории Монголии в пространстве и во времени. Степень засушливости была рассчитана с использованием четырех индексов: 1) индекса аридности де Мартонна (IDM); 2) индекс засушливости Торнтвейта (AI); 3) коэффициент увлажнения по В.И. Мезенцеву (MI) и 4) гидротермический коэффициент сухости Селянинова (HTC). В настоящей работе использованы основные метеорологические данные 70 станций Монголии за период 1961-2015 годов. Площадь засушливых земель (аридных, семиаридных и субгумидных регионов) отличается в зависимости от используемого индекса. Площади засушливых земель по IDM, MI, AI и HTC составляет 64.1%, 70.7%, 85% и 98% от общей территории, соответственно. Из 4-х индексов засушливости высокую корреляцию с регионами засушливых земель выделенных по NDVI показали индексы AI и MI. Согласно временному анализу AI и MI около 66% всего временного ряда харектеризуется тенденцией понижения показателей, иными словами к увеличению засушливости в течении наблюдаемого периода времени. В центральных и северо-восточных регионах страны наблюдаются значительная тенденция к интенсификации засушливости. Относительные изменения показателей засушливости варьируют в пределах от 14% до 74% для станций со статистически значимым трендом линейного уравнения.

Ключевые слова: индекс засушливости, Монголия, тенденция, изменение