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APPLICATION OF THE STANDARDIZED PRECIPITATION INDEX FOR THE ASSESSMENT AND FORECAST OF ATMOSPHERIC DROUGHTS IN ALTAI KRAI

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The research objective is to identify and analyze the possibility of using the Standardized Precipitation Index (SPI) in Altai Krai for agroclimatic and meteorological research, including forecasting climate change and predicting the yield of various crops. An agroclimatic assessment of atmospheric droughts within the conditions of Altai Krai was performed using a method relatively new for national agrometeorology. At the moment, in the Russian Federation and the CIS countries, the G. T. Selyaninov Hydrothermic Factor (HF) is mainly used for assessing droughts, which makes it possible to assess the territory water availability by the ratio of the period characteristics with the temperature above 10°C. The authors have compiled the SPI calculator in the Microsoft Excel software environment. The paper presents the graphs of the moisturization course for the period of the active growing season for 31 meteorological stations of Altai Krai, and the frequency of arid events is calculated for compiling a precipitation model for the period of 1964–2020. The paper does not provide formulas described in detail in literature sources. The research results can be used in planning activities in the sphere of agriculture, developing an economic strategy for the region, and strategy in relation to adaptation to climate change. Areas are highlighted that are priority-oriented for taking measures to prevent the adverse consequences of climate change. General tendencies of changes in agrometeorological indicators have been found in those areas where they are the greatest ones. A comparison is made with the work results regarding other entities of the Russian Federation and the near abroad, wherein the possibility of using the SPI method for assessing droughts is analyzed.

Keywords: *atmospheric droughts; standardized precipitation index (spi); linear trends*

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ПРИМЕНЕНИЕ СТАНДАРТИЗИРОВАННОГО ИНДЕКСА ОСАДКОВ ДЛЯ ОЦЕНКИ И ПРОГНОЗА АТМОСФЕРНЫХ ЗАСУХ В АЛТАЙСКОМ КРАЕ

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Целью исследования является выявление и анализ возможности использования Стандартизированного индекса осадков (ИСО) в Алтайском крае для агроклиматических и метеорологических исследований, в том числе прогнозирования изменения климата и прогнозирования урожайности различных сельскохозяйственных культур. Агроклиматическую оценку атмосферных засух в условиях Алтайского края проводили относительно новым для отечественной агрометеорологии методом. В настоящее время в Российской Федерации и странах СНГ в основном используется гидротермический коэффициент Г.Т. Селянинова (ГТК) для оценки засухи, что позволяет оценить водообеспеченность территории по соотношению характеристик периода с температурой выше 10 °С. Авторы подготовили калькулятор SPI в программной среде Microsoft Excel. В статье представлены графики хода увлажнения за период активного вегетационного периода для 31 метеорологической станции Алтайского края, а также рассчитана частота засушливых явлений для составления модели осадков за период 1964-2020 годов. В статье не приводятся формулы, подробно описанные в литературных источниках. Результаты исследования могут быть использованы при планировании деятельности в сфере сельского хозяйства, разработке экономической стратегии региона и стратегии в отношении адаптации к изменению климата. Исследование выделяет области, которые являются приоритетными для принятия мер по предотвращению неблагоприятных последствий изменения климата. Общие тенденции изменения агрометеорологических показателей были выявлены в тех районах, где они являются наибольшими. Проводится сравнение с результатами работ в отношении других субъектов Российской Федерации и ближнего зарубежья, в которых анализируется возможность использования метода SPI для оценки засух.

Ключевые слова: *атмосферные засухи; стандартизированный индекс осадков (сио); линейные тренды*

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Introduction

Extremely dangerous meteorological phenomena are atmospheric phenomena that, in terms of their intensity, occurrence time, duration, or area of distribution, can cause or have caused significant damage to the economy and the population. According to RD 52.04.563 – 2013 [8], the general list of dangerous phenomena includes, among other things, agrometeorological dangerous phenomena: freezing, soil over-moisturizing, dry hot winds, atmospheric drought, and soil drought, etc.

The research subject is atmospheric droughts, which act as an indicator of climate change on the planet. The research relevance is due to the presence of land aridization threats, to the factors of which researchers include atmospheric droughts [2]. Land aridization is a real threat to the Altai Krai, which has significant areas of agricultural land. Besides, land aridization in a particular area is a factor of human environmental safety violation [1], which creates a threat to the favorability of its existence as a biological and social organism [6].

Atmospheric drought is conditions with a precipitation amount of no more than 5 mm per day for at least 30 consecutive days at a maximum air temperature above 25°C (in the regions of the Russian Federation to the south of 54° north latitude – above 30°C). On some days (no more than 25% of the period duration), the presence of maximum temperatures below the specified limits is possible [7].

At present, the Selyaninov Hydrothermic Factor (HF) is mainly used to assess the manifestation of droughts in Russia. However, the Standardized Precipitation Index (SPI) is widely used in international practice to characterize meteorological drought at various time scales [15]. There are also other methods that can be applied to assess atmospheric droughts under various conditions [9; 14; 18].

SPI was recommended by the World Meteorological Organization (WMO) for drought monitoring [20]. SPI quantifies observed precipitation as a standardized deviation from a selected probability distribution function that simulates initial precipitation data. We can interpret SPI values as the number of standard deviations by which the observed anomaly deviates from the long-term mean [12].

The possibilities of using the SPI to assess the manifestation of droughts are confirmed by a number of national publications [5; 7].

E. A. Cherenkova, A. N. Zolotokrylin [7] emphasize that based on the properties of the normal distribution, droughts (as negative extremes of moisturization) account for 15.9% of cases (regardless of their observation location). In comparison with the SPI, the recommended gradations of droughts in terms of the HF do not consider the climate normal at each point. Thus, at their core, the HF and SPI cannot define drought in the same way. Researchers have revealed the usefulness of the SPI in terms of forecasting.

P. Zh. Kozhakhmetov, E. A. Iskakov and D. K. Baybazarov [4] also emphasize that the advantage of using it is that a sufficiently reliable precipitation database has been created. The index values do not depend on the geographic location of the territory, and when calculating it, normalization is performed over time. The approach idea is due to the fact that the distribution of precipitation is fairly well described by the gamma distribution.

E. K. Isaev and Sh. A. Omurzakova rightly state in their paper [3] that SPI calculations can be made for any period – month, season, year, that is, in winter, where it is ensured that the frequencies of emergency events at any place and at any time scale are agreed.

Based on the materials of the paper by A. I. Strashnaya, V. A. Tishchenko, O. V. Bereza, and N. A. Bogomolova [5], it may be said that the SPI is applicable for revealing and analyzing droughts in Russia.

The approach to measure atmospheric droughts based on the SPI assessment is used not only in Russia but also in other countries. It is confirmed by the works of such researchers as M. Karatayev et al. [11], S.-J. Sohn et al. [19], D. Khadka et al. [13], I. Chitedze and S. R. Chikabvumbwa [10], Z.M. Yaseen et al. [21], P. Mahmoudi et al. [16].

Materials and Methods

The paper aims to analyze the possibility of using the SPI within Altai Krai.

The research tasks include calculating the SPI, identifying regional features of the index distribution, detecting the frequency of droughts regarding this indicator, describing the power of dry phenomena, and making a short-term forecast based on the revealed regularities.

The following research methods were used in the course of the work: literature analysis, logical analysis, and synthesis, as well as statistical, descriptive, comparative-geographical, cartographical, and geoinformation system methods. The index being researched was obtained by the method of T. B. McKee, N. J. Doesken, and J. Kleist [17], first-ever applied in 1993. To interpret the obtained index, we compare it with the HF in order to identify the regional drought criterion in the paper.

The basis for calculating the index is a mathematical gamma function that converts the precipitation amount into an index with due regard to a series of corrections for the completeness of the data series for successful interpolation of the values missing in the array. The skips in the series were due to the breakdown of equipment at the observation posts.

The initial data for writing the paper were the archive materials of the Altai Center for Hydrometeorology and Environmental Monitoring. Agrometeorological annual books are the main information sources.

For the period of 1964–2020 being researched, the calculation of the precipitation amount has been performed for the April-October period as for the growing season months, within which active temperatures above 10°C are observed. These values serve as a key indicator for calculating the standardized precipitation index.

The hypothesis and applicability of the index being researched were tested using statistical methods – by checking for Student's t-test and the Kolmogorov-Smirnov test. The above-mentioned techniques made it possible to confirm the normal distribution of both precipitation and index. This fact means the correct selection of calculation tools and the reliability of a meteorological indicator selected from the archive materials.

Results

When conducting these studies according to the methodology [5], the precipitation time series was transformed into a standardized normal distribution through a theoretical cumulative probability distribution using the gamma distribution to obtain the SPI.

Since precipitation has extremely large spatial and temporal variability, a transformation is applied to make the precipitation values follow a normal distribution first of all. The SPI was developed to clearly express the fact that it is possible to experience wet conditions on one or more-time scales and dry conditions on other time scales simultaneously. According to the SPI algorithm, a comparison is made with a precipitation rate (via subtracting the precipitation amount from the rate) for the region being researched and their distribution according to the possibility of a particular hazardous phenomenon from over-moisturizing to drought (ratio to the standard deviation). The research task is to trace the cycle of droughts and predict whether the precipitation level will rise or fall.

The SPI analysis (Fig. 1) has made it possible to determine the interval with which precipitation predominantly decreases (negative extremes) – a two-year/three-year cycle: 1965, 1968, 1971, 1974, 1977, 1981, 1983, 1986, 1988, 1991, 1993, 1997, 1999, 2001, 2003, 2005, 2008, 2010, 2012, 2015, 2017, 2019 The onset of drought is considered to be a decrease in the SPI from –1, and its end is considered to be an overcoming 0 in the recommendations of Mc Kee et al. [17].

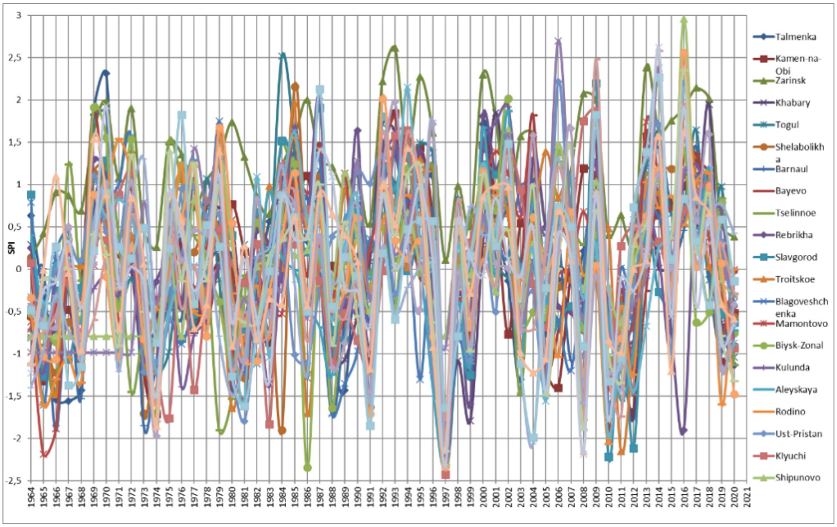

Fig. 1. SPI for meteorological stations of Altai Krai for 1964–2020

These values will shift for Altai Krai: the beginning of the drought will be a decrease in the SPI by –0.5 and less.

This consistent pattern was calculated by comparing the SPI with the percentage deviation from the precipitation rate along the edge and at the station. In cases of 0 mm precipitation, the SPI was equal to various negative values. That is, the major problem of the SPI for the region being researched is the correct interpretation of the indicator and the correct gradation of phenomena. The SPI value always lies between the precipitation rate percentages at the station and along the edge – the exceptions are the cases of severe droughts and over-moisturizing – in such conditions, the SPI becomes less than the percentages of the rate. In terms of intensity, the 1997 drought was the most severe. Qualitative data analysis is hampered by the general coverage of all meteorological stations, a large area of the territory with various precipitation distributions.

If a significant decrease in the precipitation amount occurred once every three years in the period of 1964–1997, then this interval had decreased to two years since 1997. It can be assumed that the decrease in the precipitation amount will continue in the future. If we calculate the ratio of the number of droughts occurring every two years, then the drought continuation probability is estimated as 52.4% in 2021. There were 11 cases of a significant decrease in precipitation with a recurrence of two years, 8 cases for three years, 1 case for four years, and 1 case for five years; 11/21*100=52.4% – the drought probability onset once every two years.

The likelihood that there will be an increase in aridity – 90.5% during the period of 2021–2022.

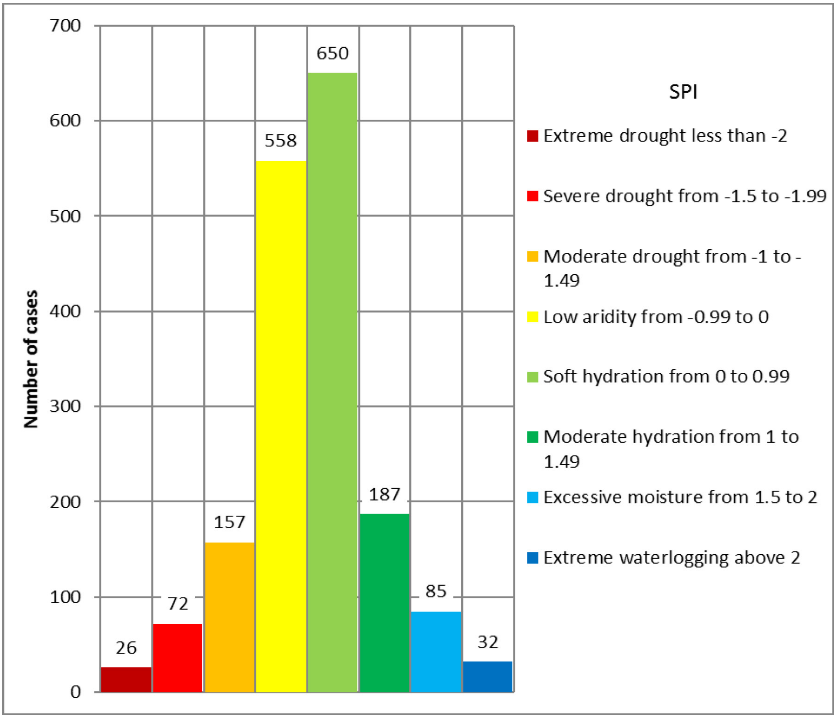

Fig. 2. Climatic phenomena frequency distribution by observation points for the period of 1964–2020

As can be seen from the histogram (Fig. 2), the edge is generally characterized by mild moisture conditions. The moving average method was applied for the Kulunda station. Analysis of the correlation between the five-year SPI moving averages and the calculated SPI for 1964–2020 showed satisfactory results in general (K corr. = 0.702461).

After linear trends are constructed, it is possible to make a long-term forecast of a climatic situation for the specific territories.

Thus, an increase in atmospheric moistening is expected within the service area of the following meteorological stations: Shipunovo, Ust-Kalmanka, Klyuchi, Kulunda, and Mamontovo.

An increase in aridity is expected in the area of meteorological stations: Slavgorod, Volchikha, Zmeinogorsk, Gornyak, and Biysk-Zonalnaya. Most often, droughts were observed within the following territories: Ust-Pristan, Tselinnoe, Kamen-na-Obi, Soloneshnoe, and Uglovskoe. Years of the most severe drought manifestation are as follows: 1974, 1997, and 2010. The SPI significantly differs according to the moving averages of the Zarinsk meteorological station, where no aridity phenomenon was observed over the entire observation period.

Discussion

The SPI is a widely used index to characterize meteorological drought at various time scales. We can compare the SPI in various regions with markedly different climates. For the operational community, the SPI has been recognized as a standard index that should be available globally for quantitative assessment and meteorological drought reporting (4 – John Keyantash). The key strong points of the method are the use of precipitation only and the fact that it can characterize drought or anomalous moisture at different time scales.

The methodology of T. B. McKee, N. J. Doesken, and J. Kleist [17] assumes a certain aridity and moisture phenomena gradation. After our attempt to apply the SPI, new features of its use were revealed; that is, we assume that droughts are recorded at the SPI from –0.5 under our conditions. Furthermore, we have determined that the SPI can be smoothed down no more than by a five-year cycle. Besides, we can supplement the description of the McKee methodology [17] with a description of the SPI ratio and precipitation rate percentages at the station and along the edge.

We managed to compile a series of atmospheric droughts on an annual basis and identify their frequency and severity, which was not done in other papers known to us.

Comparative research of the applied approaches that are highlighted in the current paper with other territories of the near abroad and Russian regions demonstrated that for Kazakhstan, the authors [4] revealed acceptable adequacy of identification of territories' droughts and humidification by SPI, compared to HF for the Kazakhstan territory.

To determine the gradations of drought intensity according to HF data, E.A. Cherenkova and A.N. Zolotokrylin [7] suggest using the intervals of values calculated for each weather station for the plain territory of the European part of Russia (550’ N to the south). The calculation is performed in such a way that the data for different stations become comparable with each other and comparable with the statistics of droughts according to the SPI index.

Besides, we confirm the possibility of detecting droughts by the SPI like other researchers mentioned in the paper.

We have not analyzed the papers related to global warming, but the research results incorporated into the framework of this well-known theory.

Conclusion

Based on the aforesaid, it may be concluded that the transition to the SPI drought assessment is complicated due to the use of meteorological data recording methods in Russia, which are not congruent with the software developed by the WMO. Concurrently, the studies have shown the possibility of using the SPI index to assess and predict the onset of droughts within the territory of Altai Krai.

References

1. Boyarov Ye.N., Abramova S.V., Gershinkova D.A. Bezopasnost’ cheloveka v svete sovremennoy klimaticheskoy tekhniki [Human security in the light of the current climate agenda]. *Siberian journal of life sciences and agriculture*, 2021, vol. 13, no. 1, pp. 111-133. https://doi.org/10.12731/2658-6649-2021-13-1-111-133
2. Zolotokrylin A.N., Cherenkova E.A., Titkova T.B. Aridizatsiya zasushlivykh zemel’ okhvatyvayet chasti Rossii i svyaz’ s zasukhami [Aridization of arid lands in the European part of Russia and its connection with droughts]. *Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya* [Proceedings of the Russian Academy of Sciences. Geographical series]. 2020, vol. 84, no. 2, pp. 207-217. https://doi.org/10.31857/S258755662002017X
3. Isaev E.K., Omurzakova Sh.A. O vozmozhnosti vybora i modelirovaniya zasukh v Kyrgyzstane [On the possibility of drought detection and modeling in Kyrgyzstan]. *Vestnik Kyrgyzsko-Rossiyskogo slavyanskogo universiteta* [Bulletin of the Kyrgyz-Russian Slavic University]. 2019, vol. 19, no. 8, pp. 145-151.
4. Kozhakhmetov P.Zh., Iskakov E.A., Baibazarov D.K. Ispol’zovaniye standartizirovannogo indeksa temperatury (SIO) dlya nablyudeniya za sukh v Kazakhstane [Using the Standard Precipitation Index (SPI) to detect droughts in Kazakhstan]. *Gidrometeorologiya i ekologiya. Yezhekvartal’nyy nauchno-tekhnicheskiy zhurnal* [Hydrometeorology and ecology]. 2016. vol. 1, no. 80, pp. 22-31.

5. Strashnaya A.I., Tishchenko V.A., Bereza (Chub) O.V., Bogomolova N.A. O vozmozhnosti ispol'zovaniya standartizirovannogo indeksa dinamiki dlya otsenki zasukh i v prognozakh otsenki urozhaynosti zernovykh i zernobobovykh kul'tur [On the possibility of using a standardized precipitation index to detect droughts and in forecasts of quantitative assessment of grain and leguminous crop yields]. *Trudy gidrometeorologicheskogo nauchno-issledovatel'skogo tsentra Rossiyskoy Federatsii* [Proceedings of the Hydrometeorological Research Center of the Russian Federation]. 2015, no. 375, pp. 81-97.
6. Sokolskaya E.V., Dolgov Yu.A., Lobkovsky V.A. Mnogofaktornaya model' kak osnova dlya upravleniya kachestvom okruzhayushchey sredy urbanizirovannykh mestorozhdeniy [Multifactor model as a basis for environmental quality management in urban areas]. *Teoreticheskaya i prikladnaya ekologiya* [Theoretical and Applied Ecology]. 2018, no. 2, pp. 256-234. https://doi.org/10.25750/1995-4301-2018-2-026-034
7. Cherenkova E.A., Zolotokrylin A.N. O sravnimosti nekotorykh kolichestvennykh pokazateley postavok [On the comparability of some quantitative drought indices]. *Fundamentalnaya i prikladnaya klimatologiya* [Fundamental and applied climatology]. 2016. no. 2, pp. 79-94. https://doi.org/10.21513/2410-8758-2016-2-79-94
8. Shamin S.I. Struktura i soderzhaniye zaklyucheniya o vrednykh i neblagopriyatnykh gidrometeorologicheskikh yavleniyakh, nanesshikh material'nyy i sotsial'nyy ushcherb [Structure and content of the database of information about dangerous and adverse hydrometeorological phenomena that caused material and social damage]. *Trudy vserossiyskogo nauchno-issledovatel'skogo instituta gidrometeorologicheskoy informatsii - mezhdunarodnogo tsentra dannykh* [Proceedings of the All-Russian Research Institute of Hydrometeorological Information]. 2018, no. 182, pp. 144-158.
9. Al-Khafaji M.S., Al-Ameri R.A. Evaluation of drought indices correlation for drought frequency analysis of the Mosul dam watershed. *IOP conference series: earth and environmental science*, 2021, vol. 779, e012077. https://doi.org/10.1088/1755-1315/779/1/012077
10. Chitedze I., Chikabvumbwa S.R. Assessing the impact of spatio-temporal drought regimes using timescale standardized precipitation index in Malawi. *Journal of sustainable development of energy, water and environment systems*, 2021, vol. 9, no. 4, e1080341. https://doi.org/10.13044/j.sdewes.d8.0341
11. Karatayev M., Clarke M., Salnikov V., Bekseitova R., Nizamova M. Monitoring climate change, drought conditions and wheat production in Eurasia: the case study of Kazakhstan. *Heliyon*, 2021, vol. 8, no. 1, e08660. https://doi.org/10.1016/j.heliyon.2021.e08660

12. Keyantash J. The climate data guide: Standardized precipitation index (SPI), 2018. URL: https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi
13. Khadka D., Babel M.S., Shrestha S., Virdis S.G.P., Collins M. Multivariate and multi-temporal analysis of meteorological drought in the northeast of Thailand. *Weather and climate extremes*, 2021, vol. 34, e100399. https://doi.org/10.1016/j.wace.2021.100399
14. Liu Q., Zhang J., Zhang H., Yao F., Bai Yu., Zhang S., Meng X., Liu Q. Evaluating the performance of eight drought indices for capturing soil moisture dynamics in various vegetation regions over China. *Science of the total environmen*, 2021, vol. 789, e147803. https://doi.org/10.1016/j.scitotenv.2021.147803
15. Lloyd-Hughes B., Saunders M.A. A drought climatology for Europe. *International Journal of climatology: a journal of the royal meteorological society*, 2002, vol. 22, no. 13, pp. 1571-1592. https://doi.org/10.1002/joc.846
16. Mahmoudi P., Ghaemi A., Rigi A., Amir Jahanshahi S.M. Recommendations for modifying the Standardized Precipitation Index (SPI) for Drought Monitoring in Arid and Semi-arid Regions. *Water resources management*, 2021, vol. 35, no. 10, pp. 3253-3275. https://doi.org/10.1007/s11269-021-02891-7
17. McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration to time scales. Eighth conference on applied climatology, Anaheim, Department of Atmospheric Science Colorado State University, 1993. https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf
18. Prajapati V.K., Khanna M., Singh M. Kaur R., Sahoo R.N., Singh D.K. Evaluation of time scale of meteorological, hydrological and agricultural drought indices. *Natural hazards*, 2021, vol. 109, pp. 89-109. https://doi.org/10.1007/s11069-021-04827-1
19. Sohn S.-J., Tam C.-Y., Ashok K., Ahn J.-B. Quantifying the reliability of precipitation datasets for monitoring large-scale East Asian precipitation variations. *International journal of climatology*, 2012, vol. 32, no. 10, pp. 1520-1526. https://doi.org/10.1002/joc.2380
20. Svoboda M., Fuchs B. Handbook of drought indicators and indices, 2016. URL: https://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf
21. Yaseen Z.M., Ali M., Sharafati A., Al-Ansari N., Shahid S. Forecasting standardized precipitation index using data intelligence models: regional investigation of Bangladesh. *Scientific reports*, 2021, vol. 11, e3435. https://doi.org/10.1038/s41598-021-82977-9

Список литературы

1. Бояров Е.Н., Абрамова С.В., Гершинкова Д.А. Безопасность человека в свете современной климатической повестки // Siberian journal of life sciences and agriculture. 2021. Т.13. №1. С. 111-133. https://doi.org/10.12731/2658-6649-2021-13-1-111-133
2. Золотокрылин А.Н., Черенкова Е.А., Титкова Т.Б. Аридизация засушливых земель Европейской части России и связь с засухами // Известия Российской академии наук. Серия географическая. 2020. Т.84. №2. С. 207-217. https://doi.org/10.31857/S258755662002017X
3. Исаев Э.К., Омурзакова Ш.А. О возможности выявления и моделировании засух в Кыргызстане // Вестник Кыргызско-Российского славянского университета. 2019. Т.19. №8. С. 145-151.
4. Кожахметов П.Ж., Искаков Е.А., Байбазаров Д.К. Использование стандартизированного индекса осадков (СИО) для выявления засух в Казахстане // Гидрометеорология и экология. Ежеквартальный научно-технический журнал. 2016. Т.1. №80. С. 22-31.
5. О возможности использования стандартизированного индекса осадков для выявления засух и в прогнозах количественной оценки урожайности зерновых и зернобобовых культур / Страшная А.И., Тищенко В.А., Береза (Чуб) О.В., Богомолова Н.А. // Труды гидрометеорологического научно-исследовательского центра Российской Федерации. 2015. №357. С.81-97.
6. Сокольская Е.В., Долгов Ю.А., Лобковский В.А. Многофакторная модель как основа для управления качеством окружающей среды урбанизированных территорий // Теоретическая и прикладная экология. 2018. № 2. С. 256-234. https://doi.org/ 10.25750/1995-4301-2018-2-026-034
7. Черенкова Е.А., Золотокрылин А.Н. О сравнимости некоторых количественных показателей засухи // Фундаментальная и прикладная климатология. 2016. № 2. С. 79-94. https://doi.org/10.21513/2410-8758-2016-2-79-94
8. Шамин С.И. Структура и содержание базы сведений об опасных и неблагоприятных гидрометеорологических явлениях, нанесших материальный и социальный ущерб / Труды всероссийского научно-исследовательского института гидрометеорологической информации - мирового центра данных. 2018. №182. С. 144-158.
9. Al-Khafaji M.S., Al-Ameri R.A. Evaluation of drought indices correlation for drought frequency analysis of the Mosul dam watershed // IOP conference series: earth and environmental science, 2021, vol. 779, e012077. https://doi.org/10.1088/1755-1315/779/1/012077
10. Chitedze I., Chikabvumbwa S.R. Assessing the impact of spatio-temporal drought regimes using timescale standardized precipitation index in Malawi //

Journal of sustainable development of energy, water and environment systems, 2021, vol. 9, no. 4, e1080341. https://doi.org/10.13044/j.sdewes.d8.0341
11. Karatayev M., Clarke M., Salnikov V., Bekseitova R., Nizamova M. Monitoring climate change, drought conditions and wheat production in Eurasia: the case study of Kazakhstan // Heliyon, 2021, vol. 8, no. 1, e08660. https://doi.org/10.1016/j.heliyon.2021.e08660
12. Keyantash J. The climate data guide: Standardized precipitation index (SPI), 2018. URL: https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi
13. Khadka D., Babel M.S., Shrestha S., Virdis S.G.P., Collins M. Multivariate and multi-temporal analysis of meteorological drought in the northeast of Thailand // Weather and climate extremes, 2021, vol. 34, e100399. https://doi.org/10.1016/j.wace.2021.100399
14. Liu Q., Zhang J., Zhang H., Yao F., Bai Yu., Zhang S., Meng X., Liu Q. Evaluating the performance of eight drought indices for capturing soil moisture dynamics in various vegetation regions over China // Science of the total environmen, 2021, vol. 789, e147803. https://doi.org/10.1016/j.scitotenv.2021.147803
15. Lloyd-Hughes B., Saunders M.A. A drought climatology for Europe // International Journal of climatology: a journal of the royal meteorological society, 2002, vol. 22, no. 13, pp. 1571-1592. https://doi.org/10.1002/joc.846
16. Mahmoudi P., Ghaemi A., Rigi A., Amir Jahanshahi S.M. Recommendations for modifying the Standardized Precipitation Index (SPI) for Drought Monitoring in Arid and Semi-arid Regions // Water resources management, 2021, vol. 35, no. 10, pp. 3253-3275. https://doi.org/10.1007/s11269-021-02891-7
17. McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration to time scales // Eighth conference on applied climatology, Anaheim, Department of Atmospheric Science Colorado State University, 1993. https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf
18. Prajapati V.K., Khanna M., Singh M. Kaur R., Sahoo R.N., Singh D.K. Evaluation of time scale of meteorological, hydrological and agricultural drought indices // Natural hazards, 2021, vol. 109, pp. 89-109. https://doi.org/10.1007/s11069-021-04827-1
19. Sohn S.-J., Tam C.-Y., Ashok K., Ahn J.-B. Quantifying the reliability of precipitation datasets for monitoring large-scale East Asian precipitation variations // International Journal of climatology, 2012, vol. 32, no. 10, pp. 1520-1526. https://doi.org/10.1002/joc.2380
20. Svoboda M., Fuchs B. Handbook of drought indicators and indices, 2016. URL: https://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf

21. Yaseen Z.M., Ali M., Sharafati A., Al-Ansari N., Shahid S. Forecasting standardized precipitation index using data intelligence models: regional investigation of Bangladesh // Scientific reports, 2021, vol. 11, e3435. https://doi.org/10.1038/s41598-021-82977-9

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