

Assessment Of The Potential For Zoning Water-Saving Irrigation Technologies Based On The Aridity Index

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Abstract: This article presents the results of assessing aridity indicators by districts of Jizzakh region for the period 2021–2024. Table 1 provides calculations of M.I. Budyko’s radiation aridity index for total and irrigated areas, showing that the values vary within a very narrow range across districts, which indicates a relatively uniform background of natural radiation aridity in the region. Table 2 presents a comparative analysis of an improved aridity index that accounts for irrigation-specific factors and components of the water balance; it is shown that the aridity index for total areas generally ranges from 1.2 to 1.6, while for irrigated areas in some districts it reaches 2.0–3.0. This reflects a deficit of water resources and a high drought potential during the vegetation period, and confirms the urgency of introducing water-saving and innovative irrigation technologies, differentiating crop structure, and implementing adaptive water resources management, especially in the districts of Zomin, Zafarabad, Arnasay and Mirzachul.

Keywords: Water-saving irrigation technologies, dryness index, irrigated farming, agroecosystem, agrolandscape, total area and irrigated lands, water resources management.

INTRODUCTION:

The aridity index is an important integral criterion for assessing the degree of drought under climatic conditions, and the radiation aridity index (R) proposed by M.I. Budyko reflects the relationship between water resources and the radiation balance in the natural environment. However, when irrigation and artificial watering are not taken into account, this index does not provide a sufficiently accurate assessment under irrigated agriculture and agrolandscape conditions. Therefore, in this study separate aridity indices were introduced for total and irrigated areas, and Budyko’s equation was improved by incorporating atmospheric precipitation, irrigation water supplied to the agrolandscape, horizontal and vertical drainage water, filtration losses from main canals, field discharge losses, changes in soil water storage in the aeration zone, as well as water exchange between the aeration zone and groundwater[6]. Separate calculations for total and

irrigated areas at the district level in Jizzakh region make it possible to assess the role of irrigated agriculture in reducing drought intensity, to characterize drought conditions more precisely in agrotechnical processes, and to provide a scientific basis for strategic decisions on the rational use of agrolandscapes and adaptation to drought[7].

The studies of E.A. Cherenkova on moisture indicators, including the radiation aridity index (RIS), in the sub-boreal plain landscapes of Russia confirm the existence of relationships among various moisture indicators and their important role in assessing the ecological state of landscapes [1].

METHODS

The aridity index (dryness index) is used to assess the tendency of climatic conditions toward drought. This indicator is based on the relationship between natural precipitation and solar radiation [2,3,4].

In this study, two types of aridity indices were applied to evaluate drought intensity:

- the classical radiation aridity index proposed by M.I. Budyko,
- an improved aridity index that takes into account factors specific to irrigated agriculture and the components of the water balance.

Budyko's equation was taken as the basis for calculating the aridity index.

$$\bar{R} = \frac{R}{L \cdot O_c} (1)$$

In the unit system applied in this study, the calculated dryness index was used to evaluate relative spatio-temporal differences across districts and periods (non-vegetation, vegetation, and annual). An increase in the index value under the same meteorological background indicates a relative decrease in moisture availability and an increase in drought potential, whereas a decrease in the index reflects an improvement in moisture conditions. Table 1 presents the distribution of radiation aridity index values for total and irrigated areas across the districts of Jizzakh region for the period 2021–2024.

To calculate the dryness index for the total area, Budyko's original equation was modified to account for irrigated agriculture and artificial irrigation processes, resulting in the following expression [5,6,7,8]:

$$\bar{R}_{ym} = \frac{R}{L \cdot (O_c + B + B_{r3} + B_{B3} + \Phi_{MK} + \nabla W_a)} (2)$$

When the same approach is applied to irrigated areas, the following analytical expression (equation) for the aridity index is obtained.

$$\bar{R}_{cm} = \frac{R}{L \cdot (O_c + O_p + B_{r3} + B_{B3} + (1 - \alpha) \Phi_K + \nabla W_a \pm g^a)} (3)$$

Here: R - is the radiation balance (kJ/cm²), L - is the latent heat of vaporization; O_c- is atmospheric precipitation (mm); B - is the volume of water supplied to the total area; Φ_{MK} - is filtration losses in the main (magistral) canals; B_{r3} - is the amount of water used for irrigation from horizontal collector–drainage networks; B_{B3} - is the amount of water used for irrigation from vertical drainage wells; ΔW - is the change in water storage in the aeration zone; O_p- is the volume of water supplied to the irrigated area; α- is the fraction of canal filtration losses that contributes to groundwater recharge; Φ_K- is seepage

(infiltration) from canals into the soil; g^a- is the amount of water exchange between the aeration zone and groundwater.

The following scale was used to interpret the values of the improved aridity index: when it is in the range **0–1.0**, water resources are considered sufficient or close to water balance conditions; a value of ≈ **1.0** is regarded as a nearly optimal moisture regime; and when the index is **greater than 1.0**, water resources are considered deficient and the drought potential is assessed as high. Based on these criteria, the district-level values presented in Table 2 were comparatively analyzed in order to evaluate agroclimatic conditions and determine the need for irrigation.

RESULTS AND DISCUSSION

The aridity index (dryness index) is an important integral criterion for assessing the degree of drought under climatic conditions, and the radiation aridity index (R) proposed by M.I. Budyko reflects the relationship between water resources and the radiation balance in the natural environment. However, when irrigated agriculture and artificial irrigation are not taken into account, this index does not provide a sufficiently accurate assessment under agrolandscape conditions. Therefore, in this study separate aridity indices were introduced for total and irrigated areas, and Budyko's equation was improved by incorporating atmospheric precipitation, irrigation water supplied to the agrolandscape, horizontal and vertical drainage water, filtration losses from main canals, field discharge losses, changes in soil water storage in the aeration zone, as well as water exchange between the aeration zone and groundwater. The implementation of separate calculations for total and irrigated areas at the district level in Jizzakh region makes it possible to assess the effect of irrigated agriculture on reducing drought intensity, to describe drought conditions more precisely in agrotechnical processes, and to provide a scientific basis for strategic decisions on the rational use of agrolandscapes and adaptation to drought.

For the period 2021–2024, aridity index values for total and irrigated areas in the districts of Jizzakh region were calculated on the basis of M.I. Budyko's radiation aridity index, and their changes over the non-vegetation, vegetation and annual periods are presented in Table 1.

Table 1.

District-wise analysis of the aridity index (M.I. Budyko) for 2021–2024

Year	District	Total area	Irrigated area on
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		Non-vegetation	Vegetation	Annual	Non-vegetation	Vegetation	Annual
2021	Arnasay	0.02	0.23	0.05	0.02	0.24	0.05
2022		0.02	0.05	0.03	0.02	0.06	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.05
2024		0.02	0.05	0.03	0.02	0.05	0.03
2021	Dustlik	0.02	0.23	0.05	0.02	0.24	0.05
2022		0.02	0.05	0.03	0.02	0.05	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.05
2024		0.02	0.05	0.03	0.02	0.05	0.03
2021	Zafarabad	0.02	0.23	0.05	0.02	0.24	0.05
2022		0.02	0.05	0.03	0.02	0.05	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.05
2024		0.02	0.05	0.03	0.02	0.05	0.03
2021	Mirzachul	0.02	0.23	0.05	0.02	0.24	0.05
2022		0.02	0.05	0.03	0.02	0.05	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.05
2024		0.02	0.05	0.03	0.02	0.05	0.03
2021	Pakhtakor	0.02	0.23	0.05	0.02	0.24	0.05
2022		0.02	0.05	0.03	0.02	0.05	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.05
2024		0.02	0.05	0.03	0.02	0.05	0.03
2021	Sh.Rashidov	0.02	0.18	0.04	0.02	0.19	0.04
2022		0.02	0.05	0.03	0.02	0.06	0.03
2023		0.02	0.12	0.04	0.02	0.12	0.04
2024		0.03	0.05	0.04	0.03	0.05	0.04
2021	Zarbdor	0.02	0.18	0.04	0.02	0.19	0.04
2022		0.02	0.05	0.03	0.02	0.06	0.03
2023		0.02	0.11	0.04	0.02	0.12	0.04
2024		0.03	0.05	0.04	0.03	0.05	0.04
2021	Zomin	0.02	0.18	0.04	0.02	0.19	0.04
2022		0.01	0.03	0.02	0.01	0.03	0.02
2023		0.02	0.11	0.04	0.02	0.12	0.04
2024		0.03	0.05	0.04	0.03	0.05	0.04

Table 1 shows that, for the period 2021–2024, the spatio-temporal variations of M.I. Budyko's radiation aridity index across the districts of Jizzakh region are not very large. In the districts of Arnasay, Dustlik, Zafarabad, Mirzachul and Pakhtakor, the dryness index values for total and irrigated areas during the non-vegetation and vegetation periods are almost the same (0.02 in the non-vegetation period; 0.05–

0.23 in the vegetation period; 0.03–0.05 annually), which indicates that the influence of irrigation on the structure of the radiation aridity index is rather limited. In the districts of Sh. Rashidov, Zarbdor and Zomin, the slightly lower values during the vegetation period (0.11–0.18) or the decrease to 0.01–0.03 in the non-vegetation period can be explained by orographic conditions and the local characteristics of

precipitation. In terms of interannual variability, the vegetation-period index values are relatively higher in 2021 and 2023, and lower in 2022 and 2024, which is associated with the seasonal distribution of precipitation and changes in the radiation balance. The fact that the index values lie within a very narrow range (0.02–0.24) for all districts indicates that the radiation aridity conditions in the region are spatially quite homogeneous; therefore, from an agro-practical point of view, it is advisable to use this

indicator in combination with the moisture coefficient, the hydrothermal coefficient (HTC), and the moisture index for assessing drought intensity.

Taking into account factors specific to irrigated agriculture and the components of the water balance, improved aridity index values for the period 2021–2024 were calculated by districts, and the comparative results for total and irrigated areas are presented in Table 2.

Table 2.
District-wise analysis of the aridity index (2021–2024)

Year	District	Total area			Irrigated area on		
		Non-vegetation	Vegetation	Annual	Non-vegetation	Non-vegetation	Vegetation
2021	Arnasay	1.19	2.84	1.83	1.59	1.34	1.43
2022		1.25	1.54	1.41	1.56	0.96	1.14
2023		1.67	2.00	1.85	2.08	0.89	1.16
2024		1.92	1.49	1.64	2.43	0.95	1.26
2021	Dustlik	0.79	2.11	1.26	1.31	1.39	1.36
2022		1.23	1.33	1.29	1.76	1.18	1.36
2023		1.15	1.68	1.41	1.71	1.70	1.71
2024		1.42	1.56	1.50	2.04	1.63	1.77
2021	Zafarabad	1.04	1.94	1.44	1.87	1.39	1.55
2022		1.20	1.39	1.30	1.88	1.26	1.45
2023		1.23	1.66	1.45	2.22	1.23	1.51
2024		1.72	1.30	1.44	2.78	1.21	1.56
2021	Mirzachul	0.80	2.11	1.27	1.57	1.46	1.50
2022		1.21	1.49	1.36	1.78	1.28	1.45
2023		1.39	1.22	1.29	2.20	1.17	1.45
2024		1.24	1.18	1.21	2.03	1.23	1.46
2021	Pakhtakor	1.14	1.60	1.37	1.69	1.38	1.49
2022		0.65	1.56	0.99	0.84	1.34	1.08
2023		1.24	1.87	1.55	2.12	1.11	1.38
2024		1.73	1.37	1.50	2.67	1.03	1.37
2021	Sh.Rashidov	0.95	1.49	1.23	1.45	1.50	1.48
2022		0.98	1.08	1.04	1.53	1.35	1.41
2023		1.10	1.29	1.21	1.29	1.25	1.26
2024		1.57	1.26	1.37	1.72	1.38	1.50
2021	Zarbdor	0.90	1.50	1.20	1.24	1.29	1.27
2022		0.88	1.07	0.99	1.01	1.19	1.12
2023		1.29	1.44	1.38	1.54	1.15	1.27
2024		1.88	1.41	1.57	2.08	1.31	1.54
2021	Zomin	1.00	1.32	1.17	1.42	6.62	2.79

2022		1.21	0.93	1.02	2.44	4.46	3.44
2023		1.31	1.28	1.29	1.69	4.51	2.76
2024		1.80	1.27	1.44	2.28	3.37	2.81

The data in Table 2 clearly reflect the spatial and temporal variability of the improved aridity index for the period 2021–2024, calculated by districts while taking into account factors specific to irrigated agriculture and the components of the water balance. In all districts, the annual values for the total area generally range between 1.2 and 1.6, which indicates a persistent deficit of water resources. For irrigated areas, the annual index for most districts lies in the range of 1.3–1.7, showing that, despite irrigation, drought demand remains high and irrigation systems mainly serve to mitigate, but not fully eliminate, the effects of natural aridity.

In the districts of Arnasay, Zafarabad, Mirzachul and Pakhtakor, in some years the aridity index for irrigated areas increases to 2.0–2.8, indicating periods of sharply intensified seasonal water scarcity. The highest values are recorded in irrigated areas of Zomin district (annual values of 2.76–3.44, and in some cases up to 6.62 in the non-vegetation period), which demonstrates an extremely high drought risk in zones with limited water resources and complex relief and drainage conditions. At the same time, in Pakhtakor and Dustlik districts relatively low values of the index (0.79–0.88) were recorded for the total area during the non-vegetation period in some years, indicating somewhat better natural moisture conditions in the autumn–winter season; however, the fact that **the aridity index remains greater than 1 for all districts during the vegetation period** confirms the existence of persistent water deficit during the crop-growing season.

Overall, the data in Table 2 show that, even when irrigated agriculture is taken into account, the aridity potential in the districts of Jizzakh region remains high. In particular, in the districts of Zomin, Zafarabad, Arnasay and Mirzachul, the placement of water-saving technologies, the differentiation of crop patterns by district, and the adaptive management of water resources should be considered priority directions.

CONCLUSIONS

The analysis of Tables 1 and 2 shows that, according to M.I. Budyko's radiation aridity index (Table 1), the values by districts vary within a very narrow range (0.02–0.24), indicating relatively small spatial and temporal differences and a fairly uniform background of natural radiation aridity across the region.

However, when factors specific to irrigated agriculture and the components of the water balance are taken into account, the improved aridity index (Table 2) forms values above 1.0 both for total areas and, especially, for irrigated areas (2.5–3.0 in some districts and 3.0–3.4 and higher in Zomin), clearly demonstrating that water resource scarcity during the vegetation period is at a high level and that agrolandscapes are under considerable drought stress. This confirms that, in addition to natural climatic aridity, the overall drought potential is also determined by water distribution, relief, drainage conditions and the state of irrigation systems.

Recommendations

In districts with pronounced water scarcity (Zomin, Zafarabad, Arnasay, Mirzachul and others), the introduction and spatial targeting of water-saving and innovative irrigation technologies (drip, sprinkler, pulse irrigation, etc.) should be set as a priority direction.

Based on separately calculated aridity indices for total and irrigated areas, the crop structure should be differentiated by district, giving priority to drought-resistant varieties and species.

Hydromeliorative measures aimed at reducing losses associated with the components of the water balance (irrigation water, drainage, filtration, field discharges) should be strengthened.

Continuous monitoring of integral indicators such as the improved aridity index, moisture coefficient (Ku), hydrothermal coefficient (HTC), and moisture index (Md) should be established, and on this basis agroclimatic zoning and adaptive water resources management strategies should be developed at the district level.

Water-saving irrigation methods and corresponding technologies (drip, sprinkler, pulse, etc.) should be zoned according to climatic and moisture conditions and the values of the aridity index, and strategies for their spatial placement by districts should be elaborated.

A computer software "Dengizdan Tomchi" (Drop from the Sea), registration number DGU-42138, was registered with the State Intellectual Property Agency under the Ministry of Justice of the Republic of Uzbekistan for the methodology of rapid determination of irrigation elements in drip irrigation

systems for agricultural crops.

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