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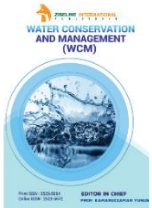

RESEARCH ARTICLE

SUSTAINABILITY OF WATER CONSERVATION PRACTICES IN ARID UZBEKISTAN: ADAPTATION TO CLIMATE CHANGE AND WATER SCARCITY

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ABSTRACT

Uzbekistan, an arid region in Central Asia, faces significant challenges due to water scarcity and climate change, which jeopardize agricultural productivity and food security. The average air temperature in the Bukhara region, a key agricultural area, increased by 1.18 °C from 1941–1985 to 1986–2020. This necessitates the urgent adoption of sustainable water conservation practices. This research aimed to assess the impact of climate change on the Bukhara region's water resources, conduct hydromodule zoning of irrigated lands using GIS technology, and develop optimized parameters for water-saving irrigation technologies, specifically drip and sprinkler systems, for key crops like cotton and winter wheat.The study utilized B.A. Dospehov's multifactorial method, SPSS, and ArcGIS software. Hydromodule zoning maps were created by integrating data on groundwater and soil mechanical composition. In medium sandy soils, optimized drip irrigation for cotton, with droppers consuming 1.8 l/h spaced 30 cm apart along 90 cm rows, was irrigated 14 times per season with a total rate of 3563 m3/ha. This technique yielded 46,300–46,500 kg/ha and achieved a water saving of 32–36% compared to conventional methods. For winter wheat, sprinkler irrigation with pre-irrigation soil moisture kept at 70–80–65% of limited field moisture capacity resulted in a grain yield of 66,700 kg/ha. This method, irrigated 12 times a season, saved 2194 m3/ha of water, or 42% less compared to furrow irrigation. The findings underscore the potential of advanced irrigation technologies to enhance water efficiency and crop productivity under arid conditions, providing scientific recommendations for sustainable water-energy-agricultural food production

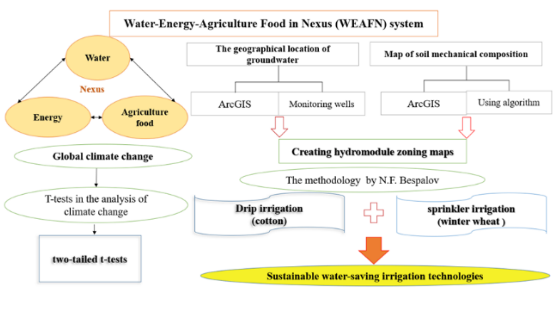
KEYWORDS

Climate change, water scarcity, hydromodule zoning, drip irrigation, sprinkler irrigation

HIGHLIGHTS

- T-test in the analysis of global climate change
- Monitoring wells of the groundwater
- Creating hydromodule zoning maps
- Sustainable water-saving irrigation technologies

GRAPHICAL ABSTRACT



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1. INTRODUCTION

e was entered based on the digitization method of 2590 observation wells. Graphical monitoring of wells was converted to vector format and entered into the database. Imported well points contain only location (coordinate) information. As a result, wells monitoring the level of seepage water in the research area were included in the geodatabase and geovisualized. Based on the inverse distance weighting (IDW) algorithm, the geographical location of groundwater is formed according to the data obtained from monitoring wells, that is, the data obtained on the level of seepage water (Figure 3).

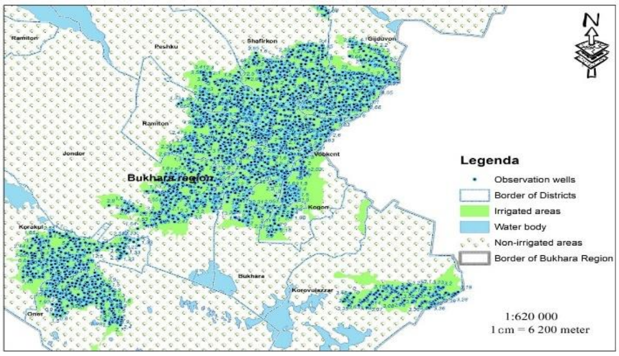

Figure 3: Map of the Groundwater level observation wells of Bukhara region

1.1 Soil Mechanical Composition Mapping

A map of the distribution of stormwater of existing districts was created in the research areas. Based on the above, the mechanical composition of soils plays an important role in research work. In the development of maps, data and information collected based on the results of field research were analyzed and used to create soil maps. In this process, paper maps were digitized (rasterized) using a large-scale scanner and geospatially linked using ArcGIS software. The electronic digital map in the form of a raster is vectorized based on thematic layers, and the corresponding soil classifications are entered into attributive tables. As a result, a map with the mechanical composition of the soil in electronic digital form is created (Figure 4).

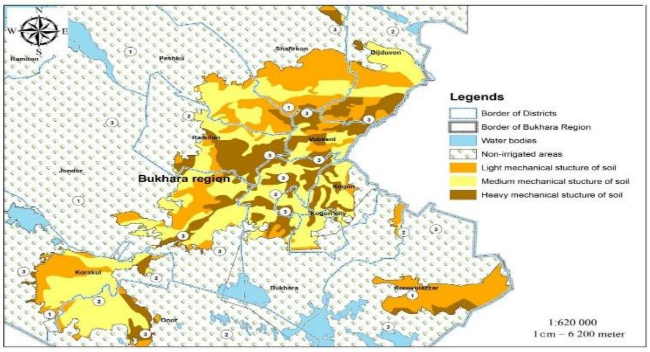

Figure 4 : Map of soil mechanical composition of Bukhara region

1.2 Hydromodule Zoning Algorithm and Distribution

The creation of hydromodule zoning maps of irrigated agricultural land in the research areas was carried out based on the methodology developed by Bespalov and the generally accepted schedule.

An algorithm was developed using the ArcGIS program to map the geographical location of groundwater and the mechanical composition of the soil, created on the basis of the hydromodule zoning table (Table 4).

Table 4 : Algorithm developed for hydromodule zones

Hydromodule zones	Groundwater level, (cm)	Algorithm
I	300<	Con ((("soil_mech_15.TIF"==1) & ("ugv" > 300)),1,0)
II	300<	Con((("soil_mech _15.TIF"== 2) & ("ugv" > 300)),1,0)
III	300<	Con ((("soil_mech _15.TIF" == 3) & ("ugv" > 300.01)),1,0)
IV	200-300	Con ((("soil_mech _15.TIF"== 1) & ("ugv" <= 300)& ("ugv" > 200)),1,0)
V	200-300	Con ((("soil_mech _15.TIF"== 2) & ("ugv" <= 300)& ("ugv" >= 200)),1,0)
VI	200-300	Con ((("soil_mech _15.TIF" == 3) & ("ugv" <= 300)& ("ugv" >= 200)),1,0)
VII	100-200	Con((("soil_mech _15.TIF"== 1) & ("ugv" <= 200) & ("ugv" >= 100)),1,0)
VIII	100-200	Con ((("soil_mech_15.TIF"== 2) & ("ugv" <= 200)& ("ugv" >= 100)),1,0)
IX	100-200	Con ((("soil_mech_15.TIF"== 3) & ("ugv" <= 200)& ("ugv" >= 100)),1,0)

Today, the irrigated lands of the Bukhara region are divided into 9 hydromodule zones according to the location of the soil in the aeration layer, thickness, mechanical composition and the level of seepage water. In hydromodule zoning, a conditional symbol base was created and brought to a unified system based on the color spectrum. High-resolution electronic digital maps of the research areas were created based on the rules of companization on the possibility of visualization on the basis of unique and bright colors for 9 hydromodule zones (Figure 5).

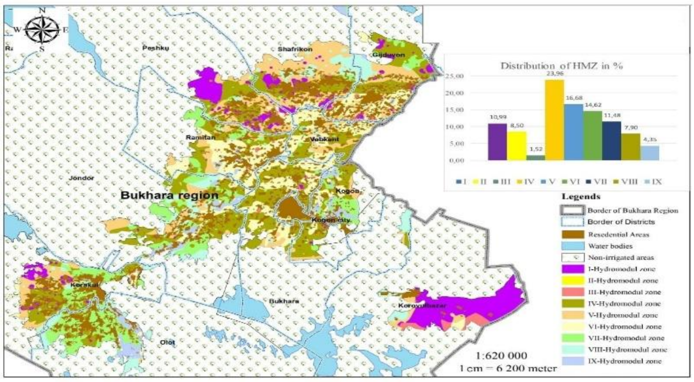

Figure 5 : Map of hydromodule zoning of irrigated lands of Bukhara region

According to the results of the research, the distribution of irrigated land of the region by hydromodule regions is presented in the table below (Table 5)

Table 5 : Distribution of irrigated land of Bukhara region by hydromodule zones, %

Province	Irrigated area, thousand ha	Monitoring wells, pc	Hydromodule zones								
			I	II	III	IV	V	VI	VII	VIII	IX
Bukhara	275,0	2590	10,9	8,5	1,5	23,9	16,6	14,62	11,48	8,15	4,35

1.3 Optimization of Water-Saving Irrigation Technologies

1.3.1 Drip Irrigation for Cotton (Field Experiment Results)

Research on determining the optimal parameters of the irrigation method and irrigation technique elements in the IV hydromodule zones, the most common in the region, was carried out in the following scheme (Table 6) according to the mechanical composition of the Bukhara Agrocluster field (Figure 6) in the conditions of medium sandy soils (Table 6):

Figure 6 : Location of the experimental field

Table 6 : Experimental system for determining the elements of irrigation technique of drip irrigation technology

Options	Distance between irrigation pipes, m	Water consumption of the dropper, l/h	The distance between the drops, cm	Pre-irrigation soil moisture relative to limited field moisture capacity, %
1 (control)	irrigation	-	-	70-75-65
2	to each edge, 0.9 m	1,6	30	75-80-65
3	1.8 m	1,6		
4	to each edge, 0.9 m	1,8		
5	1.8 m	1,8		

The experimental field's soil is medium loamy (physical clay content 30.66-38.14%). The volume weight in the 0-30 cm layer is 1.37%, in the 0-70 cm layer, 1.32% in terms of mechanical composition, and 1.31% at 0-100 cm. The water permeability was 0.241 mm/min.

In the studies conducted on the introduction of drip irrigation technology in medium loamy soils according to the mechanical composition, in the 1st option of the experiments with cotton, the soil moisture before irrigation was irrigated at 70-75-65% of the limited field moisture capacity, and during the season it was irrigated on the basis of the 1-3-1 system, irrigated once. The standard of cotton irrigation was 812-1057 m3/ha and the seasonal irrigation standard was 5084 m3/ha. In options 2-5, in which the drip irrigation technology was introduced in the irrigation of cotton in medium sandy soils, the soil moisture before irrigation was kept at 75-80-65% compared to the limited field moisture capacity, and cotton was irrigated 14 times in the 2-11-1 system. Irrigation rates were 248-365 m3/ha, and seasonal irrigation rates were 3364-3642 m3/ha (Figure 7).

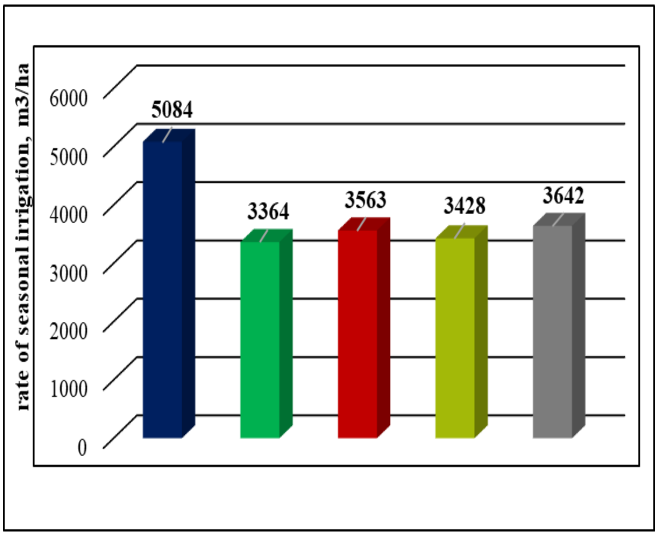

Figure 7 : Seasonal irrigation standards for cotton based on drip irrigation technology

According to the results of scientific studies on the effect of cotton cultivation on the cotton yield based on the mechanical structure of medium-loamy soils, the cotton yield was 38400 kg/ha in the 1st option, while in the 2nd-5th options, the drip irrigation technology was used, cotton yield was 44200-46300 kg/ha, compared to the control option, 5800-8100 kg/ha higher yield was achieved (Table 7).

Table 7 : Effect of Drip Irrigation Technology on Cotton Yield,

Options	Placement of drip hoses	Water consumption of the dropper l/h	harvesting			Average annual ts/ha
			I	II	III	
1	watering along the furrow	-	24,3	10,6	3,5	38,4
2	on every furrow	1,6	33,6	8,9	3,8	46,3
3	between the furrows	1,6	32,4	9,5	2,3	44,2
4	on every furrow	1,8	33,8	9,1	3,6	46,5
5	between the furrows	1,8	34,2	7,2	3,4	44,8

(mechanical composition in medium sandy soils) Sprinkler Irrigation for Winter Wheat (Field Experiment Results)

Experiments on the development of winter wheat sprinkler irrigation were carried out in the following system (Table 8) in the field of "Yangi Asr" farm (Figure 7) located in Ortachol Massif, Qiziltepa District, Navoi Region.

Table 8 : An experimental system for the development of a sprinkler irrigation system for winter wheat.

Options	Irrigation method	Pre-irrigation soil moisture, limited field moisture capacity relative %	fertilizer rate	calculation layer
1	furrow irrigation	65-65-65	30 t/ha organic matter N-250 kg/ha P-180 kg/ha K-125 kg/ha	0-30 cm to the base, in later phases 0-50 cm
2	sprinkler irrigation	65-70-65		
3		70-70-65		
4		70-75-65		
5		75-75-65		
6		70-80-65		

Figure 7 : Location of the experimental field

According to N.A. Kachinsky's description, the soil of the experimental field is physically clayey soil (less than 0.01 mm) and belongs to the type of soils with a mechanical composition of sandy loam and light sand. The volumetric weight of the soil is equal to 1.38 g/cm3 in the driving layer 0-30 cm, 1.43 g/cm3 in the sub-driving layer 30-50 cm and 1.42 g/cm3 in the 1-meter layer. It was equal to 0.28 mm/min. In the 1st option of the experiment on the development of the irrigation procedure of the Antonina variety of winter wheat using the OPAL PIVOT sprinkler irrigation machine, when the winter wheat was irrigated in the traditional way by dividing the winter wheat into floors, the soil moisture of the winter wheat before irrigation was kept at 65-65-65% compared to the limited field moisture capacity, irrigated 6 times in the 1-4-1 system, the irrigation rates were 785-1023 m3/ha, and the seasonal irrigation rate was 5285 m3/ha, the pre-irrigation soil moisture of the sprinkler-irrigated winter wheat in the experiments was 65-70-65% compared to the limited field moisture capacity. When irrigation was carried out, winter wheat was irrigated 9 times during the season in the 3-5-1 system, the irrigation rates were 372-408 m3/ha, and the seasonal irrigation rate was 3349 m3/ha. In the 6th option of the experiment, i.e., the soil moisture before irrigation of winter wheat was irrigated 12 times in the 3-8-1 system during the season, and the seasonal irrigation rate was 3091 m3/ha 2194 m3/ha or 42% less water was used compared to the control option. In the observations made in the studies on the length of the ear of winter wheat, the number of grains in one ear and the weight of 1000 grains, in the 1st option of the research, the length of the ear was 9.2 cm, the number of grains in one ear was 46 grains, and the number of grains in the ear was 0.0015 kg. 1000 grains weighed 0.0326 kg. During the experiments, in options 2-6, where winter wheat was irrigated by sprinkler, the length of the ear of winter wheat was 9.6-11.2 cm, the number of grains in the ear was 48-58 grains, and the number of grains in one ear was equal to 0.0016-0.0019 kg, 1000 grains grain weight is 0.0333-0.0362 kg, spike length is 0.4-1.4 cm, number of grains in one spike is 2-6 grains, grain weight in one spike is 0.00001-0.00003 kg, and The weight of 1000 grains increased by 0.0007-0.0032 kg.

The grain yield of winter wheat in the first option of the experiment was 44900 kg/ha, and in the sixth option, which was irrigated with an irrigation machine, the soil moisture before irrigation was 70-80-65% compared to the limited field moisture capacity, the grain yield was 6670 kg/ha. It was found to be equal 21800 kg/ha higher than the control option.

The findings are in line with traditional irrigation method have caused 40-45% of water loss and crop yield decline in eight water consumer associations (WCAs) in Kashkadarya Province of Uzbekistan, which highlights the need of implementing modern water-saving irrigation technologies (Djumaboev et al., 2017). Additionally, a water loss of 20% at the main canals and a loss of 35% at the secondary and tertiary canals in Bukhara province (Hamidov et al., 2024). Recent adoption of Water Resources Development Strategy 2020–2030 (Presidential Decree No. 6024, adopted on 10 July 2020), water-saving irrigation technologies should be installed on 2 million ha (about 50% of the total irrigated area) of irrigated lands by 2030, out of which 600,000 ha should be installed with drip should facilitate the improvement of water use efficiency and achievement of higher agricultural yields in Uzbekistan (Hamidov et al ., 2022).

4. Conclusions

Based on the research findings, the following conclusions are drawn regarding the sustainability of water conservation practices in the arid Bukhara region:

The average air temperature at the Karakol meteorological station increased by 1.18∘C during 1986–2020 compared to 1941–1985, confirming a significant climate change trend in the region.

Electronic maps of hydromodule zoning for the Bukhara region's irrigated lands were successfully created using GIS and remote sensing, categorizing the 275,000 hectares of irrigated land into nine zones. The most common zone is IV (23.9%), followed by V (16.6%) and VI (14.62%).

The optimal parameters for drip irrigation in medium sandy soils were determined as a dropper consumption of 1.8 l/h, a dropper distance of 30 cm, and an irrigation pipe distance of 90 cm. This method yielded a high cotton harvest of 46,300–46,500 kg/ha. Implementation of this technology saves up to 32–36% of river water compared to traditional methods.

Sprinkler irrigation is optimal when maintaining pre-irrigation soil moisture at 70–80–65% of the limited field moisture capacity. This technique achieved a high grain yield of 66,700 kg/ha. It saves 2194 m3/ha (or 42%) of water resources compared to furrow irrigation.

These findings confirm the significant potential of integrating advanced GIS-based hydromodule zoning with modern, water-saving irrigation technologies to achieve both water conservation and higher crop yields in the arid conditions of Uzbekistan.

Conflicts of Interest

The authors declare no conflict of interest.

References

Aripov, B. F., Akhmedova, Z. R., and Farmonov, B. B., 2023. Characteristics of irrigated soils of Bukhara region intended for cotton sowing. E3S Web of Conferences, 389, 03115. https://doi.org/10.

1051/e3sconf/202338903115

Balabanov, V., Zhizdyuk, A., Karpov, M., Khudaev, I., Usmonov, N., Norov, B., and Kannazarova, Z., 2024. Assessment of the ecological state and organization of works on cleaning the reservoir from siltation products. E3S Web of Conferences, 563, 03095. https://doi.org/ 10.1051/e3sconf/202456303095

Barak, N., 2009. The Israeli case study of agricultural use of reclaimed water with drip irrigation. Proceedings of the Water Environment Federation, 2009(8), 6546–6554. https://doi.org/10.2175/ 193864709793957247

Barandun, M., Fiddes, J., Scherler, M., Mathys, T., Saks, T., Petrakov, D., and Hoelzle, M., 2020. The state and future of the cryosphere in Central Asia. Water Security, 11, 100072. https://doi.org/10.1016/ j.wasec.2020.100072

Bo'riyeva, D., Xalilova, M., and Atayeva, Z., 2023. Dependence of microbiological activity of alluvial soils of irrigated meadow of Bukhara oasis on salinity levels. E3S Web of Conferences, 420, 03013. https://doi.org/10.1051/e3sconf/202342003013

de Freitas, E. M., da Silva, G. H., Guimarães, G. F. C., Vital, T. N. B., Vieira, J. H., da Silveira, F. A., Gomes, C. N., and da Cunha, F. F., 2023. Evapotranspiration and crop coefficient of Physalis peruviana cultivated with recycled paper as mulch. Scientia Horticulturae, 320, 112212. https://doi.org/10.1016/j.scienta.2023.112212

De Wrachien, D., Schultz, B., and Goli, M. B., 2021. Impacts of population growth and climate change on food production and irrigation and drainage needs: A world-wide view. Irrigation and Drainage, 70, Pp. 981–995. https://doi.org/10.1002/ird.2597

Djumaboev, K., Hamidov, A., Anarbekov, O., Gafurov, Z., and Tussupova, K., 2017. Impact of institutional change on irrigation management: A case study from southern Uzbekistan. Water, 9, 419. https://doi.org/10.3390/w9060419

Hamidov, A., Kasymov, U., Allahverdiyeva, N., and Schleyer, C. 2024. Governance of technological innovations in water and energy use in Uzbekistan. International Journal of Water Resources Development, 40, Pp. 123–139. https://doi.org/10.1080/ 07900627.2022.2062706

Hamidov, A., Kasymov, U., Djumaboev, K., and Paul, C. 2022. Rebound effects in irrigated agriculture in Uzbekistan: A stakeholder-based assessment. Sustainability, 14, 8375. https://doi.org/10.3390/ su14148375

Han, F., Zheng, Y., Zhang, L., Xiong, R., Hu, Z., Tian, Y., and Li, X. 2023. Simulating drip irrigation in large-scale and high-resolution ecohydrological models: From emitters to the basin. Agricultural Water Management, 289, 108500. https://doi.org/10. 1016/j.agwat.2023.108500

Hui, X., Zhang, H., Zheng, Y., Wang, J., Wang, Y., and Yan, H. 2024. Selection of end gun and optimization of water distribution under a center pivot irrigation system. Agricultural Water Management, 298, 108846. https://doi.org/ 10.1016/j.agwat.20 24.108846

Ilbas, A. I., Al-Azzawi, R. M. M., Abdulhamed, Z. A., and Gokalp, Z. 2023. Determination of effective irrigation intervals in the center pivot sprinkler system for maize (Zea mays L.) varieties. MOJES, 8, Pp. 163–169. https://doi.org/10.15406/ mojes.2023. 08.00287

Jadhav, M. A., 2024. A review on drip irrigation system. IJSREM, 8, Pp. 1–5. https://doi.org/10.55041/IJSREM31365

Joraev, A., 2024. Scientific and practical basis of effective use of water resources in the cultivation of cotton and winter wheat in conditions of saline soils (on the example of the Bukhara oasis) (DSc dissertation). Tashkent

Juliev, M., Mergili, M., Czaran, L., Nurtaev, B., and Hübl, J., 2018. GIS-based statistical landslide susceptibility analysis: A case study from the Bostanlik District, Uzbekistan. https://doi.org/10.13140/ RG.2.2.35183.33442

Kannazarova, Z., Balabanov, V. I., and Lee, A., 2021. Advanced method for cleaning horizontal closed drainage. Prirodoobustrojstvo, Pp. 36–40. https://doi.org/10.26897/1997-6011-2021-3-36-40

Kannazarova, Z., Juliev, M., Abuduwaili, J., Muratov, A., and Bekchanov, F., 2024. Drainage in irrigated agriculture: Bibliometric analysis for the period of 2017–2021. Agricultural Water Management, 305, 109118. https://doi.org/ 10.1016/ j.agwat. 2024.109118

Khamidov, I., Inamov, A., Islomov, U., and Mamatkulov, Z., 2023a. Application of advanced computer technologies in determination of irrigation regimes for cotton in water scarcity areas. E3S Web of Conferences, 365, 01008. https://doi.org/10.1051/ e3sconf/ 202336501008

Khamidov, I., Ishchanov, J., Hamidov, A., Shermatov, E., and Gafurov, Z., 2023c. Impact of soil surface temperature on changes in the groundwater level. Water, 15, 3865. https://doi.org/10.3390/ w15213865

Khamidov, Khamidov, J., Juraev, U. A., Buriev, X. B., Juraev, A. K., Saksonov, U. S., Sharifov, F. K., and Isabaev, K. T., 2024. Efficiency of drip irrigation technology of cotton in the saline soils of Bukhara oasis. BIO Web of Conferences, 103, 00019. https://doi.org/ 10.1051/ bioconf/202410300019

Khamidov, M., 2024. Report of the Sustainable Water Efficient Irrigation Technologies (SUSWEF) Project for achieving water, energy and food security under climate change in Uzbekistan. Tashkent.

Khamidov, M. K., Balla, D., and Hamidov, A. M., Juraev, U. A., 2020. Using collector-drainage water in saline and arid irrigation areas for adaptation to climate change. IOP Conference Series: Earth and Environmental Science, 422, 012121. https://doi.org/10.1088/ 1755-1315/422/1/012121

Khamidov, Y., Yavmutov, D. Sh., and Burkhanov, S. N., 2023d. Problems of the effective use of irrigated land in Bukhara region and ways to improve them. E3S Web of Conferences, 431, 01056. https://doi.org/10.1051/e3sconf/202343101056

Khasanov, S., Li, F., Kulmatov, R., Zhang, Q., Qiao, Y., Odilov, S., Yu, P., Leng, P., Hirwa, H., Tian, C., Yang, G., Liu, H., and Akhmatov, D., 2022. Evaluation of the perennial spatio-temporal changes in the groundwater level and mineralization, and soil salinity in irrigated lands of arid zone: As an example of Syrdarya Province, Uzbekistan. Agricultural Water Management, 263, 107444. https://doi.org/10.1016/j.agwat.2021.107444

Kulmatov, R., Mirzaev, J., Taylakov, A., Abuduwaili, J., and Karimov, B., 2021. Quantitative and qualitative assessment of collector-drainage waters in Aral Sea Basin: Trends in Jizzakh region, Republic of Uzbekistan. Environmental Earth Sciences, 80(2), 122. https://doi.org/10.1007/s12665-021-09406-y

Kulmatov, R., Rasulov, A., Kulmatova, D., Rozilhodjaev, B., and Groll, M., 2015. The modern problems of sustainable use and management of irrigated lands on the example of the Bukhara Region (Uzbekistan). Journal of Water and Resource Protection, 7, Pp. 956–971. https://doi.org/10.4236/jwarp.2015.712078

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., and Scardigno, A., 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agricultural Water Management, 146, Pp. 84–94. https://doi.org/10.1016/j.agwat. 2014.07.012

López-Serrano, M. J., Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., and Román-Sánchez, I. M., 2020. Sustainable use of wastewater in agriculture: A bibliometric analysis of worldwide research. Sustainability, 12, 8948. https://doi.org/10.3390/su12218948

Mir-Makhamad, B., Lurje, P., Parshuto, V., Pulotov, A., Aminov, F., Shenkar, M., Saidov, M., Semenov, N., Kurbanov, S., Mirzaakhmedov, S., Rakhmanov, K., Dal Martello, R., and Spengler, R., 2024. Agriculture along the upper part of the Middle Zarafshan River during the first millennium AD: A multi-site archaeobotanical analysis. PLoS ONE, 19, e0297896. https://doi.org/10.1371/ journal.pone.0297896

Mirziyoyev, Sh. M., 2020. Concept for the development of the water sector of the Republic of Uzbekistan for 2020–2030 (Presidential Decree No. 6024).

Nabipour, R., Yazdani, M. R., Mirzaei, F., Ebrahimian, H., and Alipour Mobaraki, F., 2024. Water productivity and yield characteristics of transplanted rice in puddled soil under drip tape irrigation. Agricultural Water Management, 295, 108753. https://doi.org/ 10.1016/j.agwat.2024.108753

Nanekely, M., Al-Faraj, F., and Scholz, M., 2023. Analysis of a joint impact of climate change and anthropogenic interventions on groundwater depletion in arid and semi-arid areas. In M. Sherif, V.

P. Singh, A. Sefelnasr, and M. Abrar (Eds.), Water resources management and sustainability Pp. 167–203. Springer Nature Switzerland, Cham. https://doi.org/10.1007/978-3-031-24506-0_12

Petrović, M. Z., Blumberg, D. G., Orlovsky, L., and Maman, S., 2023. Spatiotemporal analysis of dune stabilization in the Kyzylkum and Karakum sandy deserts. Frontiers in Earth Science, 11, 1129360. https://doi.org/10.3389/feart.2023.1129360

Potapov, V. P., Oparin, V. N., Mikov, L. S., and Popov, S. E., 2022. Information technologies in problems of nonlinear geomechanics. Part I: Earth remote sensing data and lineament analysis of deformation wave processes. Journal of Mining Science, 58, Pp. 486–502. https://doi.org/10.1134/S1062739122030164

Rakhmatullaev, S., Huneau, F., Celle-Jeanton, H., Le Coustumer, P., Motelica-Heino, M., and Bakiev, M., 2013. Water reservoirs, irrigation and sedimentation in Central Asia: A first-cut assessment for Uzbekistan. Environmental Earth Sciences, 68, Pp. 985–998. https://doi.org/10.1007/s12665-012-1802-0

Salimova, H., and Artikova, H., 2023. Determination of the mechanical composition and salinity of the Bukhara Gijduvan district of the Bukhara region. E3S Web of Conferences, 389, 04012. https://doi.org/10.1051/e3sconf/202338904012

Shirokova, Y. I., Sadiev, F. F., and Paluashova, G. Q., 2023. Water conservation in the reclamation of saline irrigated lands of Uzbekistan. E3S Web of Conferences, 386, 02003. https://doi.org/10.1051/e3sconf/202338602003

Suvanov, B. 2019. Scientific and practical basis of water consumption in various economical irrigation methods of cotton and winter wheat (Doctoral dissertation, Tashkent).

Wang, M., Chen, X., Sidike, A., Cao, L., DeMaeyer, P., and Kurban, A., 2021. Optimal allocation of surface water resources at the provincial level in the Uzbekistan region of the Amudarya River Basin. Water, 13, 1446. https://doi.org/10.3390/w13111446

Yamashkin, S. A., Yamashkin, A. A., Zanozin, V. V., Radovanovic, M. M., and Barmin, A. N., 2020. Improving the efficiency of deep learning methods in remote sensing data analysis: Geosystem approach. IEEE Access, 8, Pp. 179516–179529. https://doi.org/10.1109/ACCESS.2020.3028030

Zhang, Y. F., Li, Y. P., Huang, G. H., Zhai, X. B., and Ma, Y., 2024. Improving efficiency and sustainability of water–agriculture–energy nexus in a transboundary river basin under climate change: A double-sided stochastic fractional optimization method. Agricultural Water Management, 292, 108648. https://doi.org/10.1016/j.agwat.2023.108648