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Research Article

Evaluation of the impact of natural conditions on the sprinkler irrigation system

Khumora Turgunova[1]*, Tatiana Kaletova[1,2]

[1]*Tashkent Institute of Irrigation and Agricultural Mechanization Engineers – National Research University, Faculty of Hydromelioration, Tashkent, Uzbekistan*
[2]*Slovak University of Agriculture in Nitra, Faculty of Horticulture and Landscape Engineering, Nitra, Slovak Republic*

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Natural conditions highly predict further use of the locality. Current climate change, population growth and other crises open questions of better use and design of existing and new irrigation systems. Government of Uzbekistan currently highly invest in the water-saving irrigation systems which should correspond to natural conditions of the locality. Therefore, deep study of each area of interest is necessary. Based on the available information of natural conditions of Uzbekistan, the crop production localities overlap localities with low precipitation, high temperature rise in last years and middle groundwater level. Also, part of them lays on the soils with low water holding capacity and high salinity. Especially in those areas the proper design should be done.

Keywords: climate conditions, water resources, irrigation systems, Uzbekistan

1 Introduction

Efficient use of water is important in assessing climate change and its impact on a national industry, which has become one of the most pressing issues today. It is also important to prevent the increasing number of events and processes that lead to the depletion of the ozone layer, the greenhouse effect, and the increase of carbon dioxide. If we pay attention to the issue of efficient water use, given the growing population and the fact that water is mainly used for irrigation, there is a need to adapt water-saving irrigation technologies mainly to agriculture sector due to its complexity and importance.

In rainfall water saver irrigation system, sprinkler irrigation is one of the most common types of irrigation used for field crops. In many areas there is a problem of lack of water and energy to use for irrigation. Martín- Benito, Gómez & Pardo (1992) mentioned that the sprinkler irrigation system requires less energy, saves water and, of course, plays an important role in water efficiency. This is specific in accordance with a specific region, natural conditions, and in themselves are suitable only for these areas. Natural conditions highly impact hydraulic design of irrigation systems, especially application rates, sprinkler dimension or sprinklers layout and spacings (Waller & Yitayew, 2016). The design can be done based on the soil, climate, relief, and water resources information (Playan et al., 2005; Waller & Yitayew, 2016).

Current irrigated farming remains one of the most important economic sectors in Uzbekistan. Key crops (about 30% of the total irrigated area) are cotton that ensures about 10% of export receipts and wheat that is the basis for the national food security (Khamraev et al., 2011). More than 90% of water resources is spend in the agriculture, especially for irrigation purpose (Sokolov, 2018). Development of the Water Resources in Uzbekistan for 2020–2030 adopted in the Decree of President of the Republic of Uzbekistan No. PP-5005 contains a set of priority measures aimed at the implementation of fundamentally new ideas and ways of further development and modernization of the sector, the introduction of integrated water resources management principles etc. Among other things, the development of water strategy expects up to 2023 the increase in the efficiency of the irrigation system and irrigation networks

***Corresponding Author:** Khumora Turgunova, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers – National Research University, st. Kori Niyazov 39, Tashkent, Uzbekistan
e-mail: xumora798911@gmail.com

from 0.63 to 0.66, bringing the introduction of water-saving irrigation technologies on the area more than 1.1 million hectares (increase about 350%) and reduction about 2% of saline lands. Therefore, it is important to find the most appropriate localities of Uzbekistan for the implementation of the water strategy into practice and based on local natural conditions make an appropriate design of sprinkler irrigation systems. Thus, the article presents the impact of natural conditions of Uzbekistan on the possible use of sprinkler irrigation system within the country.

2 Material and methods

The natural conditions of Uzbekistan will be analysed in order to find possible places for the irrigation system usage. The impact of climate, soil and groundwater quality and level is assessed. Therefore, study of national and international literature was selected as a main working method.

The study area covered the whole territory of Uzbekistan (an area about 448,000 km^2) located in the Central Asian region with borders Turkmenistan to the southwest, Kazakhstan to the north, and Tajikistan and Kyrgyzstan to the south and east. Uzbekistan is a double landlocked country that is extremely diverse in physical and geographical conditions ranging from the flat, desert topography that comprises almost 80% of the country's territory to mountain peaks in the east with elevation extremes: lowest point -12 m b. s. l.; highest point: 4,500 m a. s. l. Khazret Sultan (Fig. 1). Most of the country is arid and semi-arid plains (80%) that border mountains (20%) from the south, southeast, and east. The largest categories of land used are agricultural land (46.1%), forest land (21.7%), and reserve land (27.6%) within three types of ecological landscapes – deserts, steppes, and mountains (Rakhmatova et al., 2021). The most important growing crops are cereals, potatoes, vegetables, fruits, and cotton. Due to development and construction of irrigation canals within Uzbekistan, several localities have been developed as the highly productive and important for the food production. Such main localities are: Tashkent, Fergana, Samarkand, Bukhara, Khorezm provinces, Dalverzin Steppe, Karshi Steppe, Sherabad Steppe the Golodnaya Steppe and Karakalpakstan (Khamraev et al., 2011).

3 Results and discussion

3.1 Climate conditions

The study of the climate of the region is significant for the application of water-saving technologies. Climatic



Figure 1 Physical map of Uzbekistan with roads, cities, and airports
Source: Maps of the World, n.d.

parameters such as precipitation, wind, sun, humidity, are very important especially when performing a hydraulic calculation of a sprinkler system. Climate is the most important external factor that affect formation and usage of water drops from sprinkler irrigation. If we assume that the water consumption of the average raindrop is 0.5–0.7 $l.s^{-1}$, the velocity of spray water will vary according to the diameter of the sprinkler system and will not be affected by the wind speed. Meteorological data are important in assessing the impact of wind, humidity, and sun on the raindrop, as well as the distribution of irrigation time and period.

The climate of Uzbekistan is arid and continental, with hot and dry summers and short cold winters, characterized by large temperature differences between day and night, winter and summer. The climate of Uzbekistan is arid-continental in the vast steppe plains of the central-western part, while it's still continental but moderately rainy (and snowy in winter) in the east, where hills and mountains are located. Winter is cold, especially in the north where the average temperature in January is around -5 °C (the Aral Sea and the northern part of the Kyzyl Kum Desert), while it's slightly above freezing (0 °C) in the central cities of the ancient Silk Road (Tashkent, Samarkand, Bukhara), and it goes up to 5 °C in the extreme south (e.g., Termez). Summer is hot when the average temperature in July ranges from 26/27 °C in the north to 30 °C in the south. In the mountains, the temperature naturally decreases with altitude. Uzbekistan is exposed to cold air masses from Siberia, especially in the north-west, but also in the centre-south, where, however, they alternate with warmer air masses coming from the south. The clash of different air masses can cause strong winds, for instance, the warm wind blowing from the south-west, which can bring dust storms. Precipitation is typical of desert and semi-desert climates in the west, while it's slightly higher, at a semi-arid steppe level, in the central-eastern part. In the mountains, precipitation increases, especially on the more exposed slopes. Summer is sunny, and it's the driest season across the country (Rakhmatullaev et al., 2010).

The air temperature change in Uzbekistan is uneven, both spatially and temporally. The most significant increase in the long-term mean temperature values (to 1.0 °C and more) was observed in the cold half of the year, mainly in January, February, and March over most of Uzbekistan's territory. Results show that winter and spring are becoming comparatively warmer on

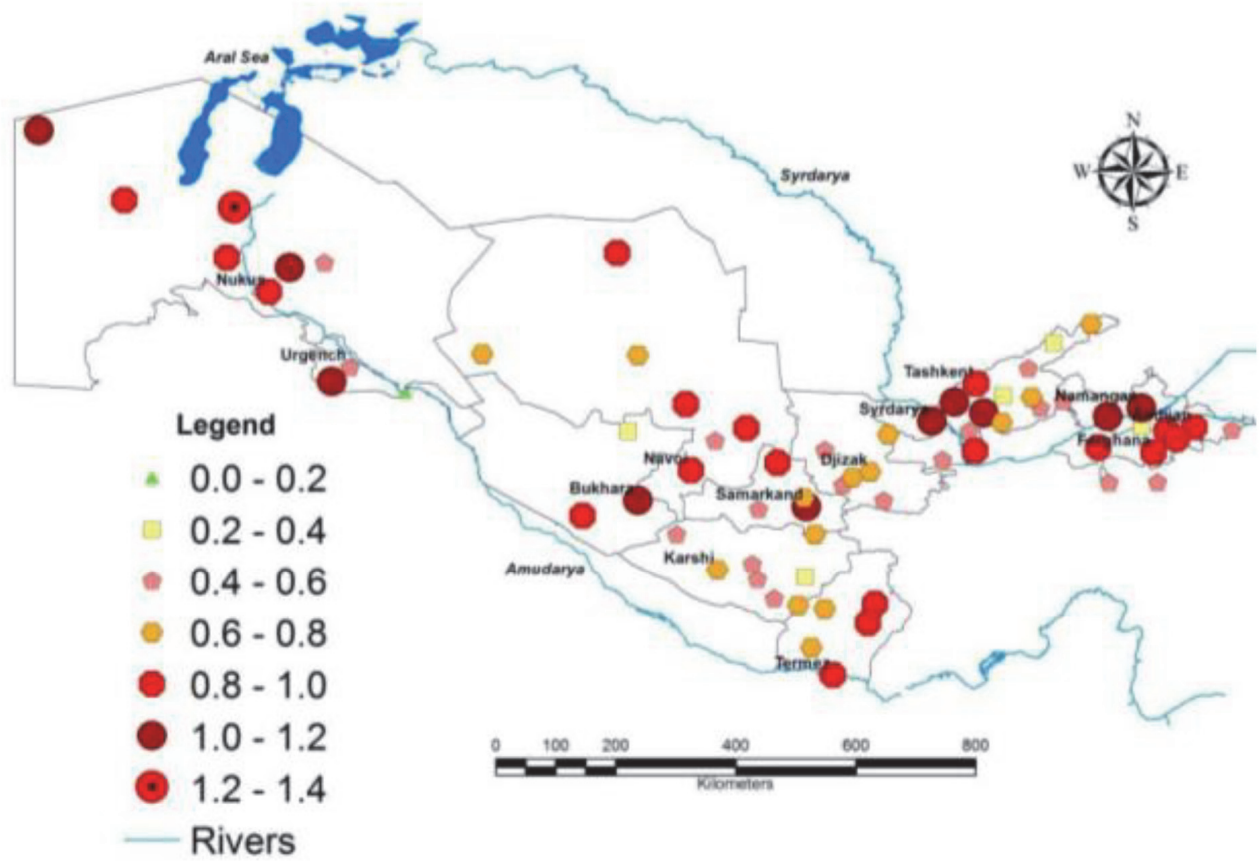


Figure 2 Average annual long-term air temperature variations in Uzbekistan for the 1991–2016 period compared to the baseline 1961–1990 period (°C)
Source: Kholmatjanov et al., 2020

average to 1.3 °C to the baseline period across the entire Uzbekistan territory (Fig. 2). The temperature rise of the autumn season (except the October) was relatively smaller, on average 0.58 °C. The most significant increase in temperatures for the summer season was observed in June and August at 0.7 °C and 0.94 °C, respectively (Kholmatjanov et al., 2020). Therefore, it is important to have in mind that in the design and selection of localities of new irrigation systems in the country. We can see that also highly productive localities, e.g., Fergana valley or Tashkent region are affected by increased temperatures last years.

Distribution of atmospheric precipitation over the territory is extremely uneven, closely related to the location of mountain systems, the altitude, and the exposure of slopes (Fig. 3). The strongly heated air over the plains of Uzbekistan is dry, therefore, in the summer period of the year the conditions for drought formation are often created. The increase in number of hot days and the decrease in air humidity cause more frequent adverse weather phenomena, such as droughts, strong winds with a speed of 15 $m.s^{-1}$ and more, and dry winds, which cause an increase in dust storms. The number of days with dust storms in the plains ranges from 10–30 to 50–64 days a year (Rakhmatova et al., 2021).

In the plains, precipitation is minimal (within the range of 80–200 mm) and occurs during the cold period of the year. The Aral Sea does not affect the quantity of precipitation very much, only contributing to the slight increase in the coastal area. Variability of precipitation is great, especially in the warm period of the year. An extremely high variability of precipitation is observed in the warm half of the year. Climate variability of precipitation in the foothills and mountainous areas is moderate and can occur all year-round (Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change). The average annual precipitation in the desert zone is less than 200 mm while in the piedmont and highland zones it can be of 400–800 mm with a maximum of 2000 mm in the mountain areas. The annual average evaporation is about 1,600–2,200 mm (Rakhmatullaev et al., 2010). As we can see (Fig. 2 and Fig. 3), the localities with highest temperature rise are identical to localities with low yearly precipitation up to 400 mm, primarily up to 200 mm. Hence, agricultural production is impossible without irrigation.

It is known that the water used for irrigation should be evenly distributed throughout the field. Part of the water from the sprinkler irrigation system is lost or affected by changes such as wind direction, speed, and evaporation in accordance with the meteorological conditions of the area. In this case, the use of sprinkler irrigation systems in areas with high winds and high evaporation is a challenge. Increased wind speed decreases the spacing of irrigators. According to an experiment conducted in Zaragoza, Spain, if the wind speed exceeds 4.0–4.5 $m.s^{-1}$, the losses in sprinkler irrigation will increase. At the same

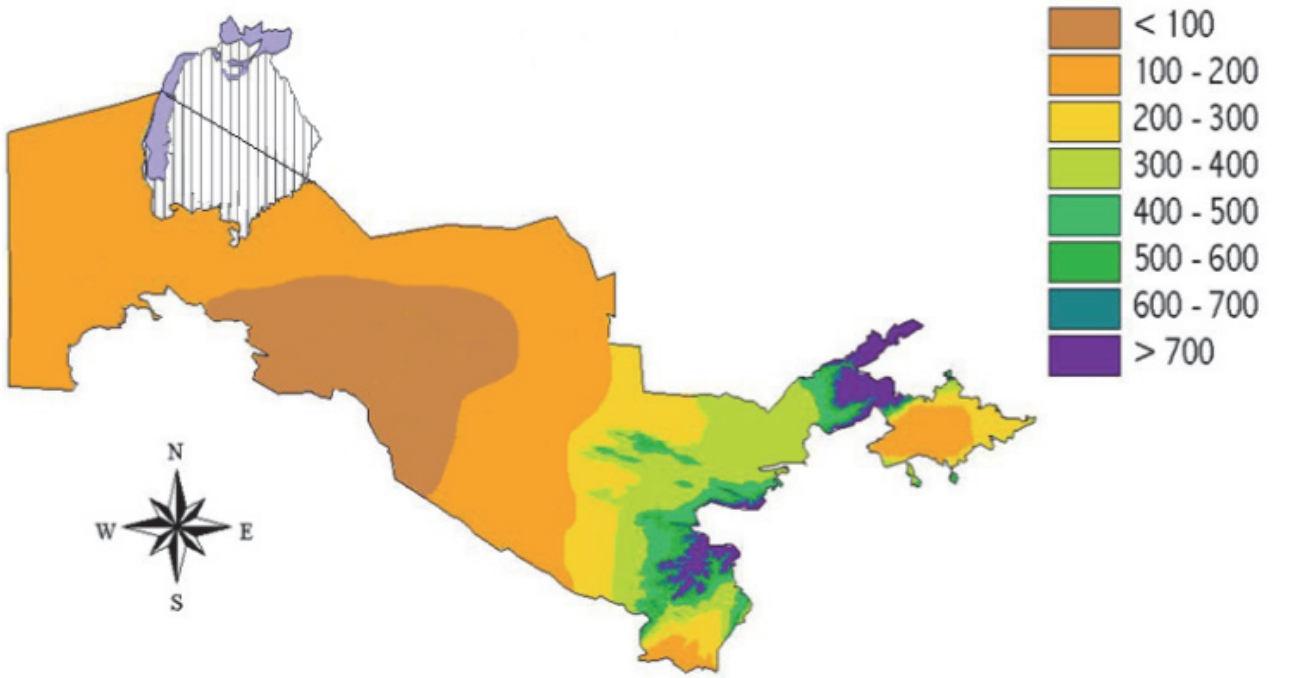


Figure 3 Distribution of annual precipitation amounts over the area of Uzbekistan (mm)
Source: Rakhmatova et al., 2021

time, night irrigation using the sprinkler irrigation system not only increases efficiency, but also allows for efficient use of water and equal irrigation of the planted field (Playan et al., 2005). Therefore, meteorological variables (humidity, temperature, and solar radiation) affecting wind and evaporation in the area affect the efficiency of sprinkler irrigation system operation and must be study and consider during the irrigation system design.

3.2 Soil conditions

Soil conditions are one of the key factors in calculating the required amount of water consumption, water holding capacity, maximum intake rate etc. (Waller & Yitayew, 2016). To do this, soil samples are taken from several parts of the field and the composition is studied. According to it, the filtration coefficient is obtained. Water consumption is calculated according to the obtained filtration coefficient, and other parameters are defined based on the soil structure.

In Uzbekistan, the soil is divided into two groups according to their geographical location. The first group is a low-lying lowland with a dry climate, which makes up to 71.7% of the total area of the country, and the second group is a humid, foothill region with 28.3%. It belongs to Chirchik-Akhangaran district and has a fertile layer that does not require reclamation measures so far. There are grey soils, meadow, and marsh meadow soils in this area (Rakhmatullaev et al., 2012).

Due to climatic conditions and aridity about 32% of all soil types within Uzbekistan are represented by desert type of soils which cannot be used for irrigation because of their inherited characteristics (Fig. 4). Saline soils (solonchak and their subtypes) are distributed in Karakalpakstan and near the Aral Sea area and occupy about 3% of the of the total surface. About a total 63% of soils in Uzbekistan cannot be used for irrigation due to their inherited soil characteristics, available irrigation, and drainage facilities. The hydromorphic soils (9% of the total surface) and the serozem belt (15% of the total surface) both have a high humus content and the serozem belt are less subject to salinization (Rakhmatullaev et al., 2010).

As we can see, the soil conditions of Uzbekistan are not very suitable for any crop production without irrigation systems. Also, the water holding capacity of desert type and sands soils is very low, and therefore the water requirements for the crop production is very high. So far, widely used open earthen canals and surface types of irrigations consume mentioned more than 90% of water in the country. This bad soil conditions hand in hand with current climate change highly impact the proper design

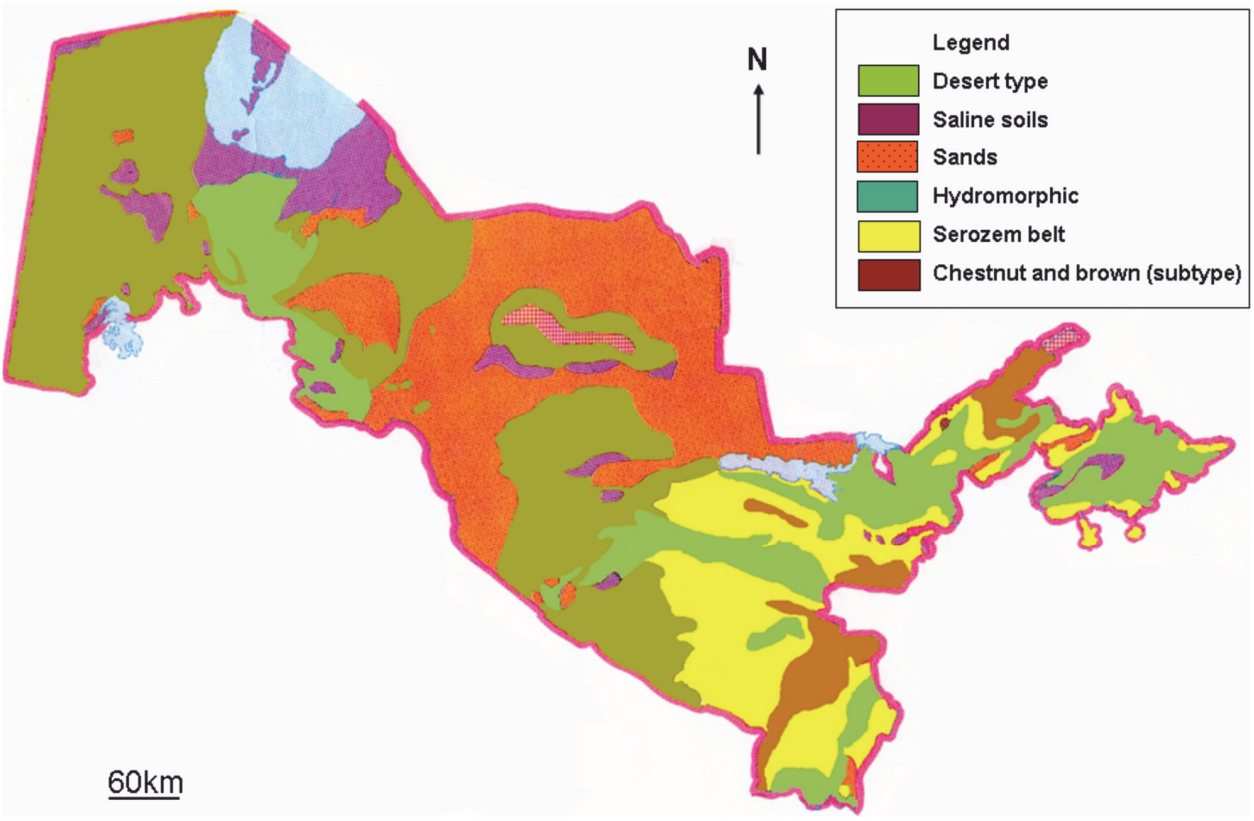


Figure 4 Soil map of Uzbekistan
Source: Rakhmatullaev et al., 2012

and management of irrigation systems, especially timing and rate. The main crop production areas fortunately lay on the serozem belt soils and hydromorphic soils. Only Karakalpakstan, and partly Bukhara and Khorezm provinces have inadequate soil conditions with low water holding capacity (Fig. 4).

3.3 Water resources

The water resources of Uzbekistan are unevenly distributed both in space and time. There is a strong dependency on winter and spring rains and snowmelt from the mountains which are major contributors to the watersheds (Rakhmatullaev et al., 2010). Available water supply is formed by renewable surface and groundwater of natural origin, and by return water of anthropogenic origin (Khamraev et al., 2011). Water resources of Uzbekistan are part of the water resources of the Aral Sea Basin. There are two main transboundary river basins in the Aral Sea Basin: the Syrdarya in the north and the Amudarya in the south. The Amudarya is the largest river in Central Asia with the maximum consumption observed in the summer and the minimum in January–February. Such availability of flow during the year is very favourable for the use of river water for irrigation. The Amudarya contains sediment more than all the rivers in Central Asia, and their composition is one of the highest in the world. The Syrdarya is the second most important river in Central Asia, but it is longer in length. The water regime is characterized by spring-summer flood which begins in April. The largest drop is in June (Sokolov, 2018).

Uzbekistan is the main water resources consumer in the region of Central Asia, as its agricultural production almost entirely depends on irrigation for which about 90% of the water withdrawal from the surface sources is used. Due to poor conditions of the irrigation network and ineffective water resources management, a great amount of water is lost through evaporation and filtration. The losses in the irrigation network are estimated 40% (Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change). Water from the abovementioned rivers is delivered within the country through the irrigation systems with total length more than 200 thousand kilometre, and almost 100 thousand kilometres of open drainage channels (Khamraev et al., 2011). All the irrigation and drainage infrastructure are connected to the Syrdarya and the Amudarya rivers (Fig. 5).

The management of the Amudarya and Syrdarya rivers and their basins have had a significant impact on the sediment discharge and solid matter. Due to the high demand for water in agriculture and household, sediments silted up the water intake structures, reservoirs, main and inland irrigation canals. This, on the one hand, deliver ready mineral fertilizers to agricultural fields, on the other hand, it has a negative impact on the efficient operation of water structures (Arifjanov, Apakxojaeva & Huska, 2018), including the water-saving irrigation systems, especially the pipes and pumps. Due to a high number of fine particles dissolved in the water,

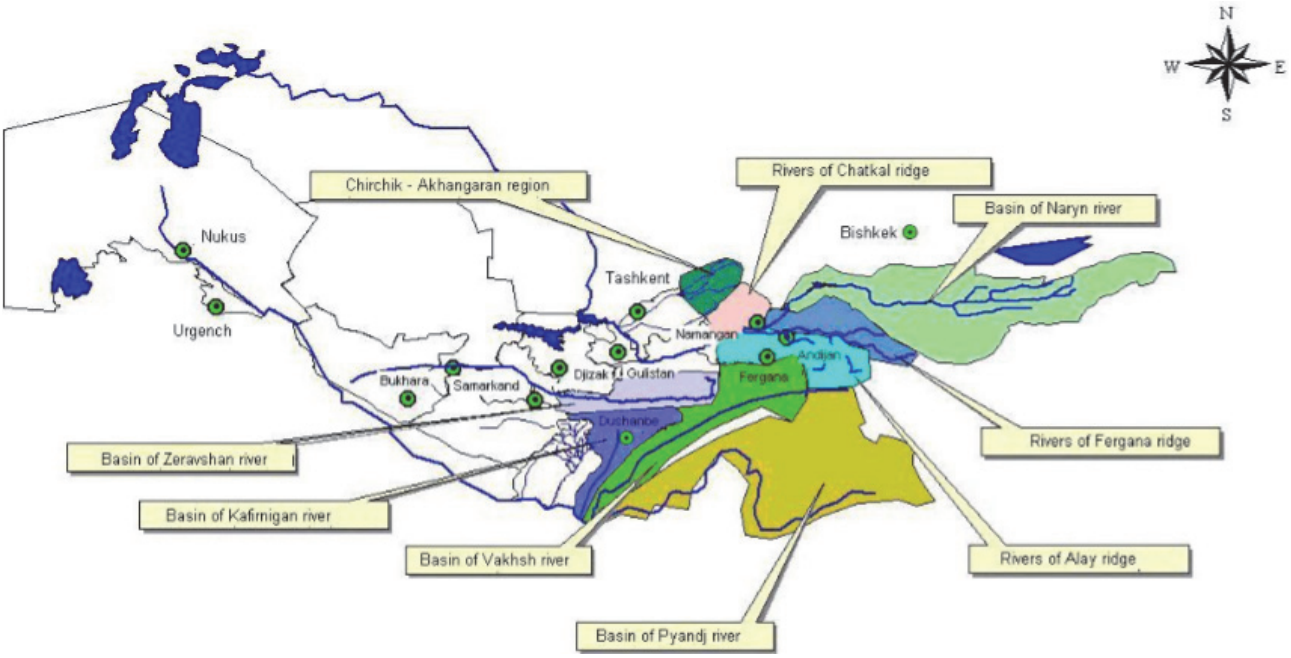


Figure 5 Scheme of hydrological regions of the runoff formation area for Amudarya and Syrdarya rivers (Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change)

the minerals have delivery medium to be distributed to the arable soil by water. However, such particles can clog the irrigation infrastructure in the field.

Groundwater quality is one of the important factors for the possible use of irrigation systems in the locality. Several groundwater quality parameters and total mineralization are studied. If its quality meets the requirements of irrigation water, would not be harm for the soil and the crop itself, it can be used for the irrigation purpose. Otherwise, the groundwater pollution level is required to return to normal. According to the total amount of dissolved substances in groundwater, freshwater is considered suitable for irrigation. There is no need to control the groundwater level, however it is useful for the appropriate management of irrigation system and irrigation rate.

Although groundwater resources constitute roughly 10% of the total water resources in Uzbekistan, about 60% of it is used for drinking water supply, domestic use, and irrigation (Rakhmatullaev et al., 2010). The sources of groundwater supply and formation of their resources are filtration canal losses from watercourses, infiltration of irrigation water, and atmospheric precipitation (Rakhmatova et al., 2021). Groundwater is widespread in the mountainous regions, and artesian basins are found on the plains. In Uzbekistan, around 94 major aquifers are found in the Ferghana valley (35% out of the total), Tashkent province (26%), Samarkand (18%) and the remaining 21% can be found elsewhere on the territory. To better assess the hydrogeological, geological, and hydrological conditions, the 13 major hydrogeological zones (Fig. 6, Table 1) have been established in Uzbekistan to estimate regional (explored) groundwater reserves (Rakhmatullaev et al., 2012).

Return water is an additional source of available water supplies, but on the other hand, its quality possess

Table 1 Major transboundary aquifers, environmental and management issues in Uzbekistan

Aquifer	Type	Shared by	Pressure factors	Transboundary impacts	Environmental issues
Osh Aravoj	medium	Uzbekistan Kyrgyzstan	agriculture industry water disposal	decline of GW* table pollution	pesticides heavy metals hydrocarbons radioactive elements
Almoe Verzin	medium	Uzbekistan Kyrgyzstan	agriculture ore mining water disposal	pollution	nitrogen species pesticides heavy metals hydrocarbons
Moiabsuv	strong to medium	Uzbekistan Kyrgyzstan	agriculture indus try	pollution	hydrocarbons sulphates
Sokh	strong	Uzbekistan Kyrgyzstan	agriculture industry	pollution	salinization
Pretashkent	large deep (artesian type)	Uzbekistan Kazakhstan	water abstraction	decline of GW table	no significant problems
Birata Urgench	quaternary sand, loam	Uzbekistan Turkmenistan	water abstraction	moderate borehole yield reduction	salinization (natural origin and irrigation) wastewater and drainage water
Karotog	moderate	Uzbekistan Tajikistan	water abstraction	change of water resources based on the water abstraction in Tajikistan	nitrate contamination
Dalverzin	moderate	Uzbekistan Tajikistan	water abstraction	moderate borehole yield reduction	moderate increase on mineralization and hardness
Zaforoboi	moderate	Uzbekistan Tajikistan	water abstraction	moderate borehole yield reduction	moderate pollution
Zeravshan	moderate	Uzbekistan Tajikista	moderate water abstraction	significant effect of the industrial activities in Tajikistan	industry
Chatkal Kurman	weak	Kazakhstan Uzbekistan	water abstraction	decline of GW table	no significant problems

Source: Rakhmatullaev et al., 2012
* GW – groundwater

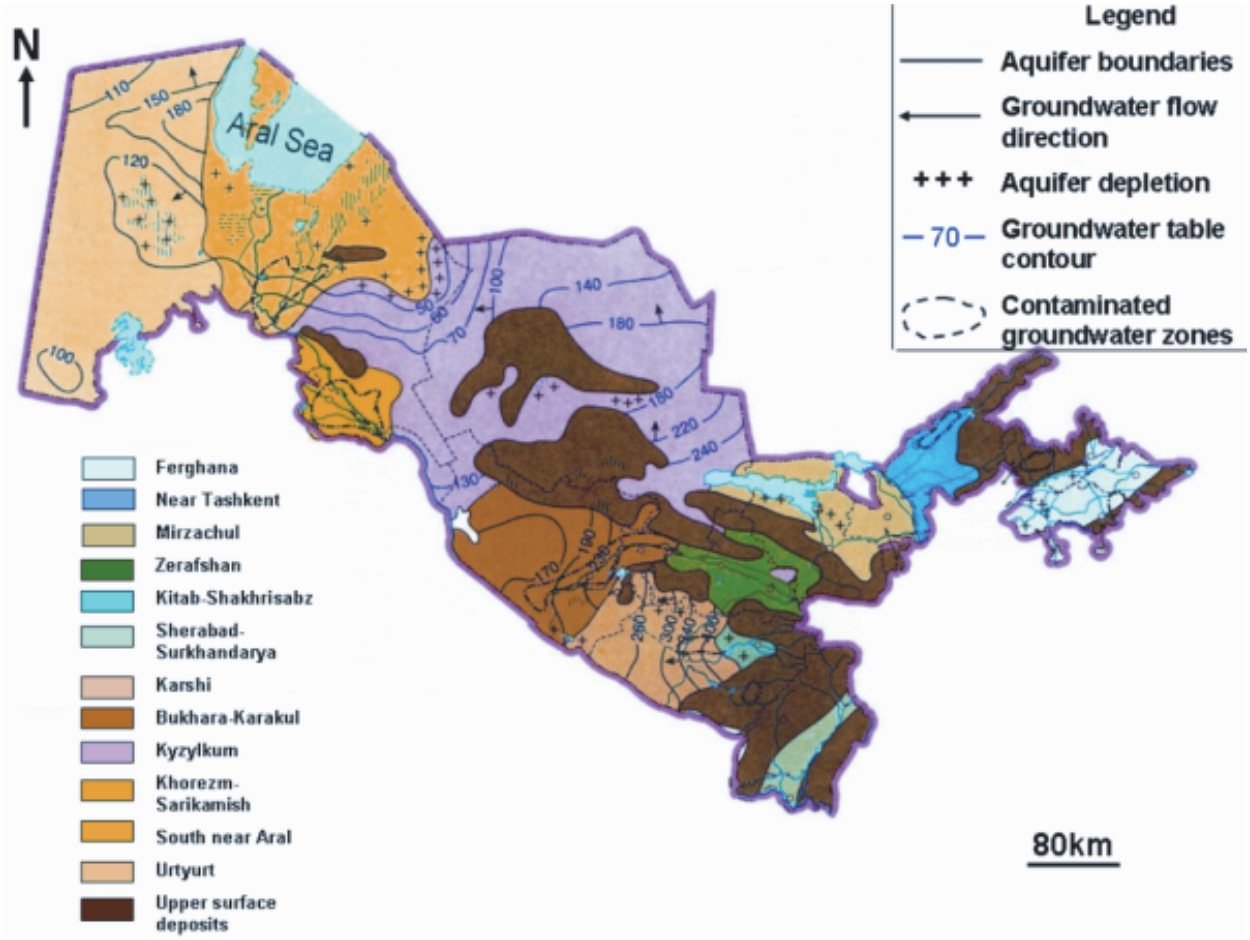


Figure 6 Hydrogeological map of Uzbekistan
Source: adapted and modified from Rakhmatullaev et al., 2012

a serious threat to aquatic and terrestrial ecosystems due to their high salinity. Drainage water and water wasted under irrigation form about 95% of the total amount of return water in the country (Khamraev et al., 2011; Rakhmatova et al., 2021).

The groundwater table vary between 0.5 and 3 m below the soil surface, occasionally is deeper (Fig. 6). Shallow groundwater level allows better connection for crop roots and decrease the need for irrigation. Due to irrigation, the groundwater table can increase and create better conditions for crop growth, but on the other hand there is the higher potential for the contamination of groundwater by fertilizers and other pollutants. Main agricultural areas on the transboundary basins cause environmental issues (Table 1). Also, Rakhmatullaev et al., (2012) mentioned that shallow aquifers have tendency to be salinized or affected by salinization processes. Furthermore, returned water delivery by drainage and irrigation canals from upstream to downstream increase the potential of groundwater salinity and pollution.

4 Conclusions

The proper use, conserve, and avoid wasting water used for irrigation in agriculture – all these are necessary to develop a methodology for adapting existing technologies to the conditions of Uzbekistan. At a time when climate change and water shortages are occurring, it is everyone's duty to use water efficiently and economically before the difficulties and shortages in delivering water to the population occur. The study of the parameters affecting the hydraulic design of the irrigation system and its implementation in the assessment of this effect will result in the expansion of the water saving irrigation system throughout Uzbekistan, thus increasing yields and efficient use of water in the regions.

The high impact on the design, and later proper use of the water for the irrigation, has natural conditions of the area of interest. Air temperature, humidity, wind direction and velocity, precipitation, soil conditions, water resources, are main parameters affecting the design of the irrigation system, e.g., the diameter of pipes, layout and spacing of irrigators etc.

As we can see, the current combination of natural conditions of Uzbekistan with the most important food production areas do not create ideal conditions for sustainable future. Furthermore, combination of temperature increase, low annual precipitations, wind occurrence, high evapotranspiration rate, open earthen canals and sandy soils brings inadequate conditions for the sustainable landscape management. Therefore, proposed changes of water management by the government will increase the sustainability and quality of the production and environment itself.

Acknowledgments

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