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Dynamics of Soil Moisture Deficit and its Impact on Irrigation Water Demand: A Case Study of Kotayk Region

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ABSTRACT

The research is dedicated to the justification of irrigation water demand to ensure the efficient use of irrigated lands in the context of climate change. To this end the dynamics of climate indicators from 1991 to 2023 at the «Yeghvard» meteorological station has been studied, and the total water consumption (evapotranspiration) together with the dynamics of the soil moisture has been calculated. To characterize the degree of annual dryness in conditions of insufficient moisture zones, years with 50 %, 75 %, and 95 % percentile of atmospheric precipitation during the vegetation period were used as reference points for calculations. Given the importance of the issue, the research was conducted using the example of semi-desert gray soils in the Kotayk region. The soil moisture deficit was calculated for both the vegetation period and the entire year. The calculations show that over the past five years, the soil moisture deficit in irrigated semi-desert gray soils in the Yeghvard area has exhibited a negative trend, resulting in a reduction of active soil moisture reserves by 1.410–4.400 m³/ha. This finding supports the observation recorded in recent years within irrigation systems that farming enterprises are using 2 to 3 times more irrigation water than the established norms.

Introduction

Currently, due to climate change, several issues have arisen related to efficient use of irrigated lands, among which the justification of irrigation water demand holds primary importance. One of the primary challenges in justifying crop water requirements on irrigated lands is determining the effective amount of atmospheric precipitation, assessing soil moisture deficit, and calculating reference/estimated evapotranspiration (Hoffman, et al., 1992, Meyer, et al., 1989, Richard, et al., 1998, Yeghiazaryan, et al., 2022). Total water consumption, also known as evapotranspiration, is calculated based on climate indicators.

However, it is evident that the water consumption requirements of crops vary from year to year, depending on changes in climatic conditions. In regions with insufficient moisture, the dryness degree during the year is typically characterized by considering the years with 50 %, 75 %, and 95 % percentile of precipitation during the vegetation period (Mkrtchyan, et al., 2004, Terteryan, et al., 2007, Yeghiazaryan, et al., 2008, Yeghiazaryan, et al., 2009). .In areas with unstable moisture levels, an extremely dry year - corresponding to 95 % of precipitation provision during the growing season - is used as a baseline for calculations. For different irrigation technologies, the recalculation of irrigation water demand is based on the already established water requirements for each crop (Armstat, 2023, Galstyan, et al., 2022). Identifying irrigation water demand is practically important in terms of concluding contracts between Water User Associations (WUAs) and water users, as well as for securing the necessary water volumes for irrigation from the water supply organizations such as “Jrar”. Considering the importance of the issue, the research was conducted using Kotayk Province as a case study, based on the climate data from the “Yeghvard” meteorological station for the years 2019–2023.

Materials and methods

The subject of this research is the justification of crop water requirements in irrigated soils, taking into account changes in climatic conditions and the soil’s hydro-physical properties. Using the average daily data from the Yeghvard hydro-meteorological station for 2019–2023, the monthly distribution of precipitation throughout the year was studied. At the same time, changes in key climate indicators were observed, including maximum (T_{max}), minimum temperatures (T_{min}), relative air humidity (RH), wind speed (V) and number of sunny/sunshine days (t). Based on these indicators the estimated evapotranspiration has been determined using CROPWAT software program. Following internationally practiced methods for determining crop irrigation water requirements, the estimated/reference evapotranspiration has been computed (ET_0) (Mkrtchyan, et al., 2004, Rao, et al., 2011, Salman, et al., 2024, Yeghiazaryan, et al., 2022).

The crops water requirement has been calculated through the following formula:

$$M_n = ET_0 - P_{efektiv}. \quad (1)$$

For different percentiles of atmospheric precipitations the following formula has been used:

$$M_{np\,\%} = ET_{0p\%} - P_{efektivp\%}. \quad (2)$$

Brutto/gross irrigation water demand will be equal to:

$$M_{bp\%} = \frac{ET_{0\,p\%} - P_{efektivp\%}}{\sigma}, \quad (3)$$

where σ is efficiency coefficient of intra-farm irrigation network.

Results and discussions

The research was conducted based on the analysis of climatic indicators recorded in the Yeghvard meteorological station for the years 1991–2023. To construct the curve of precipitation percentiles, the existing statistical series of atmospheric precipitation was processed. Based on the results of statistical data processing, both the theoretical (analytical) and empirical (observed) percentile curves were constructed (Fig. 1).

Figure 1. Theoretical and empirical curves depicting the percentiles of atmospheric precipitations per the data of Yeghvard meteorological station *(composed by the authors)*.

The calculations were conducted for atmospheric precipitation with the percentiles of 50 %, 75 %, and 95 %. Figure 2.1 and 2.2 show the variation in evapotranspiration for 2021 per the days of the month.

It should be noted that in 88 settlements across the Kotayk region, including Abovyan, Hrazdan, and Nayiri provinces, crop water requirements are planned in line with the existing 8, 9, 10, 11, 12, and 13 regimes according to which, the irrigation norms change per the described pattern.

For the justification of irrigation water requirements, the total water consumption (evapotranspiration) values were calculated by years and months, and the results are summarized in Figure 3.

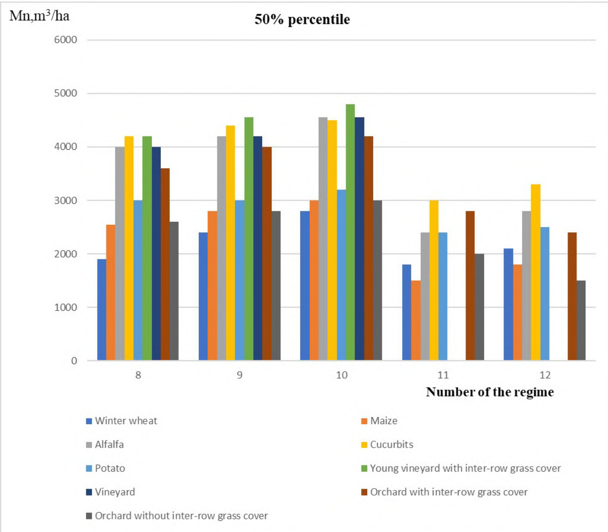

Figure 2.1. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

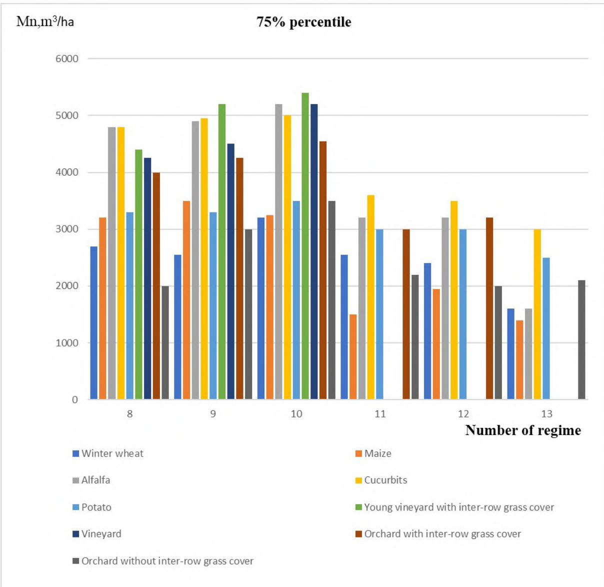

Figure 2.2. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

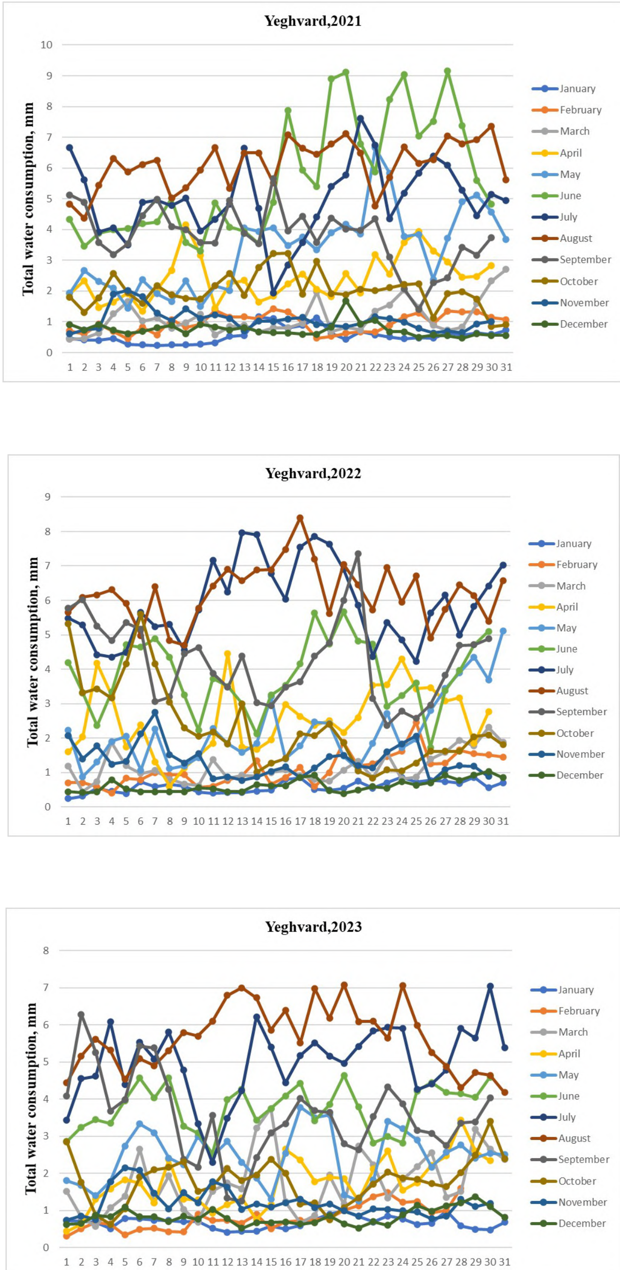

Figure 3. Estimated evapotranspiration *(composed by the authors)*.

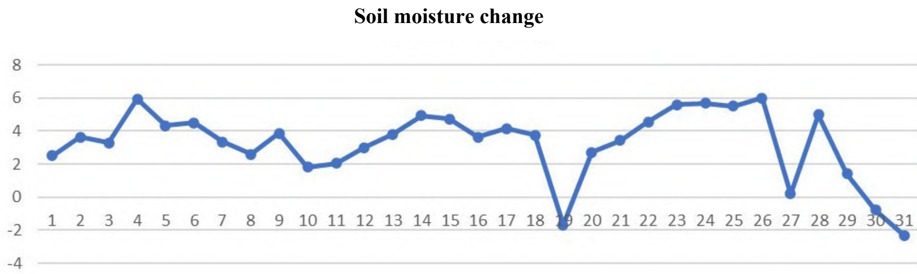

Figure 4. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

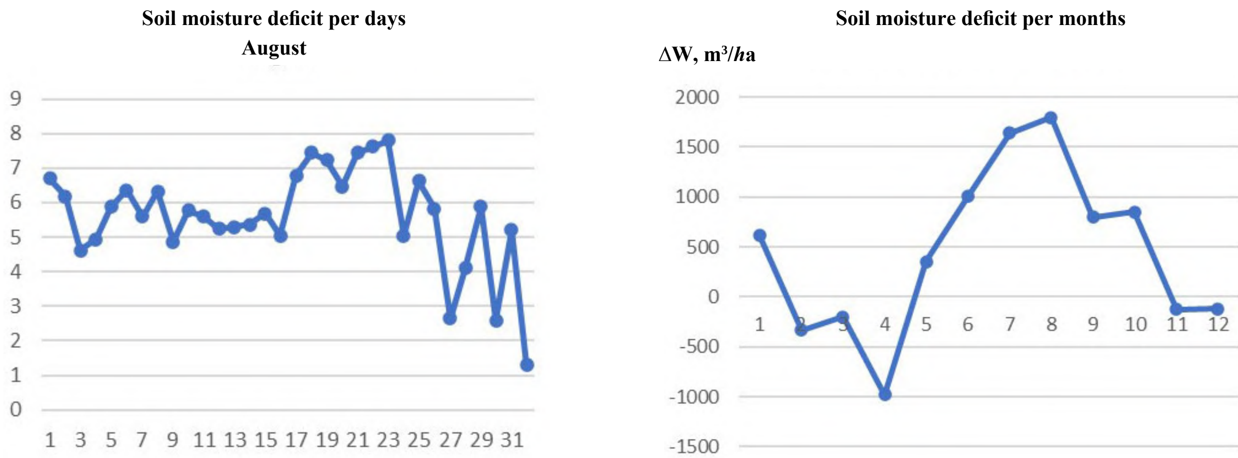

Figure 5. Dynamics of soil moisture deficit *(composed by the authors)*.

The soils in the calculation area are classified as semi-desert gray soils. In terms of mechanical composition, they are primarily medium to heavy clay-and-sandy soils. The soil density ranges between 1.3–1.33 g/cm³, while the specific gravity of the soil is within 2.53–2.72 g/cm³. The soil porosity is 49–51 %, and the field capacity moisture content ranges from 25–26 %.

The provided indicators allow for calculating the minimum moisture content in the soil at the beginning of the irrigation season, from the prospect of permanent wilting of plants. For crops with 50 cm root system, this amounts to 1.989 m³/ha. Therefore, the soil moisture deficit in conditions of the minimum moisture reserve will be 1.526 m³/ha. The soil moisture variation pattern for June is shown in Figure 4.

The calculations show that soil moisture decreases by 1,013 m³/ha. Therefore, the deficit will be 2,539 m³/ha. Respectively, in July, the moisture reduction will be 1,639 m³/ha; in August, it will be 1.795 m³/ha; in September - 800 m³/ha; in October - 847 m³/ha; in November the soil moisture will increase by 123 m³/ha; and in December it will increase by 121 m³/ha, whereas in June, the soil moisture deficit was 2.539 m³/ha. Therefore, by December, the soil moisture deficit from the prospect of minimum moisture reserve will be:

$$\Delta W_2=2539+1639+1795+800+847-123-121=7376 \text{ m}^3/\text{ha}.$$

For the year of 75% atmospheric precipitation, the soil moisture deficit throughout the year per months will have the following pattern:

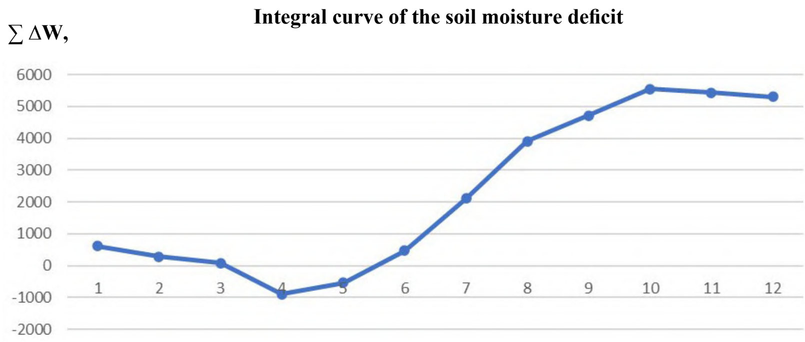

Figure 6. The integral curve of soil moisture deficit in semi-desert gray soils, based on data from the Yeghvard meteorological station *(composed by the authors)*.

Table 1. The estimates of soil moisture deficit for the annual period*

Percentile, %	Atmospheric precipitations mm		Total water consumption (Evapotranspiration, ET_0), m^3/ha	
	Year	Vegetation	Year	Vegetation
50	4970	3290	8900	8440
75	3290	2900	9400	8600
95	2650	2280	9600	9200

Table 2. The estimates of soil moisture deficit for the vegetation period*

Minimum soil moisture reserve		Soil moisture deficit, 0…50 cm		Soil moisture deficit, 0…100 cm	
0…50 cm	0…100 cm	Year	Vegetation	Year	Vegetation
1260	2520	2670	3890	1410	2630
1260	2520	4850	4440	3590	3180
1260	2520	5690	5660	4430	4400

*Composed by the authors.

The estimates of soil moisture deficit for years with different precipitation percentiles, for both the annual and vegetation periods, are presented in Tables 1 and 2.

Conclusion

Based on the climatic data obtained from the Yeghvard meteorological station for the years 1991-2023, it is recommended to identify irrigation water demand in conditions of semi-desert gray soils based on the dynamics of soil moisture deficit during the vegetation and annual periods. The calculations show that, over the past five years, the soil moisture deficit in semi-desert gray soils of irrigated lands in the Yeghvard area, has demonstrated a negative dynamic. As a result, the active moisture reserve in the soil has decreased by a volume of 1.410–4.400 m^3/ha.

This finding helps to justify the fact observed over recent years in irrigation systems, where farming enterprises use irrigation water 2 to 3 times more than the established norms. Thus, in the case of surface irrigation, it is evident that the current irrigation norms should be increased by an average of 2.905 m³/ha. On the other hand, it is important to focus on the development of irrigation technologies, as surface irrigation with such volumes could pose significant risks to the entire irrigation system.

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Declarations of interest

The authors declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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