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INTEGRATED GIS-BASED ANALYSIS OF GROUNDWATER LEVEL VARIATIONS IN RESPONSE TO IRRIGATION IN THE KARASUV RIVER BASIN USING INVERSE DISTANCE WEIGHTING (IDW)

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Abstract

Studying the relation of groundwater and surface water is complex, and concerns not only the hydraulic parameters of a river or channel, but also many other factors; that is, the climatic conditions of the region, the morphology of the river valley, and the soil-geological structure of the region due to land reclamation conditions.

For the design and operation of irrigation and drainage facilities, it is often necessary to solve the problems of water exchange on a regional scale accounting for the interaction of surface and groundwater (i.e., the estimation of the amount of groundwater, the distribution of river flow throughout the year, river basin particularities, the construction of irrigation and drainage systems, etc.).

Nowadays, the effective use of water resources, and especially the further improvement of hydro-systems of river basins, is one of the important issues in Uzbekistan. Along with the changes in the hydrological regime of rivers, their influence on groundwater is also increasing due to climate change. The change in the level of underground water in irrigated areas and its regime is of particular importance. Therefore, the elaboration of methods for assessing the dependence of the underground water regime on the overall hydrological regime of rivers, as well as new approaches to improving the means of irrigation and land reclamation become an essential priority.

This research work was conducted in the framework of solving the above-mentioned issues and to assess the impact of the change of the hydrological regime of the Karasuv River on the irrigated areas of the region around.

Keywords: Monitoring wells, groundwater, filtration, infiltration, water consumption, river, channel, water level, irrigation, hydrological regime, depression, dynamics.

Introduction

Studying the relationship between surface and underground water plays a very important role in assessing hydrological processes [Xachikyan at al., 1979]. Up to the present, the relationship

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between groundwater and river water is still poorly understood. The interaction of groundwater and terrestrial water bodies in Central Asia is discussed by Shestakov [1992], Kats [1992], Kudelin [1960] and covered in the scientific works by Mirzaev [1974].

Particularly, the influence of river hydrological regimes on groundwater in irrigated areas still remains an urgent issue.

Generally, the relation of rivers and underground water is manifested in four different ways [Klimentov & Kononov, 1985].

1) permanent one-way hydrodynamic dependence (the river saturates groundwater throughout the year);

2) permanent two-way hydrodynamic dependence (the river saturates groundwater during floods, and during periods of low water, groundwater saturates the river with water);

3) temporary hydrodynamic dependence;

4) a state without hydrodynamic dependence.

If the groundwater level in the irrigated fields is higher than the water level in the river, the water flow is directed towards the river which acts as a ditch. This situation is likely to occur beneath a river or major channel. If the groundwater level lies above the ground surface around a river or channel, groundwater extrudes at the surface, which has a significant impact on the groundwater flow regime in that area [Pan et al., 2020].

Today, it is of particular importance to continuously monitor, study and analyze the level, consumption, mineralization, and regime changes of underground water in the irrigated areas of Uzbekistan. This work presents the case study of the area around the Karasuv River to exemplify the necessity of proper assessment and surveying of water regimes.

1. Materials and methods

Research on the assessment of the change in the hydrological regime of the Karasuv River (in the Middle Chirchik District, Tashkent Region; Figure 1) and the impact on land reclamation focused on the influence of irrigated lands on the left and right sides of the river.

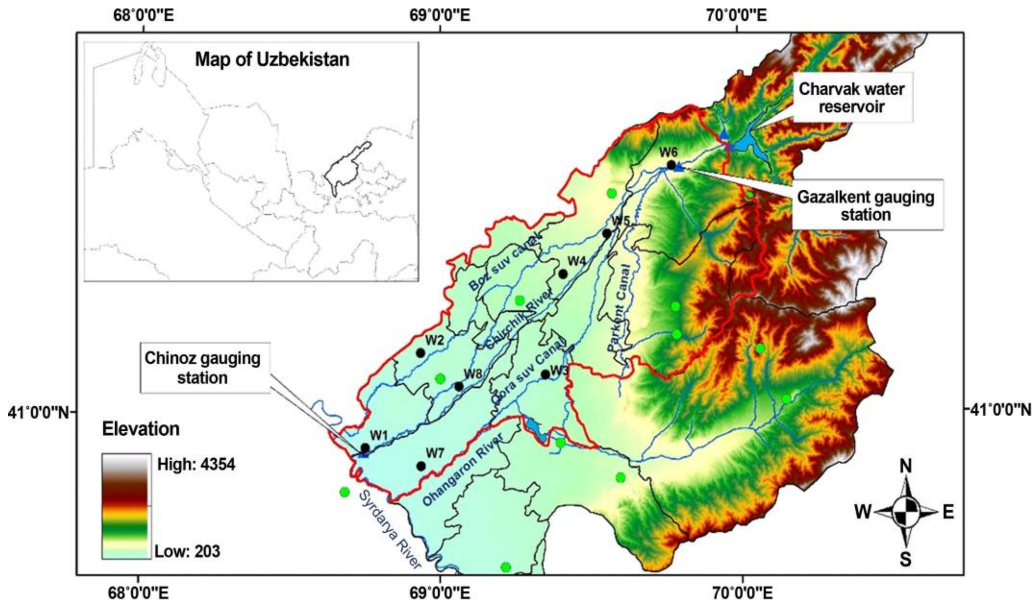

Figure 1. The province of Tashkent and the Karasuv River Basin.

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The total length of the Karasuv River is 89.3 km, the maximum water carrying capacity is 260 m^3/s, and it covers 152,200 hectares of the Upper Chirchik, Parkent, Ohangaron, Middle Chirchik, Lower Chirchik and Akkorgon Districts. The river is mainly fed by streams, of which the largest are those of Parkentsoy, Samsaraksoy, and Kyzilsoy.

The climate of the Middle Chirchik District is rapidly changing, and the growing season lasts for several months. Winters are short, there is a sharp fluctuation in air temperature, and a large amount of precipitation falls during autumn and winter. In some years, heavy precipitation can also occur during the spring months (Figure 2).

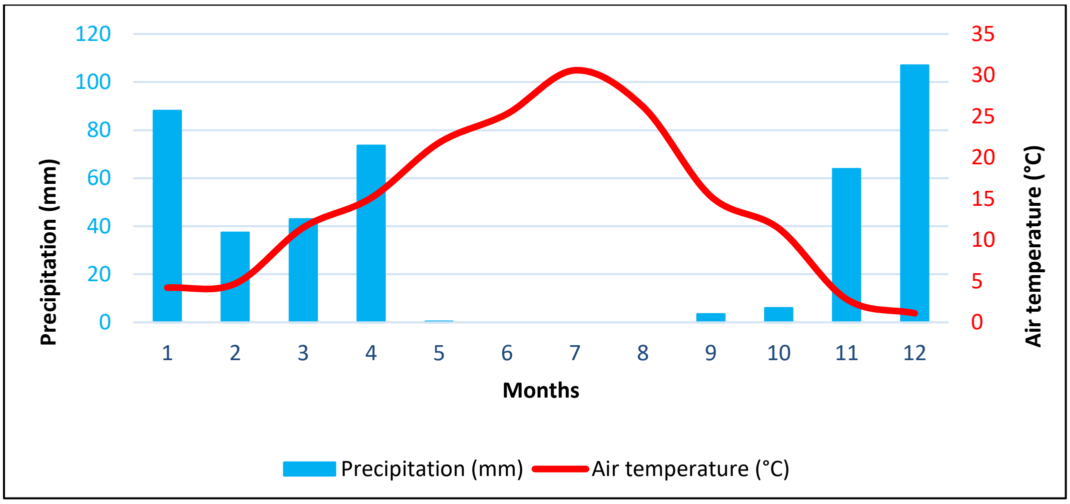

Figure 2. Changes in air temperature and precipitation observed in the study area in 2021.

The groundwater in the region is alimented by infiltration of atmospheric precipitation between winter and spring, coming from the aquifers within the upper Quaternary alluvial-proluvial deposits [Fatxulloyev et al., 2021].

Water in the Middle Chirchik District is fresh, with its mineralization reaching up to 0.4 g/l and having a total hardness of up to 6.05 mg-eq/l.

The content of clay particles in the soil layer with a depth of up to 1.0 m varies from 28.9 to 44.3%, whereas the one of sand varies from 45.6 to 71.7%; the volume mass of the soil amounts to 1.2-1.6 g/cm^3.

According to soil chemical analysis data, the amount of dry residue is 0.10-0.102%; the amount of chlorine ions is 0.02-0.04% or 0.056-0.11 mg-eq/l [Fatxulloyev et al., 2021]. The soil of the area is not saline.

The main source of groundwater formation is the inflow of irrigation water from irrigated areas by area-traction and linear inflow in from the Karasuv River as well as from smaller channels. Also, the contributions of irrigation systems are to be considered.

Studies on the influence of the river flow on the groundwater level were carried out with the help of modern and well-equipped monitoring wells. The collected data were analyzed using the software ArcMap (Figure 3).

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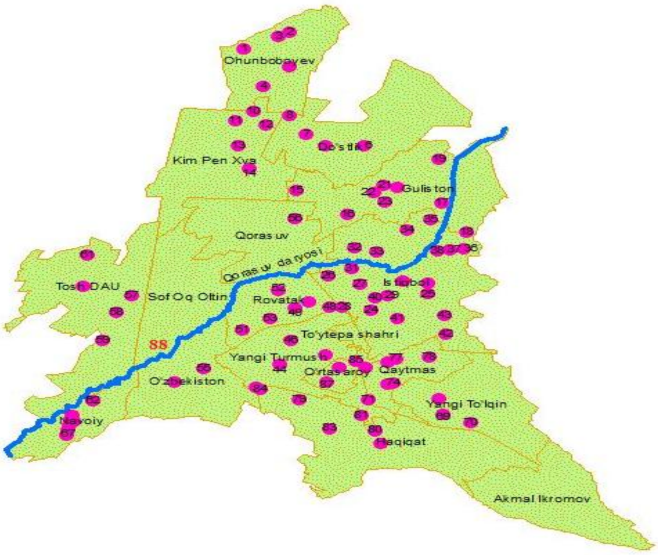

Figure 3. Groundwater monitoring wells in the research area around the Karasuv River.

Based on the data obtained from these monitoring wells in 2021, the changes in the groundwater level and its distribution over the region were analyzed by Inverse Distance Weighting (IDW), an interpolation method implemented in ArcMap.

Subsequently, and on the basis of the observed data on the change of the hydrological regime of the Karasuv River, graphs of the dependence of water consumption on groundwater were established for the year 2021.

Taking into account the complexity of the flow structure in the area of the Karasuv River, a geodetic survey was conducted in certain sections of the river to complement the regime observations; the survey was then simultaneously connected to the water levels. Within the framework of a sharp deformation of the stream, such a survey allows for assessing the layers and the diversity of rocks.

The influence of the Karasuv River can also extend to great depths, making it much more difficult to interpret hydrological regime observations (Figure 4).

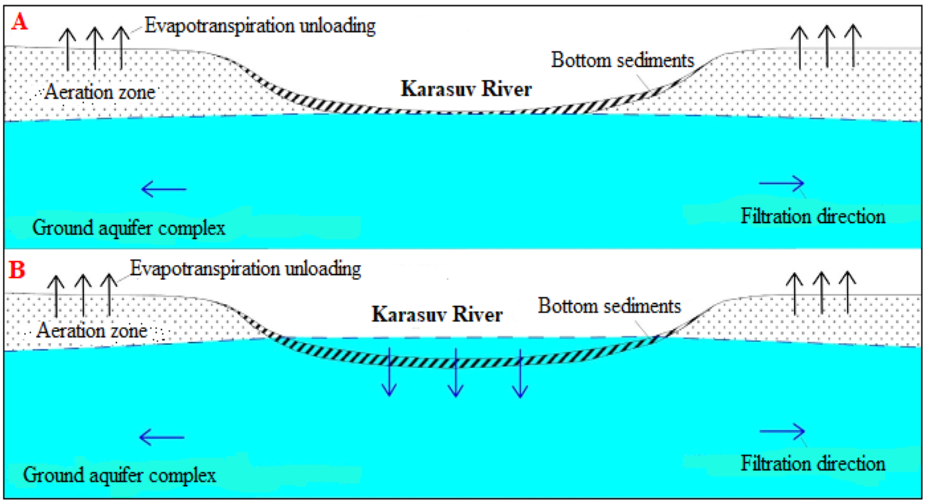

Figure 4. Scheme of the connection of the Karasuv River with the underground water complex (A – in the absence of river flow, B – in the presence of river flow).

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In this case, the hydrological regime can be divided into two zones, according to its characteristics and depending on the structure of the flow: the zone near the Karasuv River and the zone located far from it. In the zone closer to the river, the flow usually stabilizes quickly (and/or remains constant), but it shows a complex structure in the section. In the zone further away from the river, the non-stationary regime is more pronounced; however, according to the flow structure, it can usually be considered as depicted in Figure 4.

2. Results

As mathematical approach, we use a finite-difference equation. To determine the relative flow q_r of filtration from the river, a balance equation is established for the river and well (0 and 0′) interval and assuming that the field saturation in this stream is very small (i.e., with only little effect), the equation can be written as follows [Mironenko, 2009].

$$q_r = T_{01}I_{01} + T'_{01}I'_{01} + \mu\frac{\Delta F_0 + \Delta F'_0}{\Delta t} \quad (1)$$

where

$\Delta F_0 + \Delta F'_0$- is the shaded area between the river and the piezometer line)

I_{01} and I'_{01}- is the pressure gradient (the piezometer flow is assumed to be positive in the direction away from the river)

Δt – is the duration of the period of interest (in days)

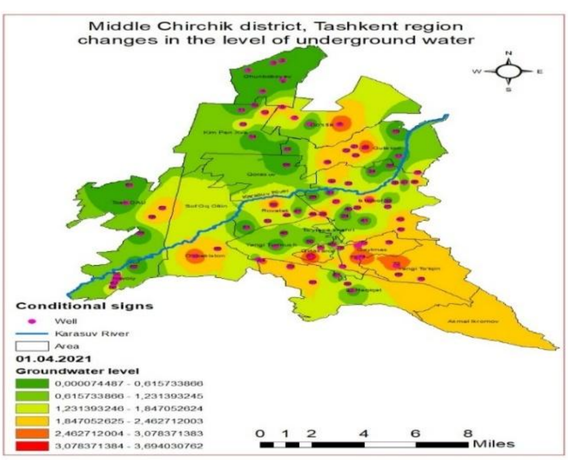
T_{01} ва T'_{01}- is the layer permeability in these sections (in each section, observational data in a non-stationary mode are used).

If we randomly place piezometers in the influence zone of the river, we have to solve the inverse problem in the models to explain the hydrological regime observations.

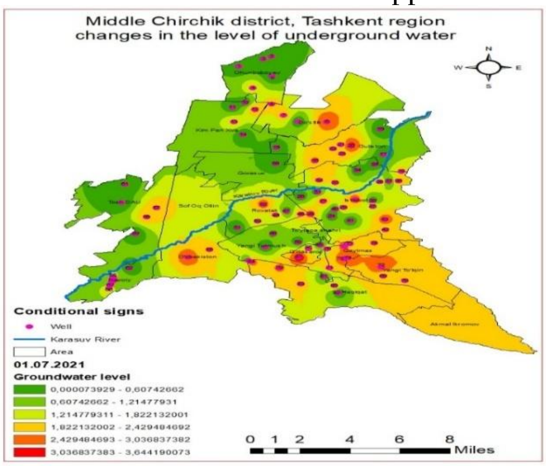
We assume, here, that particularly in the zone near the river the flow from layer to layer will not be significant.

Therefore, this zone should be considered worth conducting filtration assessments. As it is a complex system, we apprehended it in a first stage as a one-layer system for simplicity, and a hydrogeological model needed to be applied to track the movement of groundwater in the area more accurately.

On the basis of the data obtained from the monitoring wells, maps of the change of the groundwater level and its distribution patterns across the region were established in ArcMap (Figure 4). By comparing these maps, the variation of groundwater in different areas becomes apparent.



(A)



(B)

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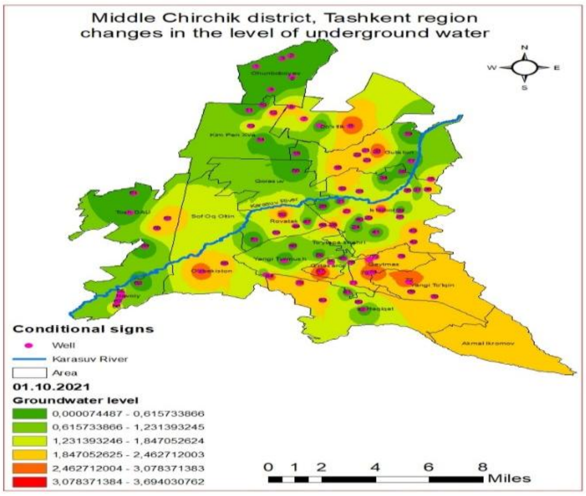

(C)

Figure 5. Variation of the groundwater level (in m) around the Karasuv River for the growing season: (A) Status as of April 1st 2021; (B) Status as of July 1st 2021; (C) Status as of October 1st 2021.

As shown in Figure 3a, the groundwater level in the area ranged from 0.61 m to 3.69 m in April 2021. By July in the same year, it ranged from 0.60 m to 3.64 m (Figure 3b), and by October it changed to a range from 0.61 m to 3.69 m (Figure 3c).

As a result, it can be seen that during the growing period, the groundwater level changes in almost equal intervals and mainly depends on irrigation water, the water content of the Karasuv River and atmospheric precipitation.

The influence of the hydrological regime of the river on the change of the groundwater level is illustrated in Figure 6.

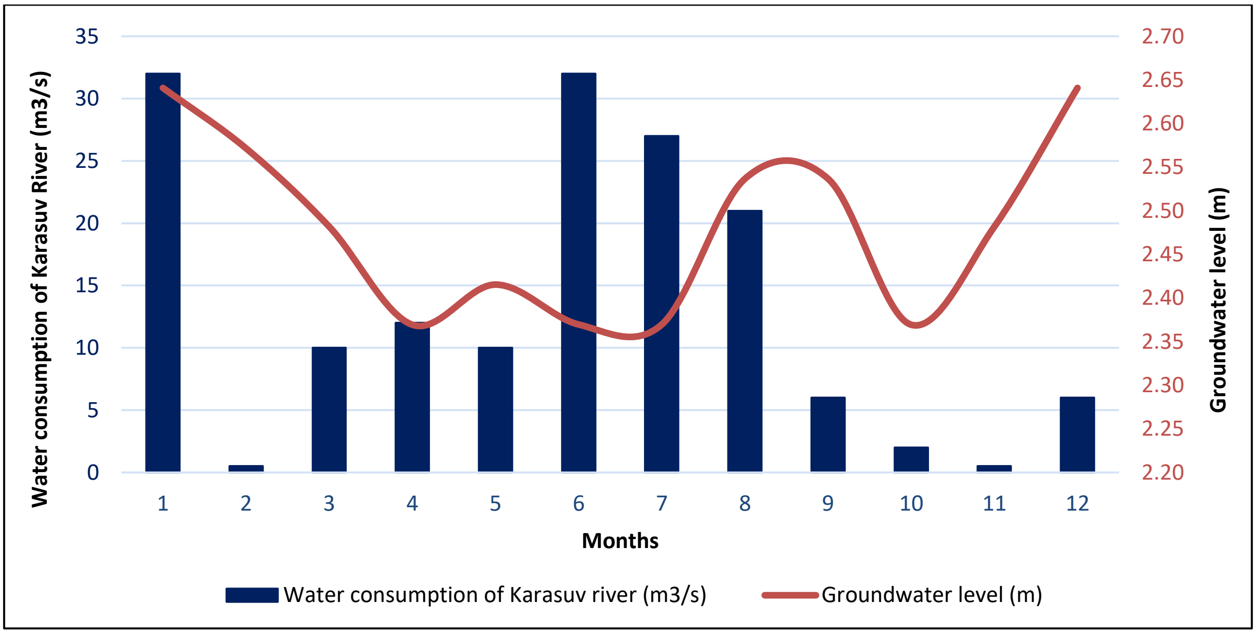

Figure 6. Karasuv River water consumption and groundwater level change in 2021.

It can be seen in this graph, that in 2021 the largest water flows observed in the Karasuv River are 32 m^3/s in January, 32 m^3/s in June, 27 m^3/s in July and 21 m^3/s in August. During the flooding periods of the river, the groundwater level in the area is 2.64 m in January, 2.37 m in June, 2.37 m in July and 2.54 m in August.

Based on the observed data, we calculate the filtration consumption according to equation 1 given above. Accounting for the selected condition, we write equation 1 in the following form:

$$q_r = T * I + \mu \frac{F}{t} \qquad [\frac{m^2}{day}] \qquad (2)$$

where:

q_r- is the filtration rate (in one running meter);

μ- is the water permeability of the soil; μ = 0.02

t- is the time (i.e., the follow-up duration; t = 10 days

I- slope of river water level with ground water level;

T- is the water permeability of the layer determined by:

$$T = K_f * m \qquad [\frac{m^2}{day}] \qquad (3)$$

in which

m- is the thickness of the rock layer $[m]$;

K_f^{ave}- is the filtration coefficient $[\frac{m}{day}]$

As the riverbed consists of several rock layers, we use the following equation given in the literature [Vsevolojskiy, 1991] to obtain a single filtration coefficient which is representative for a one-layer system:

$$K_f^{ave} = \frac{k_{f1}*h^1+k_{f2}*h^2+k_{f3}+h^3}{h^1+h^2+h^3} \qquad [\frac{m}{day}] \qquad (4)$$

where

$k_{f1}; k_{f2}; k_{f3}$- are the filtration coefficients of soil in the layer $[\frac{m}{day}]$

$h^1; h^2; h^3$- are the layer thicknesses $[m]$

We determine the slope between the surface water level and the river water level in the area using the following equation:

$$I = \frac{a}{l} = \frac{\nabla r.w.l - \nabla g.w.l}{l} \qquad (5)$$

in which

a- is the height between the ground water level and the river water level; [m?]

l- is the distance from the river to the piezometric well; [m?]

F- is the cross-sectional surface between the water level of the river and the monitoring well; it is the surface formed due to the change of the water level during the time of the observations. It is determined with the equation:

$$F = m * \frac{l}{2} \qquad [m^2] \qquad (6)$$

with

m- being the thickness of the rock layer; [m?]

l- being the distance from the river to the piezometric well; [m?]

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The above steps in determining the filtration consumption taking into account the dynamics of groundwater are calculated separately for each observation well (Figure 7).

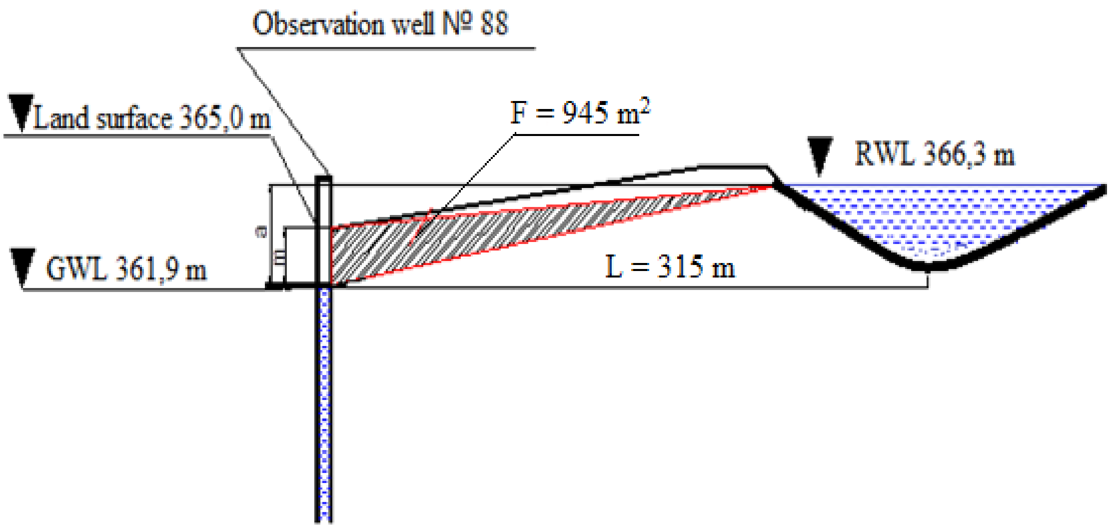

Figure 7. Ground water level height difference between the Karasuv River and the monitoring well № 88.

The monitoring well № 88 considered for the here presented regime analysis is equipped with a modern DIVER device providing high accuracy groundwater measurements.
The above steps in determining the filtration consumption taking into account the dynamics of groundwater are calculated separately for each monitoring well.
Results for well № 88 are presented in Table 1.

Table 1. Calculation of filtration consumption determined by the hydrogeological method in monitoring well № 88.

Monitoring well	*m* (m)	*a*	*L* (m)	*I*	Soil layers			C_f	*T* $(\frac{m^2}{day})$	*F* (m^2)	q_r (m^2/day)
					Name	Thickness (m)	Filtration coefficient				
№ 88	6	5,6	315	0,0177777	Loam	0-1,10	0,5	1,56	9,36	945	2,05
					Sandy	1,10-4,50	0,3				
					Gravel	4,50-6,00	5				

Interpreting the results, the change in the level of underground water in monitoring well № 88 as well as the average filtration coefficient of rocks located in several layers were determined according to the equations given above. The filtration consumption in monitoring well № 88 was equal to $q_r = 2,05$ m^2/day. As a result of the conducted research, we understand the significance of the influence of the Karasuv River on the change of the underground water level of the irrigated areas in the region.

3. Conclusion

Based on the observed data, the following results were obtained:

1. The hydrological and hydrogeological conditions of the region around the Karasuv River were analyzed.
2. Changes in groundwater levels in the area were studied based on the collected data.
3. The change of groundwater level in the Middle Chirchik District was analyzed by Inverse Distance Weighting (IDW); maps were established for the growing season in ArcMap.
4. In order to monitor the dependence of the Karasuv River and underground water, the change of the underground water level in the region during periods of high water of the river was studied and summarized in graph.
5. At present, there are 90 monitoring wells in the area – i.e., one well for every 404 hectares of the total irrigated area. With this coverage, the number of wells is not sufficient for obtaining more accurate results. Ideally, we estimated that – depending on small-scale conditions – the farmland should be covered by one or two monitoring wells per 100 hectares.
6. Based on the observed data, the filtration consumption was determined taking into account the dynamics of underground water.
7. In addition, due to the natural geographical conditions of the region, changes in river and underground water are influenced by atmospheric precipitation and air temperature.
8. Based on the calculation results, the filtration consumption of the Karasuv River was equal to $q_r = 2{,}05\ m^2$/day.
9. I order to increase the measurement accuracy of monitoring wells in the region and to monitor them from a distance, each well in the region should be equipped with modern measuring and monitoring devices.

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