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Forecasting Groundwater Level in an Arid Area According to Climatic Data

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Abstract

Development of a prediction method on groundwater level in a river basin depending on climatic data is the purpose of this study. The bases of the prediction method are water balance calculation, transient filtering an interpolation method on climatic data developed by the authors. Development of a method for predicting groundwater level depending on precipitation, abstraction and so on was carried out using the simulation model MIKE SHE. In order to demonstrate the results of this study, topographic maps and the geographic information system (GIS) were used. The calibrated predictive values of the groundwater level were compared with actual data measured in observation wells. As a result, the values of the root-mean-squared error in the calculated points are less than 0.66.

Keywords

Groundwater, Precipitation, Interpolation, Calibration, GIS

1. Introduction

As it is known, areas with an arid climate with groundwater runoff determine the main conditions of crop production [1]. In establishing mode of an irrigation plants, especially cotton, the state of groundwater determines the amount of water-supply via irrigation canals. Soil, affected by salt and in the presence of groundwater toxic salts can give condition of groundwater, which determines the main conditions of plant life, for example: a small distance from the ground surface leads to salinization and soil degradation, and causes a deep state of increased demand for irrigation water [2]. Prediction of ground water regime is a scientific challenge. The challenge is caused by the presence of a variety of factors that affect the groundwater regime; the most influential of them are precipitation and runoff [3]. At the same time, the groundwater regime has a significant impact to the area. In this regard, the object of research was established in the Chirchik river basin area in the Tashkent region of

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Uzbekistan (**Figure 1**). As a subject research, primarily influence of precipitation was determined in conjunction with other components of the water balance of a river basin in groundwater areas. The objectives of this paper are to predict the ground water regime in the region with less groundwater observation wells. Also the results of the prediction are applicable to protect soil from erosion and soil salinization.

2. Materials and Methods

The target area of research is the area of Chirchik river basin, where crop production is carried out exclusively by irrigation [4]. Therefore, prediction of the state of groundwater enhances the effectiveness of water management in the production of crops and especially of cotton. Cotton for the mentioned region is the main plant and occupies more than 60% of the irrigated area of the Syrdarya river basin [4]. As the research methods defined the water-balance method of the river basin, the method of unspecified filtering and interpolation method of climatic factors, developed by the authors.

The water balance equation in the Chirchik river basin:

$$Q_{\text{gw}} = W + Q_{\text{Char+Ugam}} + Q_{\text{Ohan}} + P + Q_{\text{return}} - Q_{\text{Chinoz}} - Q_{\text{use}} - Q_{\text{syr-darya}} - ET - E$$

W: water increment of groundwater;
$Q_{\text{Char+Ugam}}$: water inflow to the Chirchik river basin from the Ugam river and the Charvak reservoir;
Q_{ohan}: water inflow to the Chirchik river basin from the Akhangaran river;
P: precipitation;
Q_{chinaz}: water abstraction in the Chinaz station;
Q_{use}: water use in the Chirchik river basin;
ET: total amount of transpiration;
E: total amount of soil evaporation;

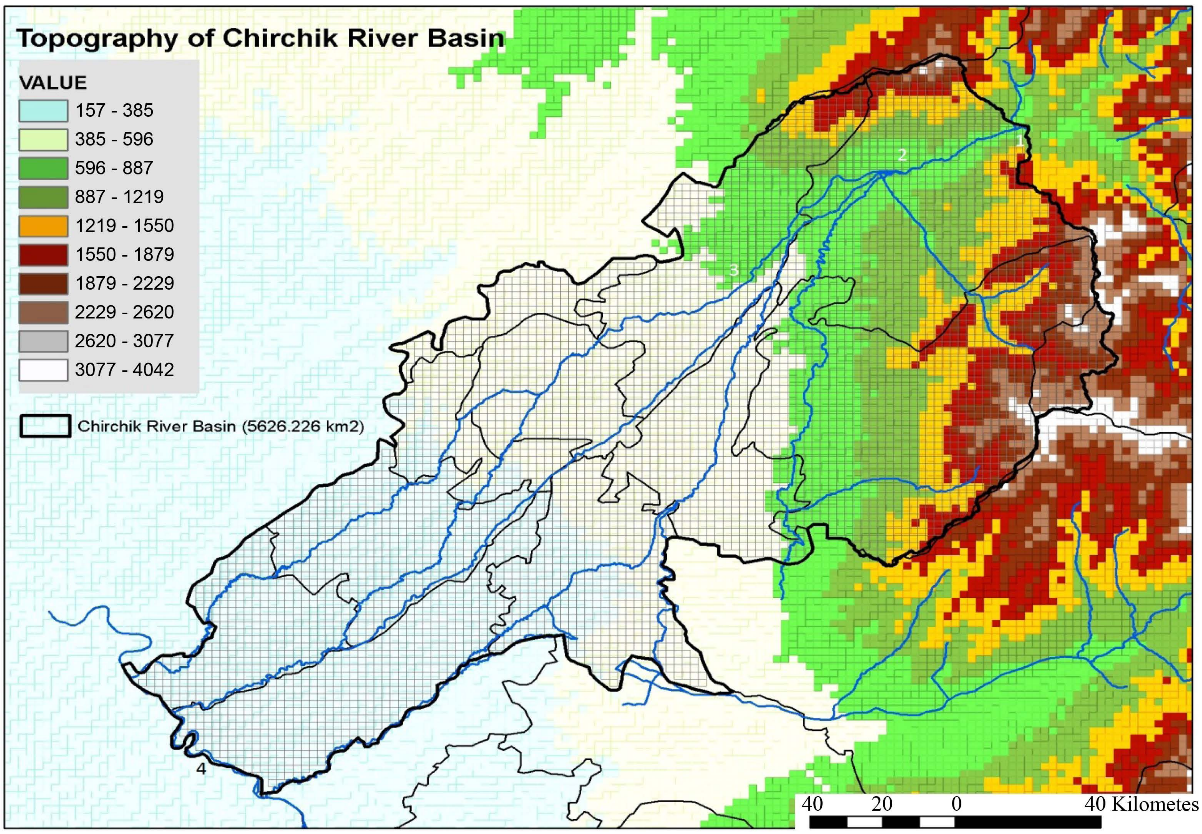


Figure 1. Topography of Chirchik river basin (1—Charvak reservoir; 2—Chirchik river; 3—Bozsuv channel; 4—Syr-Darya river).

Q_{gw}: ground water discharge and expenditure;
$Q_{syr\text{-}darya}$: effluent of groundwater to Syr-Darya river;
Q_{return}: return water from collectors.
The Richard's equation of unsteady filtration of water:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]}{\partial z} - S\left((h)\right)$$

where θ—volumetric soil moisture; *t*—time (day); *S*(*h*)—the rate of extraction of water by plant roots (evapotranspiration), m^3/m^3 day; *h*—pressure of soil moisture (cm of water); *z*—vertical coordinate pointing upwards; *K*—the coefficient of hydraulic conductivity (hydraulic conductivity), cm/day [5].

Interpolation method of the climatic data is shown in **Figure 2**.

The values of the coordinates of hydro-meteorological stations are based on the relative origin to the Tashkent weather station in meters (**Figure 3**).

3. Results and Discussions

Using the parameters of the water balance Chirchik river basin, topographic maps using the program MIKESHE simulation model to get a map of seasonal changes in groundwater levels throughout the basin of Chirchik river (**Figure 5**).

To establish reliability of the data on changes in groundwater levels were the measured values of the groundwater level according to data on observation wells in the basin with the results obtained by the simulation model (**Table 1**, **Figure 3**). Calibration and comparison of the results obtained by natural observation and calculation method of feature points in the basin are shown in **Figures 4-6**.

In **Figures 7-9** the dark lines show the land surface and the red and blue lines- groundwater levels, determined by different methods [7]. As the graphs show similar values to predicted (**Table 2**) and actual (**Table 3**) values of groundwater level fluctuations within acceptable RMSE for W06 point is 0.580954, RMSE for W03 point is 0.65943 and RMSE for W09 point is 0.645235.

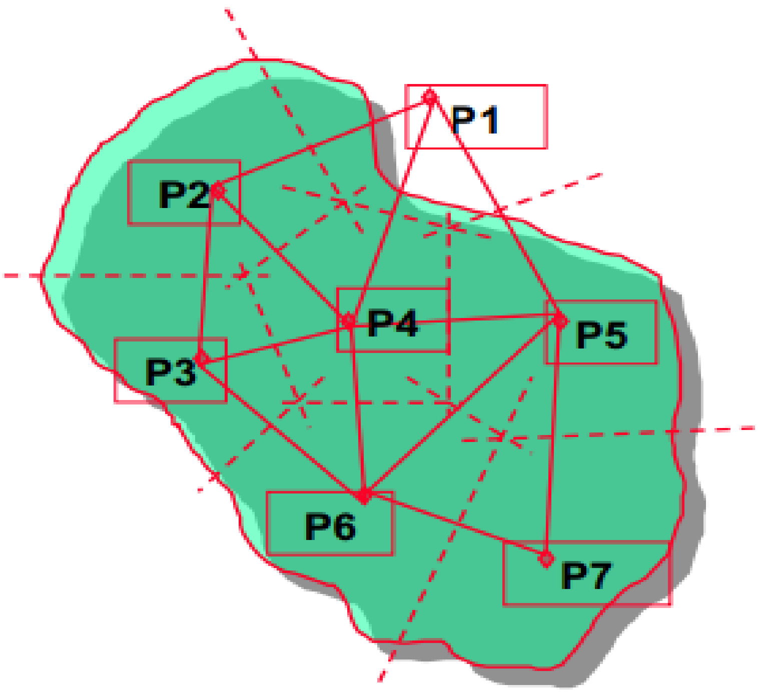


Figure 2. Thiessen polygon method in scheme of creating an interpolation method for establishing climatic factors of the Chirchik river basin [5].

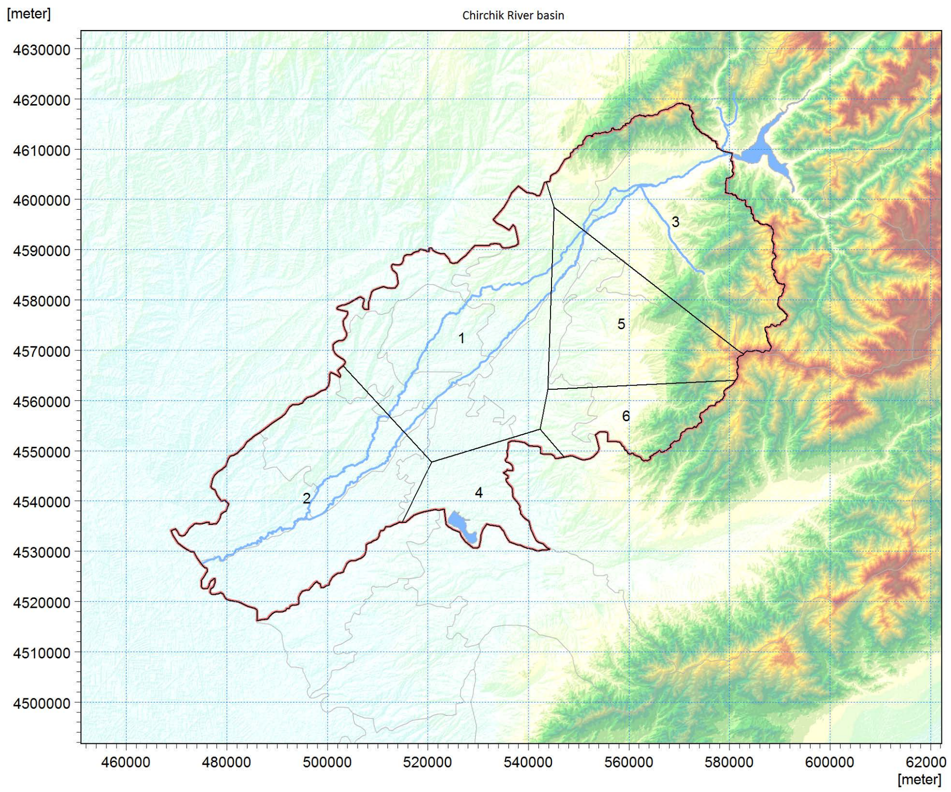


Figure 3. Layout stations in the Chirchik river basin by using Thiessen polygon method in ArcGIS.

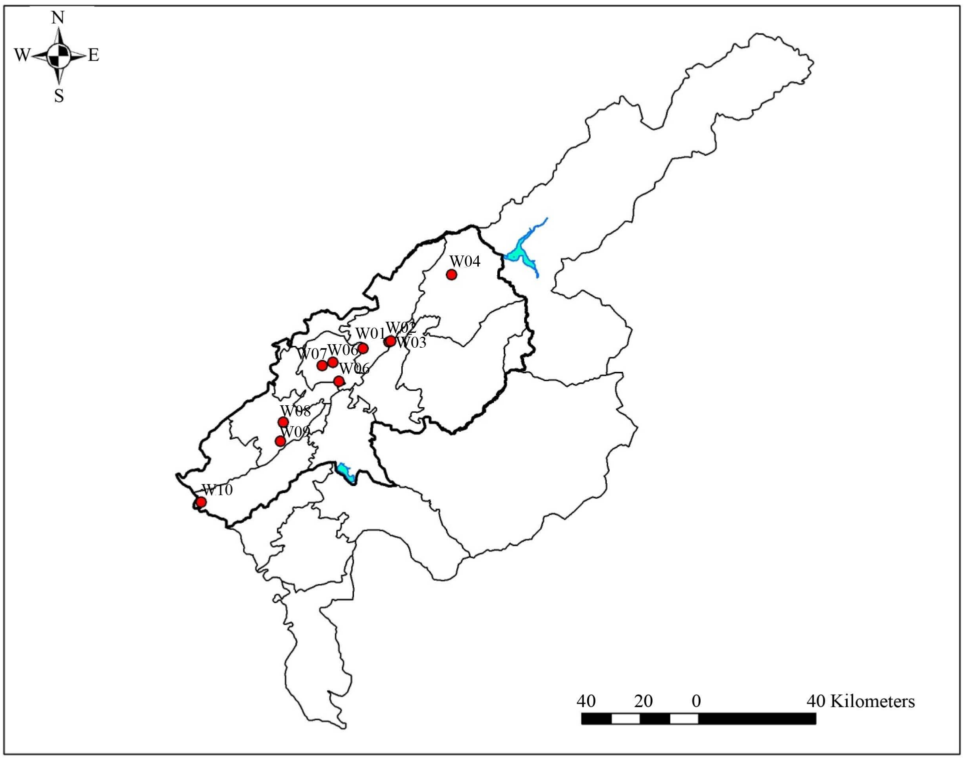


Figure 4. Location network of observation wells.

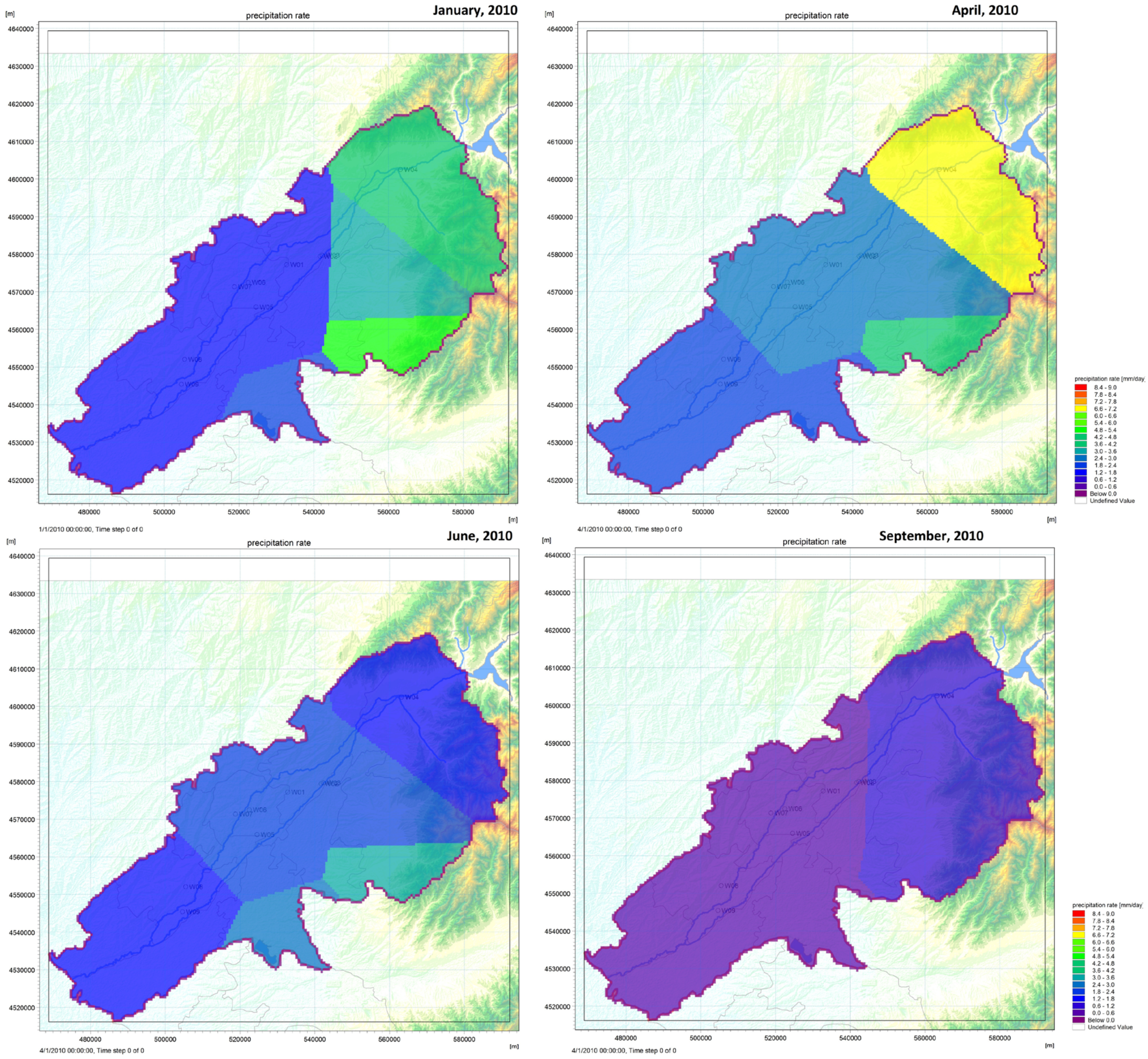


Figure 5. Seasonal changes and distributions of rainfall in the Chirchik river basin in 2010.

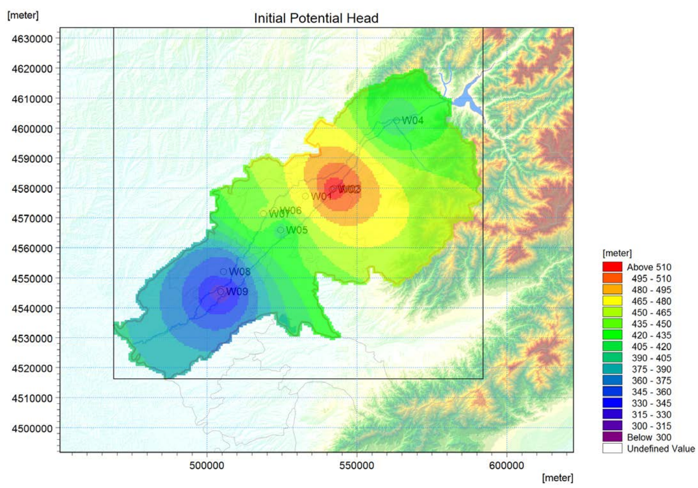
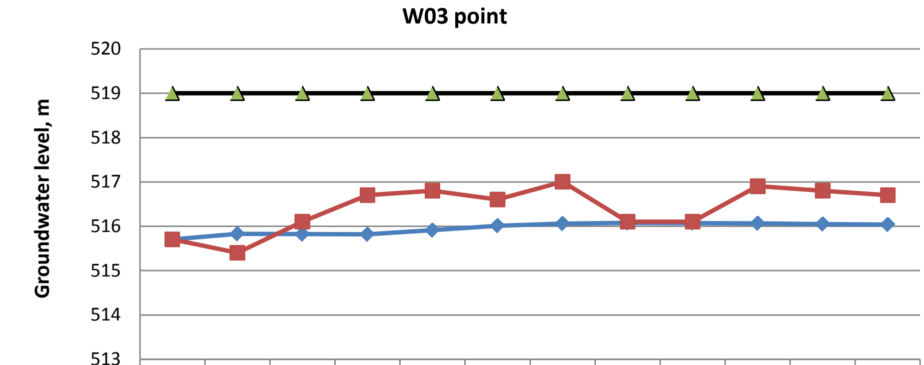
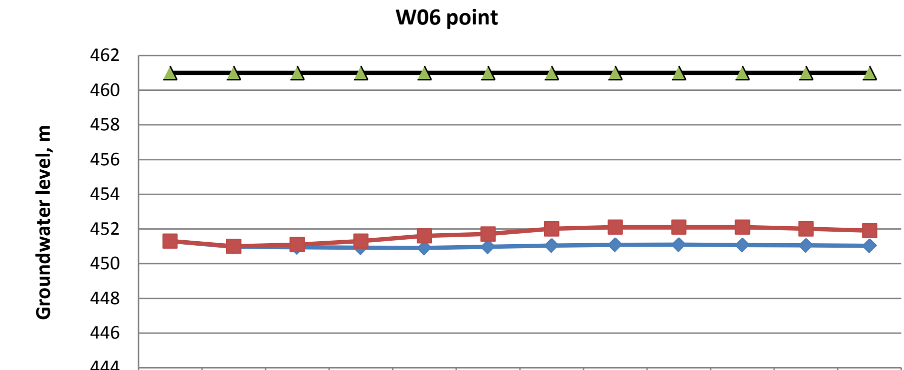


Figure 6. Interpolated ground water level based on observed water levels.



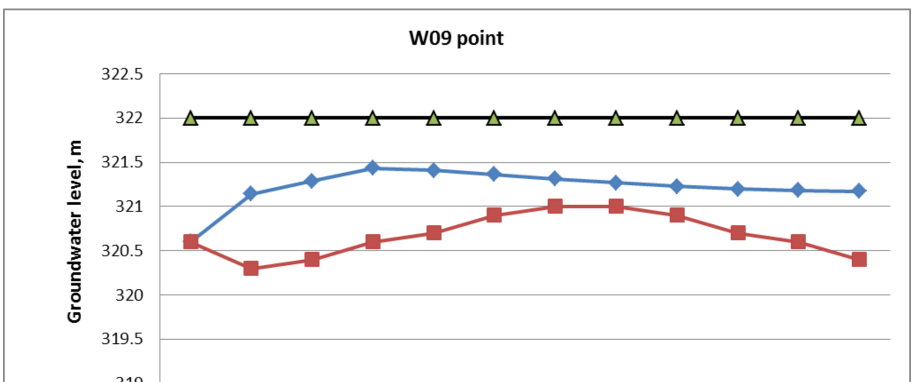
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Simulated	515.7	515.8	515.8	515.8	515.9	516.0	516.0	516.0	516.0	516.0	516.0	516.0
Observed	515.7	515.4	516.1	516.7	516.8	516.6	517	516.1	516.1	516.9	516.8	516.7
Altitude	519	519	519	519	519	519	519	519	519	519	519	519

Figure 7. Calibration results of calculation methods with the results of measurements on the well 03.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Simulated	451.3	450.9	450.9	450.9	450.9	450.9	451.0	451.0	451.0	451.0	451.0	451.0
Observed	451.3	451	451.1	451.3	451.6	451.7	452	452.1	452.1	452.1	452	451.9
Altitude	461	461	461	461	461	461	461	461	461	461	461	461

Figure 8. Calibration results of calculation methods with the results of measurements on the well 06.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Simulated	320.6	321.14	321.29	321.43	321.41	321.36	321.31	321.27	321.23	321.2	321.18	321.17
Observed	320.6	320.3	320.4	320.6	320.7	320.9	321	321	320.9	320.7	320.6	320.4
Altitude	322	322	322	322	322	322	322	322	322	322	322	322

Figure 9. Calibration results of calculation methods with the results of measurements on the well 09.

Table 1. Calculated data of the parameters of groundwater resources and reserves, Chirchik river basin [6].

Deposit and its resources on the revaluation, m^3/s	The calculation period	The arithmetic mean of the oscillation amplitude (m) by:		The coefficient of water loss breeds share of units	Deposit area, km^2	Resources of deposits of groundwater (m^3/s) for:			The value of the accumulation (+) consumption (−) of groundwater resources (3 = 31,546 × 106 × ΔQ); 106 m^3 per year
		Infiltration	Expenditure			Infiltration	Expenditure	Difference between infiltartion and expenditure	
1	2	3	4	5	6	7	8	9	10
Ahangaran, 22.773	Previous	3.32	−2.83	0.2	1023	21.53	−8.35	3.18	100.3
	Reported	2.38	−2.56			15.44	−16.6	−1.16	−36.6
Pskent, 2.0	Previous	1.34	−1.29	0.075	688	2.19	−2.11	0.08	2.52
	Reported	1.28	−1.34			2.09	−2.19	−0.10	−3.15
Chirchik, 38.2	Previous	2.23	2.48	0.25	1949	33.44	38.3	−3.86	−121.77
	Reported	2.48	2.29	0.25		38.3	35.37	+2.93	+92.43

Table 2. Simulated results of the level of groundwater by using MIKE SHE simulation model of river basin balance.

Wells	W03	W06	W09
Coordinates	69.50517 41.36778	69.26844 41.30378	69.05472 41.05992
Altitude	519	461	244
Simulated results			
JAN	515.7	451.3	320.6
FEB	515.82	450.96	321.14
MARCH	515.82	450.93	321.28
APRIL	515.81	450.91	321.43
MAY	515.91	450.89	321.4
JUNE	516	450.96	321.36
JULY	516	451.03	321.31
AUG	516	451.08	321.26
SEPT	516.1	451.08	321.22
OCT	516.06	451.06	321.19
NOV	516.05	451.04	321.18
DEC	516.03	451.02	321.17

4. Conclusion

As a result, the model developed made it possible to reliably estimate ground water level by using climatic data in the river basin. Taking into consideration that groundwater together with irrigation water is sources of water

Table 3. Initial data for the assessment of groundwater monitoring wells in 2010 (m) [6].

Wells	W03	W06	W09
Coordinates	69.50517 41.36778	69.26844 41.30378	69.05472 41.05992
Altitude	519	461	244
Observed data			
JAN	515.7	451.3	320.6
FEB	515.4	451	320.5
MARCH	516.1	451.1	320.6
APRIL	516.7	451.3	320.6
MAY	516.8	451.6	320.8
JUNE	516.9	451.7	320.8
JULY	517.0	452.0	320.8
AUG	517.1	452.1	320.7
SEPT	517.0	452.1	320.7
OCT	516.9	452.1	320.6
NOV	516.8	452.0	320.5
DEC	516.7	451.9	320.4

use plants, prediction method can effectively manage water resources for irrigation of crops, especially cotton. Forecast for the groundwater level contributes to the adoption of scientific and technical measures to protect the irrigated land from waterlogging and salinity.

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