Hydrological modeling of agricultural lands on the basis of GIS technologies (On the example of the Chimbay district of the Republic of Karakalpakstan)

S Abdurakhmonov[1*], *K* Bekanov[2], *N* Embergenov[3] and *D* Eshnazarov[4]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Kory Niyoziy str., 39, 100000, Tashkent, Uzbekistan
[2]National University of Uzbekistan named after Mirzo Ulug`bek, University str., 4, 100174, Tashkent, Uzbekistan
[3]Karakalpak State University, Ch.Abdirov str., 1, 230112, Nukus, Uzbekistan
[4]State Research Project Institute "Uzdaverloyiha", Choponota str., Chilanzar -C massiv, Tashkent.

Abstract. The article deals with the issue of hydromodule zoning of agricultural land. The negative impact of the environmental factors of the Aral Sea requires more work on the efficient use of agricultural land in the region. The focus of the research is on the efficient use of agricultural land based on the optimal placement of Agricultural crops. Optimizing the use of agricultural land by dividing areas into taxonomic units is considered to be one of the effective methods. In this study, the land of P. Seytov's massive, Chimboy district of the Republic of Karakalpakstan, within the Republic of Uzbekistan, was selected as a study area. Hydromodule zoning of the cultivated areas of the research object was done using GIS technologies. In this, data on soil types and mechanical composition of the object, groundwater, and irrigation methods were used. Overlay, raster calculation, and raster classification methods were used using ArcGIS 10.6 software. As a result, a hydromodule map of the research object was created. Based on the created hydromodule map, the scenario of placement of agricultural crops based on 2 different options was developed and water consumption was analyzed.
Keywords: GIS technologies, hydro module zoning, agricultural land, groundwater, ArcGIS, irrigation, soil.

1 Introduction

One of the most important factors in optimizing the use of agricultural land is hydromodular zoning.

The division of territories into taxonomic units for the purpose of efficient use of land and water resources and scientifically based stratification of irrigation regimes for sustainable, high yields of agricultural crops is called hydro modular zoning [1-3].

*Corresponding author: s.n.abduraxmonov@gmail.com

Operation of irrigation systems, development of water use plans, and calculation of water capacity of canals is carried out on the basis of hydromodule zoning.

It is known that at a time when water scarcity is becoming a problem of the century, the problem of water in our country is becoming more acute. Thus, the rapid transition of agriculture to a water-saving system and the development of information systems for the use of water in irrigation systems and their cartographic modeling is a matter of urgency and a very serious issue [4-6].

The principles of hydromodule zoning in Central Asia were first developed by V. M. Legostaev, V. E. Eremenko (1961). In the following years, V. R. Schroeder (1968), N. F. Bespalov (1971) and others updated the methods of hydromodule zoning and irrigation regimes of the cotton complex in accordance with the climatic conditions of Uzbekistan [7-13]. In 1980-1990, the hydromodule zoning and irrigation structure of crops was developed in the regions of the Republic of Uzbekistan and gave its results. V.Lev and M.Mirzaakhmedov from the Fergana region, A. E. Avliyokulov from Surkhandarya region (1994), A. Mirzaev from the Kashkadarya region (1979), V. Nerozin, M. Khamidov (1976) from Khorezm region, Republic of Karakalpakstan performed by B.S.Mambetnazarov (1991) and others [14-18].

In this study, the hydromodule zoning and irrigation regime of crops was developed on the basis of scientific research of V V Shreder, P M Legostaev, N F Bespalov, A E Avliyokulov B S Mambetnazarov and others [19-23].

2 Materials and methods

The irrigated lands of the farm located in the Chimbay district of the Republic of Karakalpakstan were selected as the object of research. The total area of the farm is 120 hectares, of which 100 hectares are irrigated. The farm specializes in agriculture and grows technical crops, cereals, legumes, oilseeds, vegetables, melons, potatoes, and fodder crops (fodder) [24-26]. The average score quality of irrigated lands is 43 points. The climate of the region is very variable, the groundwater is close to the surface, summers are hot and dry, and winters are short but cold [28].

It contains slightly saline soils, chloride-sulfate soils, and sulfate soils [7]. The geographical location map of the object under study is shown in Figure 1.

Climatic zones are divided into the following soil-reclamation lands:

- lands of automorphic series (groundwater depth more than 3 m);
- lands of variable row (groundwater depth is 2-3 m);
- hydromorphic soils (groundwater depth is 1-2).

In automorphic row lands where the groundwater level is above 3 m, the cotton irrigation regime depends on the moisture deficit, and the total irrigation rate of cotton in cotton fields planted in the north is likely to be much higher than in the south. Cotton varieties planted in automorphic soils use 20-40% of groundwater. The use of cotton root from groundwater depends on the mechanical components of these soils, and the conditions of the location of genetic layers. At the same time determining the irrigation regime of cotton should consider the genetic location of the mechanical composition of the soil. Cotton varieties planted on hydromorphic soils (groundwater depth 1-2 m) use 40-60% of the groundwater using roots. The use of cotton from groundwater depends on the mechanical composition, genetic location of the soils of the associations that use this water, the rate of irrigation, and the rate of general irrigation varies.

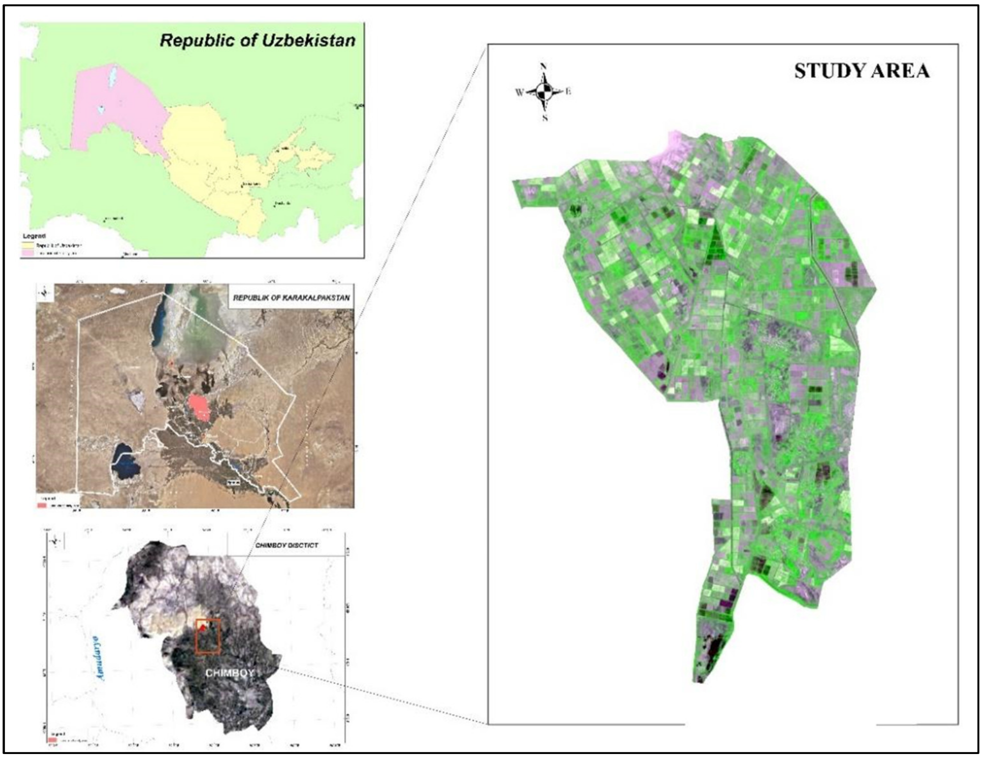

Fig. 1. Location map of the research object.

Through this zoning procedure, the climate of the Karakalpakstan Republic is divided into two northern and southern regions. Water-using associations require the division of soils into automorphic, variable, and hydromorphic soils. Automorphic soils can be divided into two districts according to their mechanical composition, or the mechanical composition can be divided into loamy and heavy sandy soils and sandy soils.

Groundwater status. Groundwater levels are regularly checked by monitoring wells installed by the land reclamation organization. Data on the average groundwater status of the object under study in 2020 were obtained and processed in the ArcGIS software. In this case, using the method of interpolation, the state of groundwater is divided into 6 groups as shown on the map in Figure 2.

In these areas, the hydrological modeling is divided into zones based on the location of groundwater, the mechanical components of the soil, the location of genetic layers, and the capillary capacity of groundwater to the cotton root. In this study, through GIS technologies, the Republic of Karakalpakstan Chimbay district P.Seytov a new technology of hydrological modeling zoning of lands of agricultural massive has been developed, which is shown in Figure 3.

The operating mode of the hydrological modeling zoning technology shown in Figure 3 includes 4 main steps. In the first stage, a thematic layer of soil types and mechanical composition of the object is created, in the second stage, a thematic layer of groundwater of the object is formed. Then, in the third stage, the hydrological modeling zoning layer is formed by combining thematic layers using special overlay methods of the GIS program, and in the fourth stage, the areas of the created hydrological modeling zoning layer are calculated.

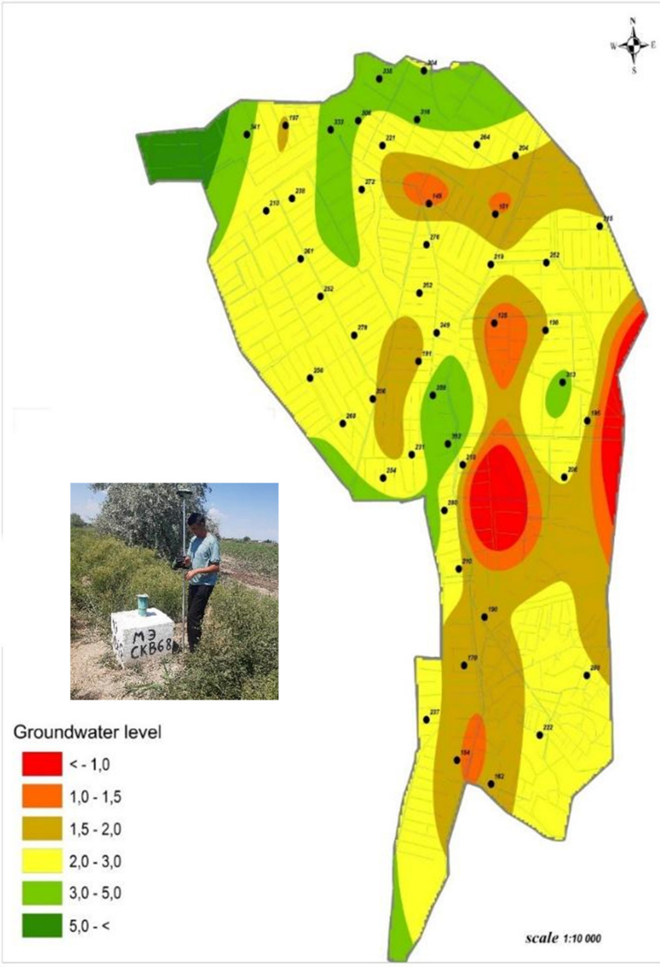

Fig. 2. Map of the level of groundwater in the massif named after P. Seytov of Chimbay district (2021).

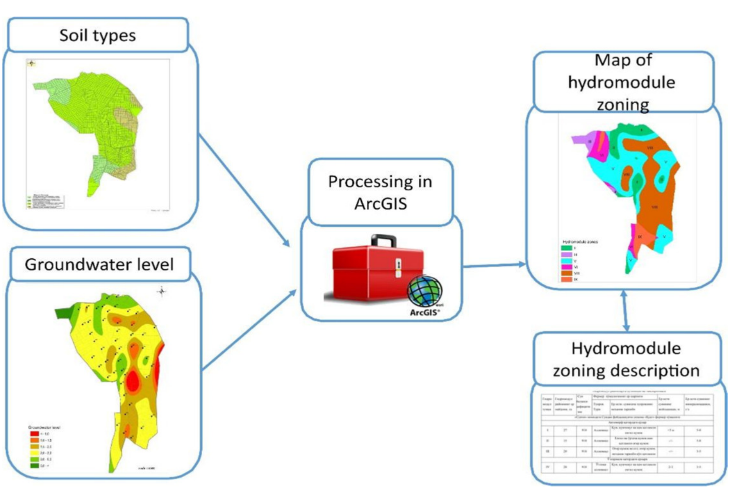

Fig. 3. The technology of hydrological zoning maps by GIS technologies.

3 Results and discussion

Hydromodule zoning in GIS. Data obtained using ArcGIS 10.6 were processed. In this case, the soil types and the groundwater layer were combined by the overlay method, and a hydromodular zoning map was created by interpolation using the IDW method in Figure 4.

Depending on the lithological composition of the soil-forming rock and the depth of groundwater deposition, the soils are grouped into 9 hydromodular regions, and during the study ArcGIS 10.6. was divided into hydromodule districts by a special reclass command in the program, as well as the location of hydromodule districts was determined per hectare in Table 1.

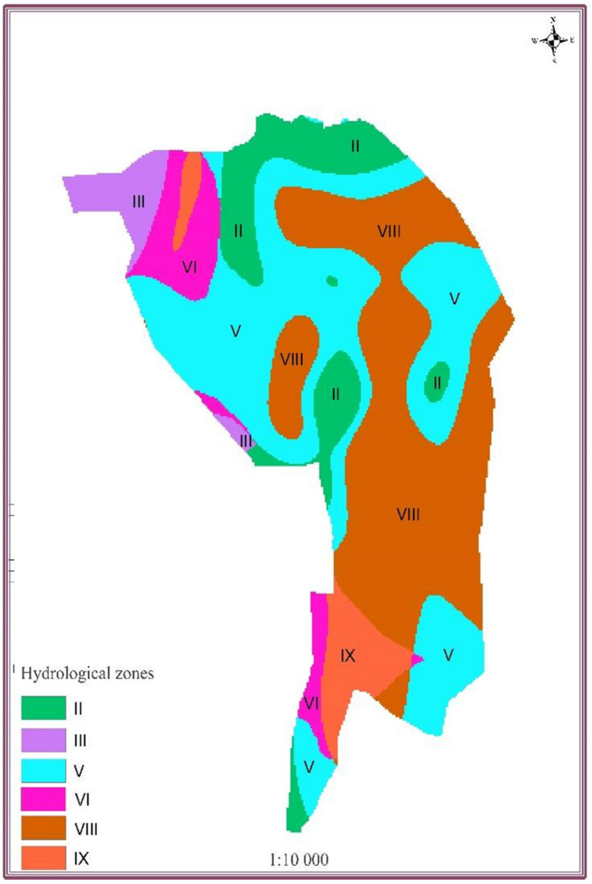

Fig. 4. Hydromodule zoning map of P.Seytov massif of Chimbay district.

Table 1. Hydromodular regions of P.Seytov massif of Chimbay district and their description.

Hydromodule districts	**Description of soils**	**The area of hydromodule districts, ha**
Automorphic soils (groundwater 3m and below)		
I	Light sand, sandy, and low-lying light sand	-
II	Light and medium sand low-layer heavy sand mechanical composition multi-layer	996.7
III	The mechanical composition of heavy sand and clay, heavy sand is multi-layered	340.2

Variable soils (groundwater 2-3 m below)		
IV	Sand, sandstone, and low-layer light sand	-
V	Light and medium sand low-layer heavy sand mechanical composition multi-layer	3128.2
VI	The mechanical composition of heavy sand and clay, heavy sand is multi-layered	588.9
Hydromorphic soils (groundwater 1-2 m)		
VII	Sand, sandstone, and low-layered, light sand	-
VIII	Light and medium sand, low-layer heavy sand mechanical composition multi-layered	1463.3
IX	Heavy sand and clay, heavy sand, multi-layered mechanical composition	498.7

Also, during the study, irrigation norms and regimes of agricultural crop types were determined for each hydromodule district, which is given in table 2.

Table 2. Irrigation norms and regimes of agricultural crop types.

Types of crops	Indicators	Hydromodule districts								
		I	II	III	IV	V	VI	VII	VIII	IX
Cotton	Norm, m3			6200	6200	4700	5600		3100	4000
	Number of irrigations			8	8	6	5		4	4
	Once irrigation rate, m3/ha			600-1000	600-1000	700-900	900-1300		700-800	900-1100
Alfalfa	Norm, m3/ha			8600	8600	6900	7700		5200	6000
	Number of irrigations			8	8	7	7		5	5
	Once irrigation rate, m3/ha			1000-1200	1000-1200	900-1100	800-1300		900-1200	1100-1300
Corn	Norm, m3			5700	5700	4600	5500		3400	4300
	Number of irrigations			6	6	5	5		4	4
	Once irrigation rate, m3/ha			800-1000	800-1000	800-1000	1100		800-900	1000-1200
Vegetables	Norm, m3			11200	11200	8500	10100		5600	7200
	Number of irrigations			20	20	17	18		11	8
	Once irrigation rate, m3/ha			500-700	500-700	400-600	500-700		500-600	800-1000
Melons	Norm, m3			4000	4000	3100	3600		2000	2600
	Number of irrigations			7	7	5	6		4	4
	Once irrigation rate, m3/ha			500-700	500-600	600-700	600		500	600-700
Gardens and vineyards	Norm, m3			4300	4300	3300	3900		2200	2800
	Number of irrigations			5	5	4	5		3	3
	Once irrigation rate, m3/ha			800-900	800-900	700-900	700-800		700-800	900-1000
Wheat	Norm, m3			3100	3100	2700	2900		2000	2200
	Number of irrigations			4	4	3	3		2	2
	Once irrigation rate, m3/ha			700-900	700-900	900	900-1000		1000	1100

According to the order of the President of the Republic of Uzbekistan dated May 6, 2020 No PP-4704 "On measures to expand potato production and further development of seed production in the country" developed in coordination with the relevant ministries and departments, using the information provided in the order of the norms of irrigation of agricultural crops of the Ministry of Water Resources of the Republic of Uzbekistan.

The data on hydromodular zoning and irrigation standards for agricultural crops presented in this paragraph is one of the key factors in optimizing the use of agricultural land.

Also, in this study, optimal placement of agricultural crops on the site was carried out. The main goal of optimization is to get a lot of profit by reducing water consumption in the cultivation of agricultural crops. In the implementation of this work, the hydromodule zoning map and the data of table 2 on the norms and modes of irrigation of agricultural crops were used. Five types of agricultural crops were placed in 2 different options in the hydromodule zones on the hydromodule zoning map (Figure 5).

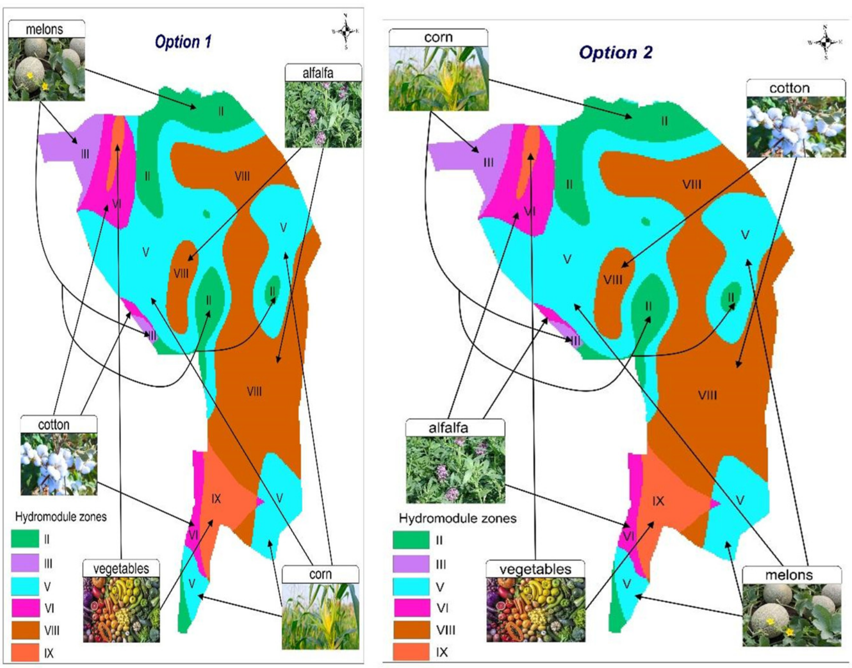

Fig. 5. Scenarios of crop placement on agricultural land (options 1 and 2).

In the proposed 1st option, cotton is placed in the VI hydromodule zone, alfalfa in the VIII hydromodule zone, corn in the V hydromodule zone, vegetables in the IX hydromodule zone, melons in the II and III hydromodule zones.

In the proposed 2nd option, cotton was placed in the VIII hydromodule zone, alfalfa in the VI hydromodule zone, corn in the II and III hydromodule zones, vegetables in the IX hydromodule zone, melons in the V hydromodule zone.

The hydromodule zones in table 3 above were obtained from the hydromodule zoning map and their areas from the calculation of the area of the zones in ArcGIS software, and the water consumption parameters were obtained from the irrigation norms and regimes of the types of agricultural crops in table 2. In this norm, the norm of water consumption per 1 hectare is specified for a particular type of crop. As a result, we can see that the total amount of water consumption for each hydromodule zones was formed based on the multiplication of the water consumption norms for the areas of the hydromodule zones.

Table 3. The amount of water consumed in one year in the cultivation of agricultural crops (option 1, option 2).

Option 1.					
No	**Crop type**	**hydromodule zones**	**Area / yes**	**Water consumption m 3 /ha**	**Total water consumption m 3**
1	cotton	VI	588.9	5600	3297840
2	alfalfa	VIII	1463.3	5200	7609160
3	corn	V	3128.2	4600	14389720
4	vegetables	IX	498.7	7200	3590640
5	melons	II and III	1336.9	4000	5347600
Total:					**34234960**
Option 2.					
No	**Crop type**	**hydromodule zones**	**Area / yes**	**Water consumption m 3 /ha**	**Total water consumption m 3**
1	cotton	VIII	1463.3	3100	4536230
2	alfalfa	VI	588.9	7700	4534530
3	corn	II and III	1336.9	5700	7620330
4	vegetables	IX	498.7	7200	3590640
5	melons	V	3128.2	3100	9697470
Total:					**29979200**

Option 1. According to the 1st option, the cotton crop was placed in the VI hydromodule zone of the object and the total area is 588.9 hectares. When planting cotton in the VI hydromodule zone, the annual irrigation norm is 5600 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 3297840 m3. Also, our second type of crop, alfalfa, was placed in the VIII hydromodule zone and the total area is 1463.3 hectares. When alfalfa is planted in the hydromodule zone VIII, the annual irrigation norm is 5200 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 7609160 m3. This type of corn crop is placed in hydromodule zone V and the total area is 3128.2 hectares. When corn is planted in the V hydromodule zone, the annual irrigation norm is 4600 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 14389720 m3. Our fourth type of vegetable crop is placed in IX hydromodule zone and the total area is 498.7 hectares. When planting vegetable crops in the IX hydromodule zone, the annual irrigation norm is 7200 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 3590640 m3. Our fifth type of crop, melon crop, is placed in II and III hydromodule zones and the total area is 1336.9 hectares. When planting a melon crop in II and III hydromodule zones, the annual irrigation norm is 4000 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 5347600 m3. According to the proposed 1st option, it was determined that the total annual water consumption for the cultivation of agricultural crops is 34234960 m3.

Option 2. According to the 2nd option, the cotton crop was placed in the VIII hydromodule zone of the object and the total area is 1463.3 hectares. When planting cotton in the VIII hydromodule zone, the annual irrigation norm is 3100 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 4536230 m3. Also, our second type of crop, alfalfa, was placed in the VI hydromodule zone and the total area is 588.9 hectares. When alfalfa is planted in the VI hydromodule zone, the annual irrigation norm is 7700 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 4534530 m3. This type of corn crop is placed in II and III hydromodule zones and the total area is 1336.9 hectares. When alfalfa is planted in hydromodule zones II and III, the annual irrigation norm is 5700 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 7620330 m3. Our fourth type of vegetable crop is placed in IX hydromodule zone and the total area is 498.7 hectares. When alfalfa is planted in the IX hydromodule zone, the annual irrigation norm is 7200 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 3590640 m3. Our fifth type of crop, the melon crop, is placed in V hydromodule zone and the total area is 3128.2 hectares. When planting a melon crop in V hydromodule zone, the annual irrigation norm is 3100 m3 per hectare, and when we multiply this by the area of the zone, the water consumption is 9697470 m3. According to the proposed 2nd option, it was determined that the total annual water consumption for the cultivation of agricultural crops is 29979200 m3. So, comparing the water consumption of option 1 and option 2, as a result, it was determined that 4255760 m3 of water consumption would be saved if we chose option 2.

4 Conclusions

In order to effectively use the irrigated lands of the P.Seytov massif of Chimbay district of the Republic of Karakalpakstan, a hydromodule zoning map was created in this study. ArcGIS 10.6 was used to create the hydromodule zoning map. As a factor of hydromodular zoning, 2 thematic layers were formed. Topic layer 1 used groundwater data from this area and data on soil networks and the mechanical components of the site were used to form topical layer 2. The information on hydromodular zoning and irrigation norms of agricultural crops presented in the created map is one of the main factors in optimizing the use of agricultural lands. On the basis of the hydromodule zoning map, the issues of efficient use of water resources through optimal placement of agricultural crops were studied.

The process of hydromodular zoning of lands irrigated by the proposed GIS technologies is effective in the optimal use of agricultural land. At the same time, it allows for significant save the number of water resources used for the cultivation of crops on agricultural lands.

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