Optimization of Agricultural Land Use in Chimbay District of the Republic of Karakalpakstan Using GIS Technologies

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Abstract
The article deals with the issue of optimizing the use 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. The main factor in optimizing the use of agricultural land is to reduce the resources spent on agricultural production and increase the productivity of agricultural products. Land use optimization work was carried out using GIS technologies and the results were mapped. Agricultural lands in the Chimbay district with complex ecological conditions were selected as a key object, and it was proposed to place crops based on 3 different solutions. Scenario maps for the placement of Agricultural crops were created using the ArcGIS program and its ArcPy application. Irrigated land for the key object was calculated as the amount and productivity of resources used for growing crops. Through the proposed optimal solution, the resources spent on crop production were reduced by 11% and yields were increased by 34%. This optimization model will greatly help to improve the efficiency of agricultural land use with the correct placement of agricultural networks, taking into account environmental and economic factors.

1. Introduction

Requires scientific approaches to the use of Agricultural lands of the Republic of Karakalpakstan. Currently, as a result of the negative impact of the ecology of the Aral Sea, the Lower Amudarya region requires a large labour force to obtain high yields. Various chemical salt dust rising from the deserted seabed have changed the nature of the region (Bekanov et al., 2020 and Safarov et al., 2020). Of course, the population and agricultural lands of the Aral Sea region are suffering from this catastrophe. As a result, the efficiency of agricultural land use is declining every year (Turdimambetov et al., 2021 Reimov and Fayzieva, 2014 and Galán-Martín et al., 2015). In this context, the most urgent task is to alleviate the ecological situation in the region, to ensure the efficient and optimal use of available land resources, to optimize land use. In this context, the most urgent task is to alleviate the ecological situation in the region, to ensure the efficient and optimal use of available land resources, to optimize land use. Optimization is the process of finding the most optimal way to use land resources, taking into account the available resources (Olshevsky and Yatsukhno, 2010). Optimizing the use of land in the region is understood as the selection of the most optimal solutions to achieve environmental, economic and social efficiency, taking into account the available natural, land, water and labour resources (Valery, 2015). The solution of such problems will lead to the improvement of the condition of agricultural lands, increasing the profitability of agricultural production, improving the living standards of the population as a result of optimizing land use in complex environmental conditions. Carrying out optimizations is an economically expensive process. With this in mind, the most effective solution to facilitate the use of agriculture in the complex environmental conditions of the Republic of Karakalpakstan is the introduction of a linear programming simplex method integrated into a GIS. Many optimization models in the world can be used to solve a variety of problems (Papalambros and Wilde, 2000 and Jain, P. and Ramsankaran, R., 2019). Such models have been developed since the 1970s (Agrawal and Heady, 1972 and Alexander Herzig, 2008). Linear and closed-form models tend to find a solution to a problem that has variables of certain functions.

In the 1980s, the development of algorithms to solve major problems of linear programming for optimization beyond the simplification method led to great success (Chuvieco, E., 1993, and Djanibekov et al., 2013). Optimization models are usually focused on the rational use of regional resources to grow competitive agricultural products. Undoubtedly, the fulfilment of the requirements of the restrictions on the numbers associated with these costs will make it possible to solve the issues of maximizing the set of key parameters of the region. To minimize costs or maximize labour productivity in the improvement of interconnected environmental tasks, methods of optimization of targets in the field of agriculture, industrial production is regularly used. Such models have been targeted at protecting the environment restoring balance, and efficient use of agricultural land (Aravossis et al., 2006).

2. Study Area

For scientific research, were selected irrigated lands of farms in the Chimbay district of the Republic of Karakalpakstan. The total area of the farm is 120 hectares, of which 100 hectares are irrigated lands. In this area Cotton, cereals, legumes, oilseeds, vegetables, gourds, potatoes, fodder crops are grown. The average score of irrigated lands is 50. The climate of the region is continental, the groundwater is close to the surface, summers are hot ($+37^0$) and dry, winters are short but cold (-20^0) (Bekanov et al., 2020 and Safarov et al., 2020). The location of the research object is shown in Figure 1.

3. Methodology

The region optimization methodology has been developed, which is shown in Figure 2 below. According to this method, the work on optimizing land use was carried out using the program ArcGIS. The simplex method of linear programming does not fully perform spatial analysis, and when it is integrated into GIS software, it can solve several spatial analysis problems. The geodata created as part of the study will be the main tool in optimizing land use. In the workflow, field data and statistical data on the object were collected, and on this basis, a database was created. The geospatial database provided the necessary spatial data for the efficient use of agricultural land. In the next process, it is planned to place agricultural crops on the agricultural land of the study area. There are a total of 8 types of agricultural crops, including cotton, cereals, legumes, oilseeds, vegetables, melons, potatoes and fodder crops were placed (Table 1).

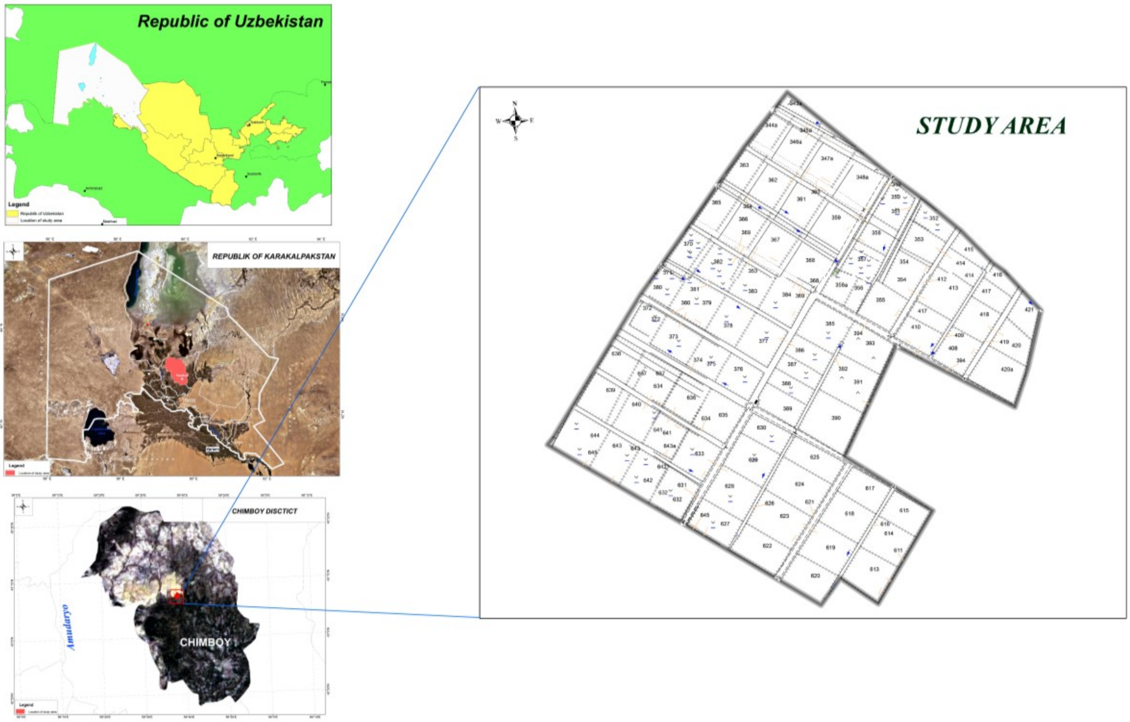

Figure 1: The location of the study area

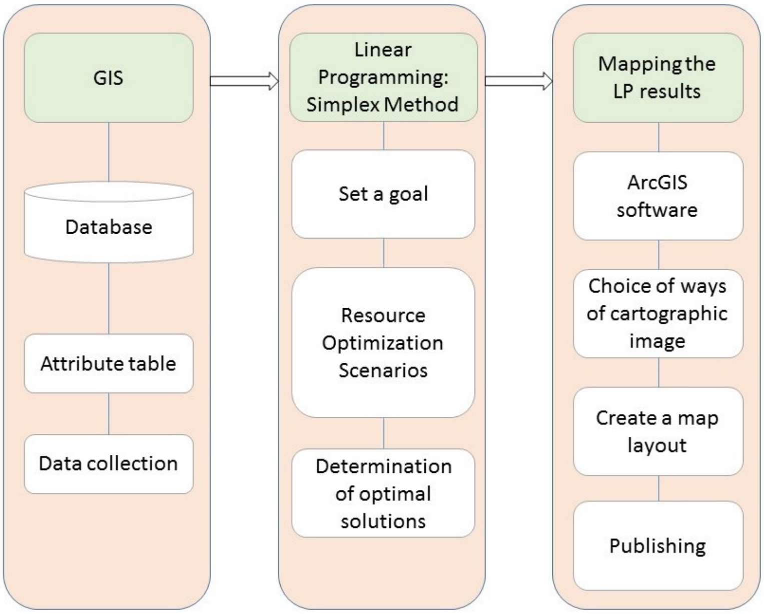

Figure 2: Technology for optimizing the use of farm land

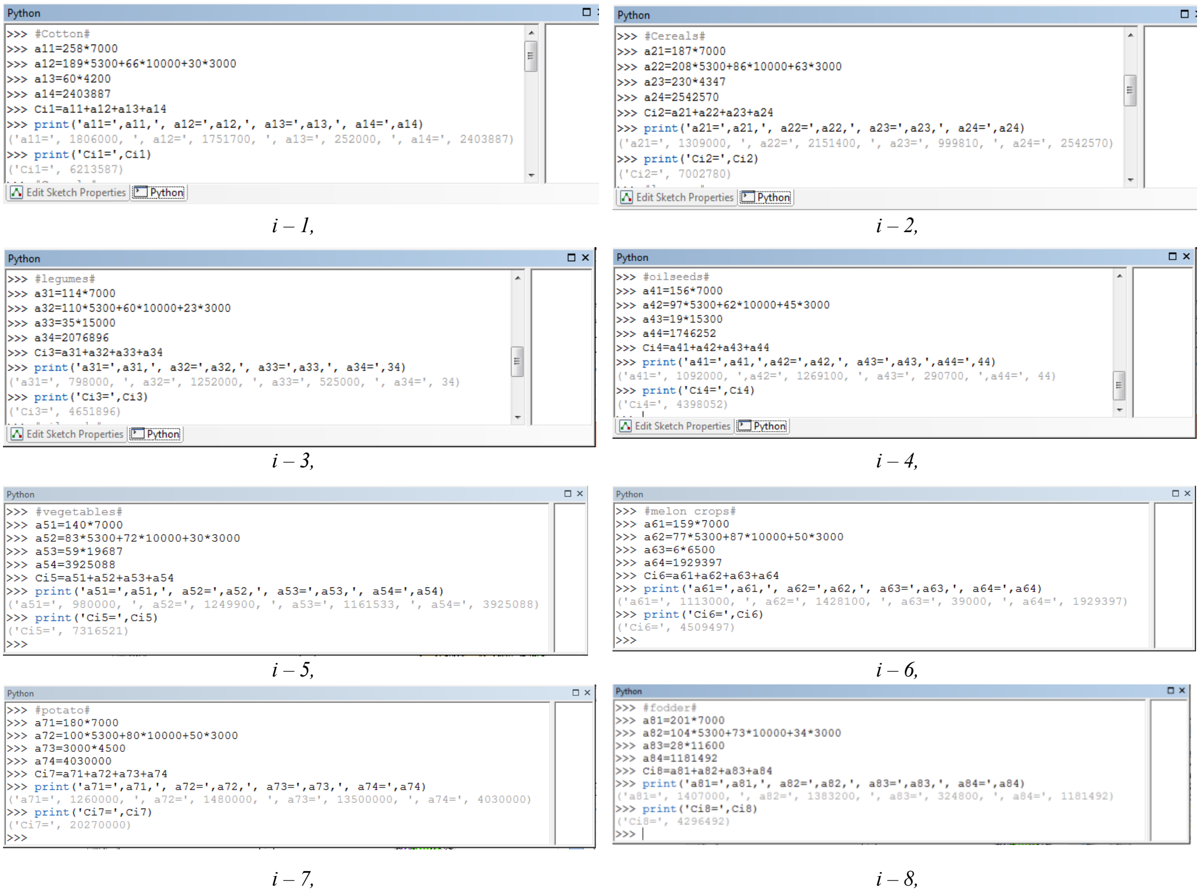

Figure 3: Algorithms for calculating the amount of resources spent on agricultural crops performed in the application ArcPy

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Table 1: Normative soil fertility of agricultural crops relative to one quality score

№	Crop type	Normative productivity of soil relative to one bonitet score, ton / ha
1	Cotton crops	0,04
2	Cereals	0,06
3	Legumes grains	0,07
4	Oilseed crops	0,07
5	Vegetables	0,3
6	Melons	0,27
7	Potatoes	0,2
8	Fodder crops	0,3

Table 2: Norms of resource consumption per 1 ha in the cultivation of crops

Crop type	Expended resources on cultivation the product					
	Fuel lubricants materials (liters)	Mineral fertilizer			Seeds (kg)	Salary contributions thousand Uzbek sums
		Nitrogen (kg)	Phosphorus (kg)	Potassium (kg)		
Cotton crops	258	189	66	30	60	2 403,8
Cereals	187	208	86	63	230	2 542,5
Legumes grains	114	110	60	23	35	2 076,8
Oilseed crops	156	97	62	45	19	1 746,2
Vegetables	140	83	72	30	59	3 925,1
Melons	159	77	87	50	5,7	1 929,3
Potatoes	180	100	80	50	3000	4 030,0
Fodder crops	201	104	73	34	27,5	1 181,4

The data in Table 1 are based on the Regulation on the normative value of agricultural lands of the Republic of Uzbekistan. Now we need to determine the types of resources that are spent on growing crops. They are below coming:

- R_1 - fuel and energy materials;
- R_2 - mineral fertilizers;
- R_3 - seed;
- R_4 - salary.

In total, 4 types of consumable resources were received and they are marked with letters. Then the indicators of resources spent on 1 hectare of land were determined (Table 2). The data in Table 2 are based on the norms of labor and material resources required for the cultivation of agricultural products, developed in 2016 by scientists of the Agricultural Research Institute of Economics of the Republic of Uzbekistan (Kholmurzaev et al., 2016).

Hence, the following formula can be used to determine the number of resources spent on growing crops:

$$C_i = \sum_{R_j=1}^{4} a_{ij}$$

Equation 1

There i is crop type, R_j – R is resource type, j is resource consumption costs, a_{ij} – i – is crop, j – is resource consumption costs, C_i is total cost of spent on crops. As well, it will also be necessary to develop planting plans for the farm's common irrigated land. The study developed scenarios and maps for the placement of agricultural crops on 100 hectares of irrigated land in 3 different variants (Figure 4). According to the data in Table 3, the first plan - for option A, cotton crops to 40 ha, cereals to 30 ha, legumes to 2 ha, oilseeds to 2 ha, vegetables to 6 ha, melons to 5 ha, potatoes to 5 ha, fodder crops 10 ha are placed. The second plan - for option B, cotton crops to 30 ha, cereals to 40 ha, legumes to 5 ha, oilseeds to 5 ha, vegetables to 10 ha, melons to 2 ha, potatoes to 2 ha, fodder crops 6 ha are placed.

The third plan - for option C, cotton crops to 42 ha, cereals to 28 ha, legumes to 3 ha, oilseeds to 4 ha, vegetables to 7 ha, melons to 10 ha, potatoes to 5 ha, fodder crops 5 ha are placed (Table 3). According to the data obtained, the products grown from agricultural crops were calculated. The cost of agricultural products is shown in Table 4. If we look at the data in the table of the values of agricultural products grown in the first place, we have selected 8 types of agricultural crops.

Table 3: Scenarios for the placement of agricultural crop types

Crop type indexation	Crop types	Proposed crop placement options (per ha)		
		a)	b)	c)
i – 1	Cotton crops	40	30	42
i – 2	Cereals	30	40	28
i – 3	Legume grains	2	5	3
i – 4	Oilseed crops	2	5	4
i – 5	Vegetables	6	10	7
i – 6	Melons	5	2	10
i – 7	Potatoes	5	2	5
i – 8	Fodder crops	10	6	5

Table 4: The cost of agricultural products

Crop type *(ET)*	Proposed crop placement options	Area (per hectare)	Average soil ballbonite *(BB)*	Productivity ton / hector	Gross product volume is in tons *(T)*	The price of 1 ton of products on the exchange (thousand sums)	The cost of agricultural products (million sums)
Cotton crops	a)	*40*	*50*	*2,0*	*80*	*3740*	*299,2*
	b)	*30*			*60,0*		*224,4*
	c)	*42*			*84,0*		*314,2*
Cereals	a)	*30*		*3,18*	*90*	*2000*	*180,0*
	b)	*40*			*120,0*		*240,0*
	c)	*28*			*84,0*		*168,0*
Legumes grains	a)	*2*		*3,5*	*7*	*10000*	*70,0*
	b)	*5*			*17,5*		*175,0*
	c)	*3*			*10,5*		*105,0*
Oilseed crops	a)	*2*		*3,5*	*7*	*3500*	*24,5*
	b)	*5*			*17,5*		*61,250*
	c)	*4*			*14,0*		*49,0*
Vegetables	a)	*6*		*15,0*	*90*	*3000*	*270, 0*
	b)	*10*			*150,0*		*450, 0*
	c)	*7*			*105,0*		*315,0*
Melons	a)	*5*		*13,5*	*67,5*	*1000*	*67,500*
	b)	*2*			*27,0*		*27,0*
	c)	*10*			*135,0*		*135,0*
Potatoes	a)	*5*		*10,0*	*50*	*2500*	*125,0*
	b)	*2*			*20,0*		*50,0*
	c)	*5*			*50,0*		*125,0*
Fodder crops	a)	*10*		*15,0*	*150*	*800*	*120,0*
	b)	*6*			*90,0*		*72,0*
	c)	*5*			*75,0*		*60,0*

-a) option *-b) option* *-c) option*

These crop species were distributed based on 3 different scenarios when placed on an area of 100 hectares. Each crop type is given in hectares in options a), b), c). This does not mean that the selected 3 different scenarios should be only 3, but you can choose 4, 5 and more scenarios in research. The reason of chosen 3 different scenarios in this research was to reduce the workload. The average score of the selected object was 50 points. Based on this score, the yield of agricultural crops was determined. This is calculated by the following formula:

T=BB*ET

***T**-ton, **BB**-soil score quality, **ET**-crop type*

Based on the data obtained, the total amount of resources spent on each proposed plan was calculated. Restrictions are then placed on the placement of crop varieties. It is recommended to use the following formula 2:

$$\sum_{i=1}^{8} x_i \le G_a$$

Equation 2

Then the amount of resources allocated to common crops can be found by the following formula 3;

$$\sum_{i=1}^{8} a_{ij}x_i \le R_j \quad (j=\overline{1,4})$$

Equation 3

There:

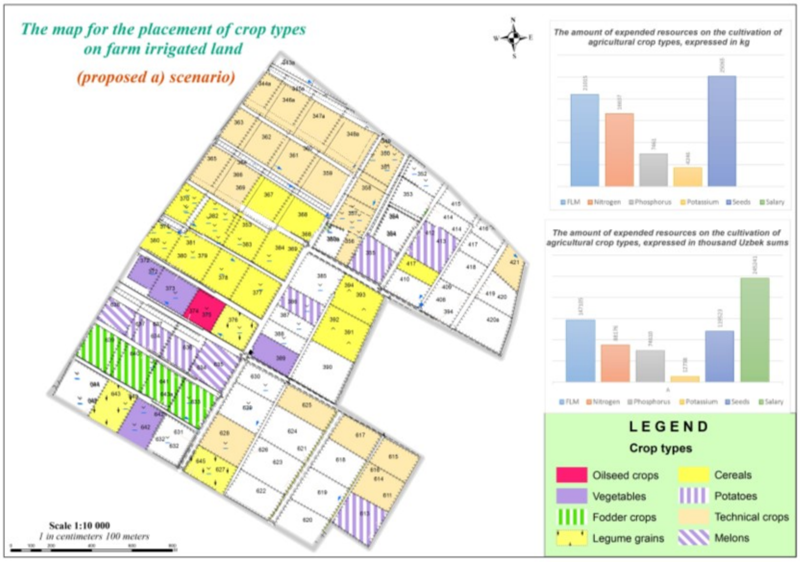
- R_j - is spent resource type,
- G_a - is total crop irrigated area,
- x_i -i – is crop type irrigated area.

The next stage is to minimize the number of resources expended in the cultivation of crop types, which can be done by the following formula;

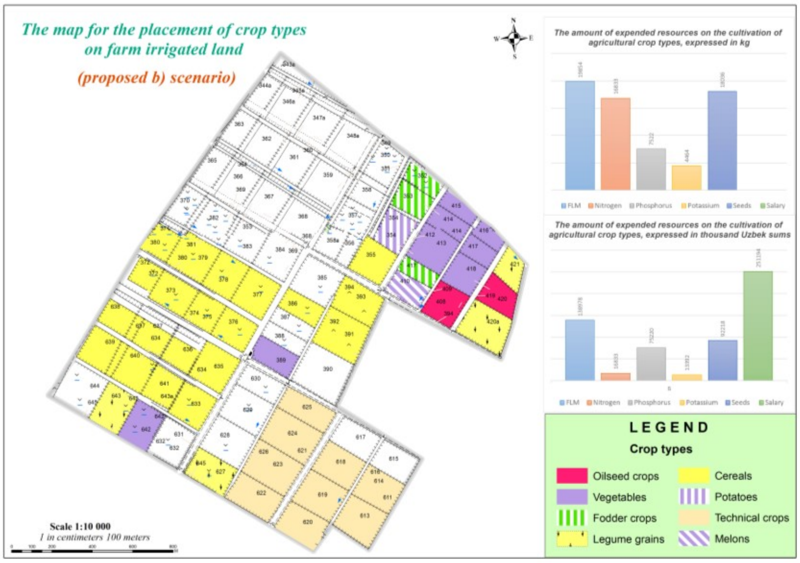
$$F(x) = \sum_{i=1}^{n} C_i x_i \rightarrow \min$$

Equation 4

Representation of the results on the map is the final stage of the model, in which the results of the placement of optimal crop types determined by the linear programming simplex method are shown on the map (Figure 4). In this case, first of all, the data is studied in ArcGIS, then queries on the area are performed and SQL is used. Now that the location of crop types has been determined, cartographic methods are selected, and each crop type is marked. A model of the maps will be developed, in which the map name, frame, scale, symbols and additional information will be placed, the map will be exported to raster mode and printed (Bekanov et al., 2021). The developed scenario maps are illustrated in the maps in Figure 4.



a)



b)

Figure 4: Scenario maps of crop species placement on farm lands (recommended a) b) c) scenario maps) (cont. next page)

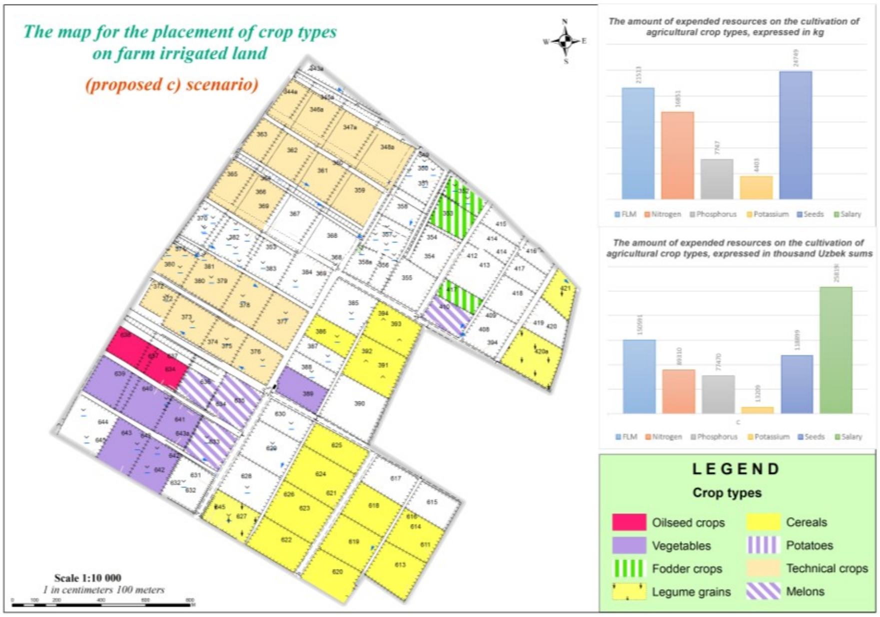


Figure 4: Scenario maps of crop species placement on farm lands (recommended a) b) c) scenario maps)

4. Results and Discussion

Nowadays, in the world there is a growing need to grow high-quality and high-quality food, efficient use of agricultural land, optimization of agricultural planning. This leads to the integration of geographic information systems with additional software packages. For example, overcoming the shortcomings of spatial decision support and so on. As a result, data exchange is carried out based on appropriate software. A several of foreign research works in this area have been reviewed by the authors. From the analysis of several scientific research, it can be seen that the implementation of the linear programming simplex method by integrating into GIS is effective in optimizing the use of agricultural land.

Based on the proposal of this research work, it should be noted that in optimizing the use of agricultural land, the simple method of linear programming using the geodata base was used. Their results were shown on the maps. Three solutions for the placement of crop varieties on the plots of the study site were proposed. Environmental and economic factors were taken as the main constraints, and scenarios for the placement of agricultural crop species were implemented in ArcGIS 10.6 and ArcPy. ArcPy is a programming language application in the Python programming language designed to solve several important perspective problems, analyze and manage processes. ArcPy is a program that helps to perform operative tasks in GIS through Python. An economic analysis of the value of crops grown as a result of the placement of Agricultural crops were based on three solutions. At the same time, the total cost of the product was a) 1156,2 million sums, b) 1299,6 million sums and c) 1271,2 million sums (Figure 8). Then the amount of expended resources on the cultivation of crop types on the selected 100 hectares of irrigated land was calculated. In this case, the total amount for each type of resource used for the total planted crops was determined in individual tons (Figure 5) and then, for each type of expended resource, were calculated in Uzbek sums (Figure 6). Then, the amount of resources spent on the cultivation of crops was calculated in the general case, in the first solution a) the total expended resources were 74,4 tons or 687,4 million Uzbek sums, in the second solution b) 66,7 tons or 587,8 million Uzbek sums, and in the third solution, c) 75,3 tons or 707,7 million Uzbek sums (Figure 7). Then, to determine the net profit, the total amount of funds spent on the cultivation of Agricultural crops was allocated from the value of gross agricultural output. As a result, the net profit amounted to in a) 468,8 million sums, in b) 711,8 million sums and in c) 563,5 million sums (Figure 8).

The analysis of the research showed that the most optimal solution is the variant b). The proposed solution resulted in the 11% reduction in the number of resources spent on crops and the 34% increase in net profit.

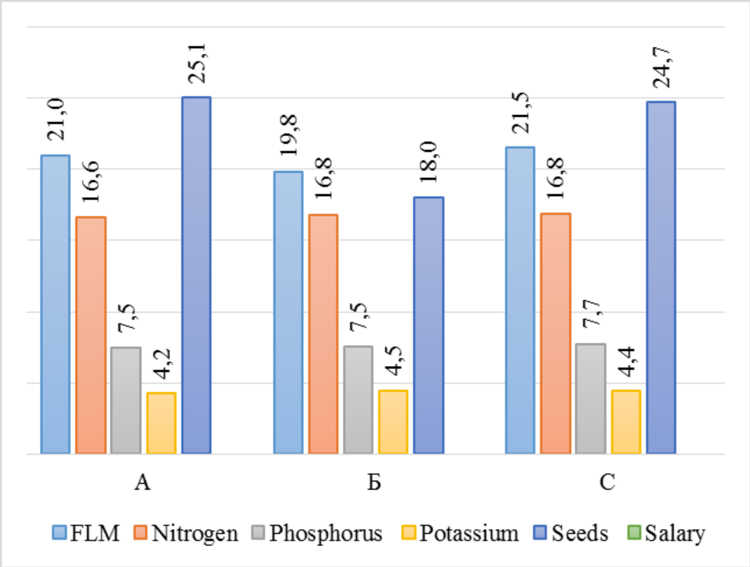


Figure 5: The amount of expended resources expressed (in ton)

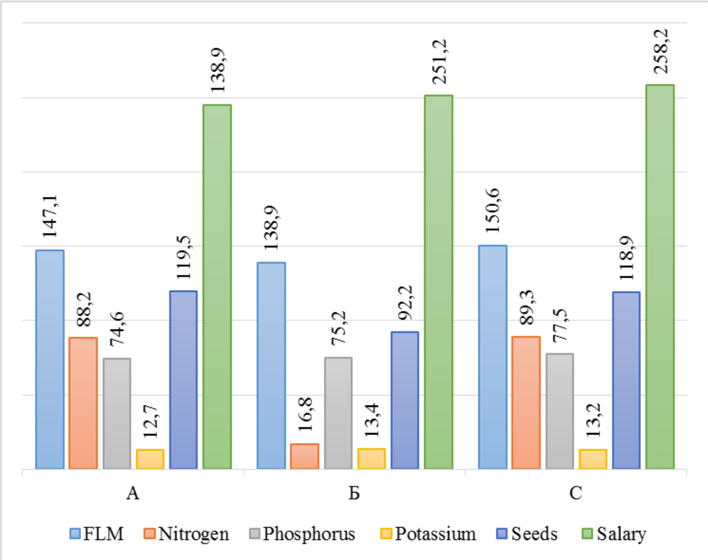


Figure 6: The amount of expended resources expressed (in a million Uzbek sums)

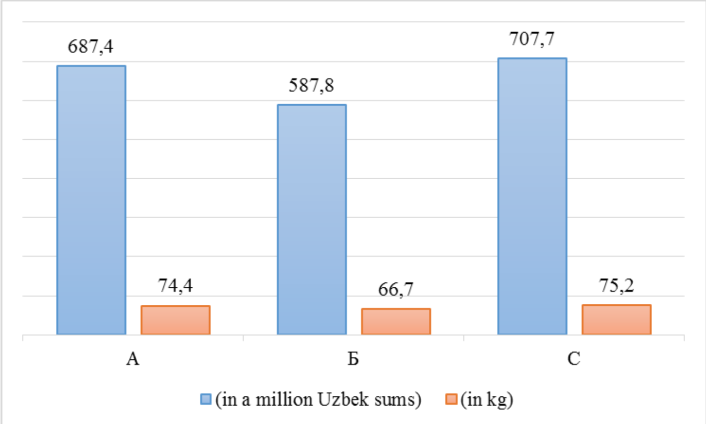


Figure 7: The amount of expended resources expressed

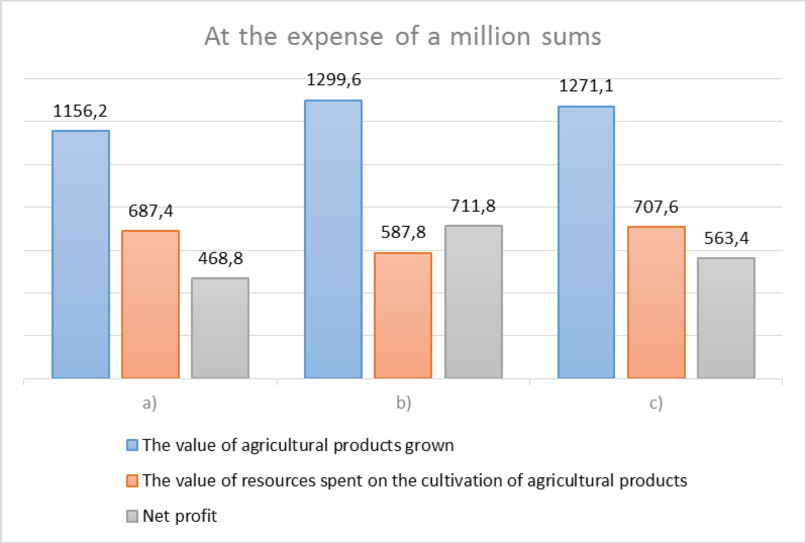


Figure 8: Economic analysis of agricultural production

5. Conclusions

In this study, the model of land use optimization was developed to increase the efficiency of the use of agricultural lands in the Aral Sea region, taking into account their ecological condition. The developed model of optimization greatly contributes to the efficient use of agricultural land through the correct placement of agricultural crops, taking into account various factors. In doing so, the parameters of land use optimization were calculated by integrating the linear programming simplex method into GIS, and the results were depicted on scenario maps. Through this optimization model, the key objective of the study was a significant improvement in the amount and productivity of resources used to grow crops on agricultural land. In other words, the resources spent on crop production decreased by 11% and productivity increased by 34%. This optimization model will greatly help to increase the efficiency of agricultural land use in the correct placement of agricultural networks, taking into account environmental and economic factors.

References

Alexander Herzig, 2008, A GIS-based Module for the Multiobjective Optimization of Areal Resource Allocation, *11th AGILE International Conference on Geographic Information Science*, 1-17.

Aravossis, K., Brebbia, C. A., Kakaras, E. and Kungolos, A. G., 2006, Environmental Economics and Investment Analysis, Southampton, England: WIT Press, 43 – 54.

Agrawal, R. C. and Heady, E.O., 1972, *Operations Research Methods for Agricultural Decisions.* Iowa State University Press, Iowa.

Bekanov K., Safarov E., Prenov Sh., Uvraimov S., Yusupov B., 2020, Creating Land Use/Land Cover Map Using Methods GIS and Remote Sensing (on the Example the Chimbay District of the Karakalpakstan Republic). *International Journal of Pharmaceutical Research*, Vol. 12(3), DOI:10.31838/ijpr/2020.12.03.231.

Bekanov, K. K., Development of Economic-Mathematical Models for Optimizing the Agricultural Land Use through GIS Technologies (on the Example of Chimbay District of the Republic of Karakalpakstan). *Economy and Society*, Vol. 9(88), 36-46.

Chuvieco, E., 1993, Integration of Linear Programming and GIS for Land-Use Modelling. *International Journal of Geographical Information Systems*, Vol. 7(1), 71-83, doi:10.1080/02693799308901940.

Djanibekov, N., Sommer, R. and Djanibekov, U., 2013, Evaluation of Effects of Cotton Policy Changes on Land and Water Use in Uzbekistan: Application of a Bio-Economic Farm Model at the Level of a Water Users' Association. *Agricultural Systems*, Vol. 118, 1-13. doi:10.1016/j.agsy.

Galán-Martín, Ángel; Pozo, Carlos; Guillén-Gosálbez, Gonzalo; Antón Vallejo, Assumpció; Jiménez Esteller, Laureano (2015). Multi-stage linear programming model for optimizing cropping plan decisions under the new Common Agricultural Policy. Land Use Policy, 48(), 515–524. doi:10.1016/j.landusepol.2015.06.022

Jain, P. and Ramsankaran, R., 2019, GIS-based Integrated Multi-Criteria Modelling Framework for Watershed Prioritisation in India—A Demonstration in Marol Watershed. *Journal of Hydrology*, doi:10.1016/j.jhydrol.2019.124131.

Jeffrey, L. A. and Darek, J. N., 1997, Clarification on the use of Linear Programming and GIS for Land-Use Modelling. *International Journal of Geographical Information Science*, Vol. 11(4), 397-402.

Kholmurzaev, I., Teshaev, Sh.J., Aripov, A.O., Qosimov, M.Ch., Sulaymanov, B.A., Xalikov, B.M., 2016, Qishloq xo'jalik mahsulotlarini yetishtirishda talab etiladigan mehnat va moddiy resurslar sarfi me'yorlari, Tashkent, 9-37.

Olshevskiy, A. V. and Yatsukhno, V. M., 2010, *Optimizatsia agrarnogo zemlepolzovaniya na landshaftnoy osnove s ispolzovaniem GIS-tehnologiy (na primere Belorusskogo polesya), Nature Management: Ecology, Economics, Technology*. Materials of the International Scientific Conference, Minsk, October Vol. 6(8), 231-238.

Papalambros, P. Y. and Wilde, D. J., 2000, *Principles of Optimal Design: Modeling and Computation.* 2nd Edition, (http://www.optimaldesign.org/), Cambridge: Cambridge University Press.

Reimov, P. and Fayzieva, D., 2014, The Present State of the South Aral Sea Area, In Micklin, P., Aladin, N.V. and Plotnikov, I., (Eds.). *The Aral Sea*, 171–206.

Safarov E., Prenov Sh., Bekanov K., Solahitdinova S., Uvraimov S.,2020, Application of Geoinformation Technologies and Remote Sensing to Detect Land Use and Changes in the Soil Cover Caused by the Drying of the Aral Sea. *Periódico Tchê Química*. Vol.17 (36), DOI:10.52571/PTQ.v17.n36.2020.390_Periodico36_pgs_390_401.pdf.

Turdimambetov, I., Madreymov, A., Foldvary L., Oteuliev, M., Kurbanov, V., Utarbaeva, K. and Bekanov, K., 2021, Influence of Adverse Ecological Factors on the Incidence of Malignant Neoplasms, E3S Web of Conferences, Vol. 227, https://doi.org/10.1051/e3sconf/-202122702001.

Valeriy, A., 2015, Sistema Optimizatsii Selskohozyaystvennogo Zemlepolzovaniya, Zemelnie Otnosheniya i Xemleustroystvo, 3-8.