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Environmental Impact Assessment of Rice Growing in the Kyzylorda Region

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ABSTRACT

In the context of the growing ecological crisis caused by climate change, irrational use of water resources and environmental pollution with dangerous pollutants, an important role is played by assessing the role of environmental damage from crop production. The authors analyzed the environmental compatibility of modern rice production in the main rice growing region in the Republic of Kazakhstan – the Kyzylorda region. The work included theoretical calculations of methane greenhouse gas emissions throughout the region for the entire vegetative season. And also calculated the costs of water resources for irrigation of rice fields, including water leaving for evaporation from the water surface, evapontranspiria, saturation of the soil, filtration flow and outflow into the drainage network. In the grain of rice varieties "Aikerim" and "Favorit" grown in the Kyzylorda region, residual amounts of such toxic substances as organochlorine pesticides (HCH α, β, γ-isomers, DDT, DDE) were determined. Heavy metals (cadmium, lead, arsenic and mercury) were also determined in these varieties of rice.

1. INTRODUCTION

Rice, a crop of paramount importance, is the cornerstone of nutrition, food security, cultural heritage, and economic sustenance for billions of individuals worldwide [1]. As a vital food source, its preservation is crucial for global food security. In addition to its culinary significance, rice paddies form a unique ecosystem, providing habitats for a diverse array of wildlife species, such as migratory birds, fish, and insects. Given its high cultivation volume and varied growth technology requirements, rice has a profound impact on ecosystems and is a significant contributor to climate change [1-3].

Nonetheless, rice cultivation is associated with significant environmental challenges, chiefly high water consumption. Statistics reveal that water usage in rice irrigation systems averages 25-30 thousand m^3/ha [4]. Rice fields account for over half of the freshwater used in crop production, demanding two to three times more water than other crops such as wheat and maize. Yet, it is estimated that merely 1.0-1.5 thousand liters of water are required for the physiological needs of 1 kg of rice, whereas existing farming technologies consume 3-4 thousand liters [5, 6]. Another adverse environmental impact of rice cultivation is ecosystem pollution due to the high specific area of rice fields, contamination with pesticides, and heavy metals, which subsequently affect freshwater and marine fish quality [7]. Organochlorine pesticides, still in use in several countries to combat pests in rice paddies, are known to harm ecosystems and cause acute poisoning in birds and other animals [8-10]. Furthermore, rice cultivation has been estimated by The Environmental Defense Fund (USA) to contribute to 2.5% of human-induced climate warming, primarily due to powerful greenhouse gases, methane and nitrous oxide, produced by soil microbes in rice paddies [11, 12].

In the Republic of Kazakhstan, the Kyzylorda region is the primary rice producer, annually sowing approximately 90 thousand hectares out of 195 thousand hectares of irrigated arable land in the region. Rice farming has been practiced here for over 90 years; however, for a long period, the use of pesticides, some classified as persistent organic pollutants, was rampant [13, 14]. Located in Southern Kazakhstan, the Kyzylorda region has witnessed one of the planet's largest ecological catastrophes – the desiccation of the Aral Sea [15].

While the peculiarities and problems of rice cultivation have been frequently discussed in prior scientific works [16, 17], the environmental issues caused by rice cultivation, particularly in the Kyzylorda region, remain largely unexplored. The present study aims to bridge this knowledge gap by analyzing the environmental challenges posed by rice cultivation in the Kyzylorda region of the Republic of Kazakhstan. Specific objectives include:

- Estimation of methane greenhouse gas emissions.
- Calculation of water resource expenditure for rice field irrigation.
- Identification of residual amounts of organochlorine pesticides (HCH α, β, γ-isomers, DDT, DDE) and heavy metals (Cd, Pb, As, Hg) in rice grain grown in the Kyzylorda region.
- Determination of toxic element content (cadmium, lead, arsenic, and mercury) in "Aikerim" and "Favorit" rice varieties.

The results of the presented study highlight the calculations of methane emissions on the example of the largest Zhalagash district. The data of water evaporation from the surface of clean water in the rice fields of the Kyzylorda region were obtained. The content of heavy metals in "Aikerim" and "Favorit" rice grains was also determined.

This paper is structured as follows: the Introduction provides an overview of the environmental problems associated with rice cultivation and introduces the study's focus, including the objectives and research questions. The Methodology details the research design, data collection methods, and data analysis techniques employed to meet the study's objectives. The Results and Discussion present the study's findings, with the Conclusion summarizing the main results.

2. LITERATURE REVIEW

Rice cultivation is a major agricultural practice worldwide, especially in Asia, and plays a vital role in the food security of millions of people [8]. However, rice cultivation has a significant impact on the environment. According to scientists [11], one of the most significant environmental problems associated with rice cultivation is water use. Rice is an aquatic plant that requires large amounts of water to grow, and traditional rice farming practices involve flooding the fields with water. This can lead to the depletion of water resources, particularly in areas where water is already scarce. Additionally, the large amounts of water used in rice cultivation can contribute to soil erosion, water pollution, and the destruction of natural habitats [12, 18].

Another significant environmental problem associated with rice cultivation is greenhouse gas emissions [13, 19]. In the study [15], the researchers noted that methane, a potent greenhouse gas, is produced when rice is grown in flooded fields. This is because the flooded fields create anaerobic conditions that promote the growth of methane-producing bacteria. Pesticide and fertilizer use is also a major environmental problem associated with rice cultivation [16]. For example, pesticides can contaminate water sources and harm aquatic ecosystems, while fertilizer runoff can lead to eutrophication, a process that depletes oxygen in water bodies and can lead to the death of aquatic organisms [16, 20].

The environmental problems associated with rice growing include water use, greenhouse gas emissions, and pesticide and fertilizer use. Efforts to address these issues will require changes in agricultural practices and the adoption of sustainable farming techniques [17, 21].

3. MATERIALS AND METHODS

The Kyzylorda region is a region where environmental indicators are deteriorating, such as the supply of fresh water, degradation of soil resources, unfavorable climatic changes, an increase in the incidence of diseases of the population from poor quality water. In this regard, intensive rice cultivation is one of the major causes of environmental problems. The following methods were used in the work:

1. Methodology for calculating greenhouse gas emissions as a result of rice growing developed by the Republican State Enterprise "Kazakh Research Institute of Energy" of the Ministry of Environmental Protection of the Republic of Kazakhstan, which is a regulatory document on environmental protection [22].

2. Method of calculating water evaporation according to the formula of V.I. Ivanov [23].

3. Method of determination of residual amounts of organochlorine pesticides according to GOST 31481 – 2012 [24]. The determination of organochlorine pesticides in was carried out by the chromatographic method according to GOST 31481 – 2012 on a gas chromatograph TRACE 1310 GC with a triple quadrupole mass spectrometric detector TSQ 8000 EVO with a capillary column Thermo Scientific GC Column TG-5SILMS 30 m-0.25 mm-0, 25 μm with low polarity 5% diphenyl 95% dimethyl polysiloxane.

4. Method for the determination of toxic elements of cadmium, lead, arsenic and mercury in rice grains "Aikerim" and "Favorit" according to GOST 26929 [25] on an atomic absorption spectrophotometer Analytik jena novAA 350, arsenic and mercury were determined with a voltammetric analyzer TA-lab.

The determination of residual amounts of organochlorine pesticides and heavy metals was carried out on the basis of the laboratory of food and environmental safety of the Kazakhstan-Japan Innovation Center of the Kazakh National Agrarian Research University.

4. RESULTS AND DISCUSSION

The region is located east of the Aral Sea in the lower reaches of the Syrdarya River. The main part of the region's territory is located within the Turan lowland (height 50-200 m) (Figure 1) [26].

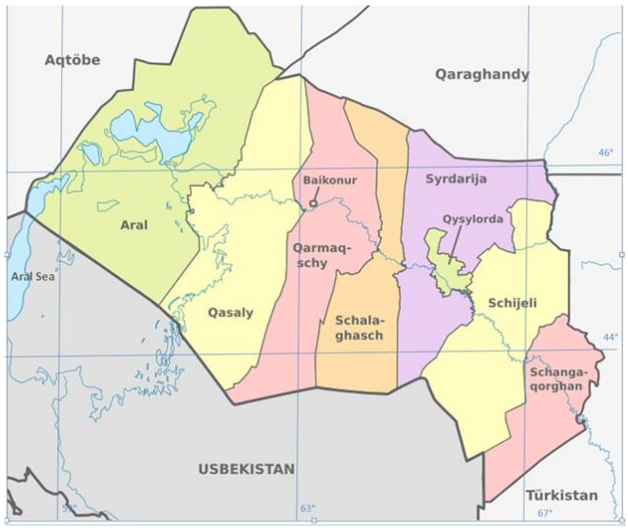

Figure 1. Kyzylorda administrative divisions

The climate of Kyzylorda region is sharply continental with hot dry long summers and cold short winters with little snow. Summer is hot and long. The average growing temperature of rice in this region varies from 17-19°C in April to 34-42°C in July [27].

According to the websites of regional akimats, in 2020 in the Kyzylorda region, the cultivated areas for rice amounted to 89.492 hectares. Of these: Zhanakorgan district 8.346 hectares [28], Shieli 14.353 hectares [29], Syrdariya 21.126 hectares [30], Zhalagash 21.6 hectares [31], Karmakshy 13.496 hectares [32], Kazaly 6.496 hectares [33], Kyzylorda 4.075 hectares [34] (Figure 2).

The rice farms of Kyzylorda region use the same technology – irrigated. On the example of the largest Zhalagash region, calculations of methane emissions are shown below using a number of formulas [22]. The results of methane emissions for other rice-growing areas are shown in Table 1.

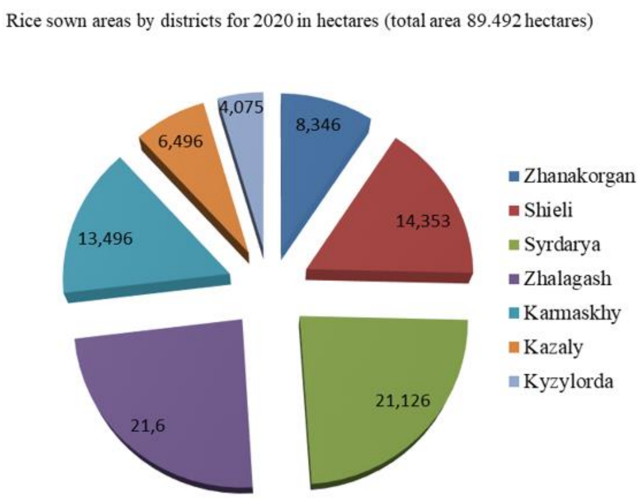

Figure 2. Actual sown area of rice crops located in Kyzylorda region in 2020

Table 1. Methane emissions from rice fields in Kyzylorda region

Name of Districts (cities)	Sowing Area, ha	The Amount of CH_4 Emissions, t/g
Zhanakorgan	8,346	1,980
Shiyeli	14,353	3,400
Syrdarya	21,126	5,010
Zhalagash	21,600	5,130
Karmakshy	13,496	3,200
Kazaly	6,496	1,540
Kyzylorda City	4,075	960
Total	89,492	21,220

The basic equation for calculating CH_4 emissions is:

$$CH_4fig = \Sigma\ i\ j\ k\ (EFijk \times tijk \times Aijk \times 10\text{-}6) \quad (1)$$

where, CH_4fig – annual methane emissions from rice cultivation, Gg (gigagrams) CH_4/year; EFijk – daily emission factor for conditions i, j and k, kg CH_4/ha per day; tijk – the period of growing rice for conditions i, j and k, days; Aijk – annual harvesting area under rice for conditions i, j and k, ha/year; i, j and k – represent different ecosystems, water regimes, type and amount of organic fertilizers, and other conditions that affect CH_4 emissions from rice production.

1) there are: the period of growing rice is t=125 days; the total rice area in region A=21.600 hectares.

2) since the application of fertilizers and the mode of growing rice (flooding mode) were the same in the region, we did not divide the plots with a total area of 21,600 hectares according to the difference in conditions, since there is no reason for this:

$$i = 1, j = k = 0 \quad (2)$$

Therefore, expression (1) is simplified:

$$CH_4fig = EF \times ti \times A \times 10\ \text{-}6 \quad (3)$$

3) the baseline emission factor for permanently flooded fields without organic fertilizers was taken from Table 2 of the guidelines [22], EF = 1.3.

The EF coefficient needs to be adjusted, then the expression was used for this according to the methodological guide [22]:

$$EFi = EFc \times SFw \times SFp \times SFo \times SFsy \quad (4)$$

4) the baseline emission factor for permanently flooded fields without organic fertilizers was taken from Table 2 of the manual [22] EFc = 1.3;

5) scaling factor, taking into account the water regime during the period of rice cultivation according to Table 3 of the manual [22]. Since the region uses the technology of the water regime – "constantly flooded", we take the multiplier SFw = 1;

6) the SFp coefficient was disregarded since the pre-season flooding period is less than 30 days;

7) the SFo, coefficient, depending on the amount and type of fertilizer applied, according to Table 4 of the manual [22] SFo = 0.14, which was corrected according to equation, gives the value:

$$SFo = (1+1\times0.14)0.59 = 2.140.59 \approx 1.46 \quad (5)$$

8) SFsy coefficients for soil type and rice cultivar were taken equal to 1.

Thus, all the factors for adjusting the baseline emission factor were found and amounted to: EFi =1.9

After all the factors for formula (1) have been found, it is possible to calculate the amount of CH_4 emissions in the Zhalagash district.

$$CH_4 = 1.9\cdot125\cdot21600\cdot10\text{-}6 = 5.13\ Gg \quad (6)$$

Thus, from the rice field in the Zhalagash district of Kyzylorda region with an area of 21.600 hectares with the introduction of fertilizers 1 t/ha (manure) for 125 days of growing season, emissions of greenhouse gas methane were:

$$5.13\ Gg = 5130\ tons \quad (7)$$

Similarly, according to this method, calculations were made for the districts of Zhanakorgan, Shieli, Syrdarya, Karmakshy, Kazaly, Kyzylorda city. The calculation results for methane emissions for these areas are presented in Table 1.

Thus, only from the total cultivated areas of rice (89.492 hectares) in Kyzylorda region, up to 21,220 tons of methane are released per year. Standards for methane emissions from rice fields, as well as maximum permissible concentrations, have not been officially established at the present time. However, this amount of greenhouse gas released into the atmosphere contributes to the overall greenhouse effect. And the amount of methane emitted into the atmosphere needs to be regulated as well as carbon dioxide emissions.

Calculation of water costs for irrigation and evaporation. Rice irrigation system is an irrigated area with water supply and drainage canals, hydraulic structures and other elements. These devices provide irrigation for rice and related crops in addition to accelerating drainage of the control surface during the non-irrigation period. The water layer in rice fields practically throughout the entire growing season contributes to an increase in the level of groundwater and the accumulation of harmful compounds in the soil, its waterlogging [35]. At the same time, the consumption of irrigation water varies depending on the irrigation regime and moisture supply throughout the year.

To calculate the total evaporation of water from rice fields, Ivanov's formula [23] was taken as the basis, which calculates evaporation from a clean water surface, which contains climatic indicators:

$$E=0.0018\cdot(100\alpha)\cdot(25+t)2\cdot0.8 \quad (8)$$

where, E is evaporation from a clean water surface; t is the average air temperature for the billing period; α is the average relative air humidity for the calculation period.

Table 2 shows the obtained data of water evaporation from a clean water surface in the rice fields of the Kyzylorda region. Here you can see that the highest evaporation occurs in the hottest months of the region, June and July: 6.73 m^3/ha and 6.76 m^3/ha, respectively. As a result, in this region for the entire growing season from May to August, the water surface with an area of 89.492 hectares was about 92,111,430.84 m^3.

According to Olzhabayeva et al. [36], in the conditions of the Kyzylorda region, rice is grown under constant flooding with a variable water layer from 5 to 15 cm, with a change in water in rice paddies during the germination period of a rice plant with an increase in water mineralization in the check up to 1.8 g/l, in subsequent phases of vegetation at 2.5 g/l. Irrigation rate for rice is 24,350 m^3/ha, of which evapontranspiria – 10,367 m^3/ha, soil saturation – 4,460 m^3/ha, seepage flow and outflow into the drainage network – 8,324 m^3/ha [36].

As a result, the rice farm of Kyzylorda region consumes a total of 2,163,940,722.84 m^3 for the entire growing season. This equals 2.163941 km^3, or 2,163,940,722.84 tons of water. Determination of residual amounts of organochlorine pesticides. To determine the residual amounts of organochlorine pesticides, grains of rice varieties "Aikerim" and "Favorit" were tested (Figures 3 and 4). The method is based on the extraction and purification of organochlorine pesticides from the analyzed sample by distillation with water vapor and quantitative determination on a gas chromatograph. Operating conditions: injection volume – 1 µL, separation ratio 1: 100, flow rate 1 ml/min, column heating rate: from 70℃ to 285℃ at 10℃/min, analysis time 34 min, injector temperature 210℃, the temperature of the detector source is 285℃. The number of pesticides identified by rice varieties is presented in Table 3.

Table 2. Calculation of the total evaporation of water from rice paddies for the growing season of 2020 in Kyzylorda region

Indicators	Months			
	May	**June**	**July**	**August**
Average air temperature, °C	22.0	27.7	28.7	25.9
Relative humidity, %	38	29	30	31
Evaporation rate, m^3/ha	197.22	283.95	290.68	257.42
The total amount of water evaporation, m^3 *Sown area for rice in 2020 in Kyzylorda region – 89,492 hectares.*	17,649,612.24	25,411,253.4	26,013,534.56	23,037,030.64
Total for the entire growing season, m^3	92,111,430.84			

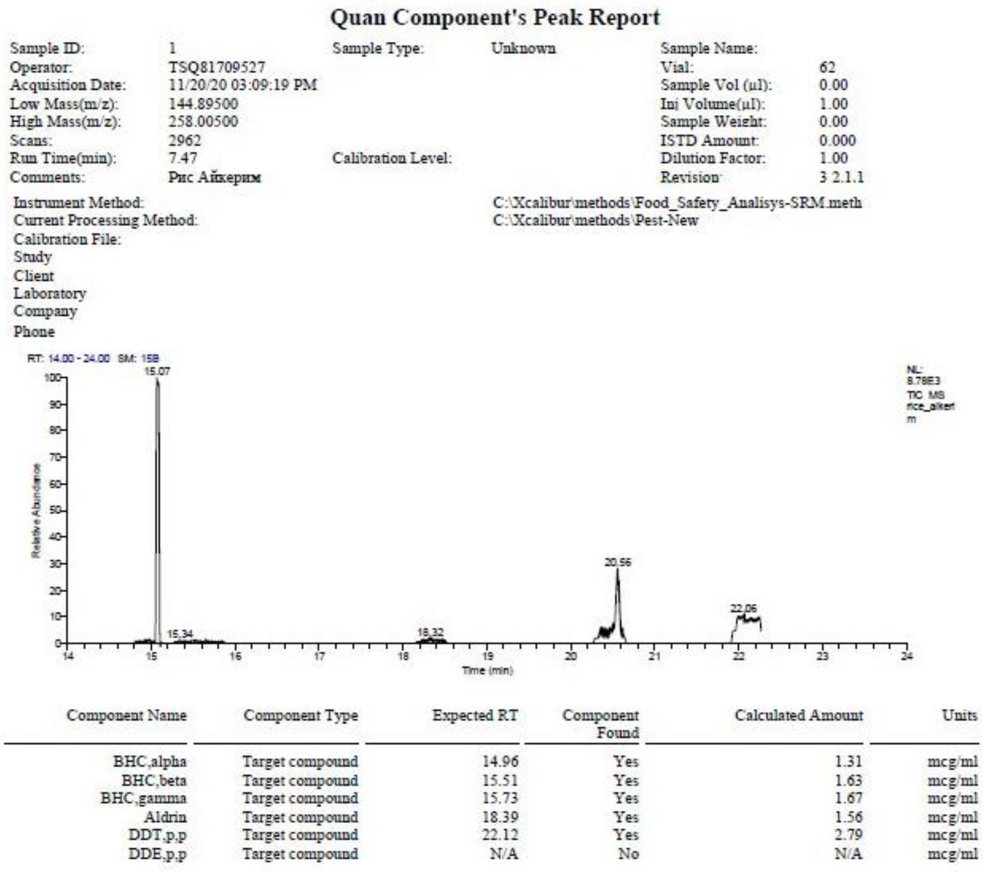

Figure 3. Chromatogram obtained in the determination of pesticides in rice of the Aikerim variety

Quan Component's Peak Report

Sample ID:	1	Sample Type:	Unknown	Sample Name:	
Operator:	TSQ81709527			Vial:	61
Acquisition Date:	11/20/20 02:30:03 PM			Sample Vol (µl):	0.00
Low Mass(m/z):	144.89500			Inj Volume(µl):	1.00
High Mass(m/z):	258.00500			Sample Weight:	0.00
Scans:	2962			ISTD Amount:	0.000
Run Time(min):	7.47	Calibration Level:		Dilution Factor:	1.00
Comments:	Рис Фаворит			Revision:	3.2.1.1

Instrument Method: C:\Xcalibur\methods\Food_Safety_Analisys-SRM.meth
Current Processing Method: C:\Xcalibur\methods\Pest-New
Calibration File:
Study
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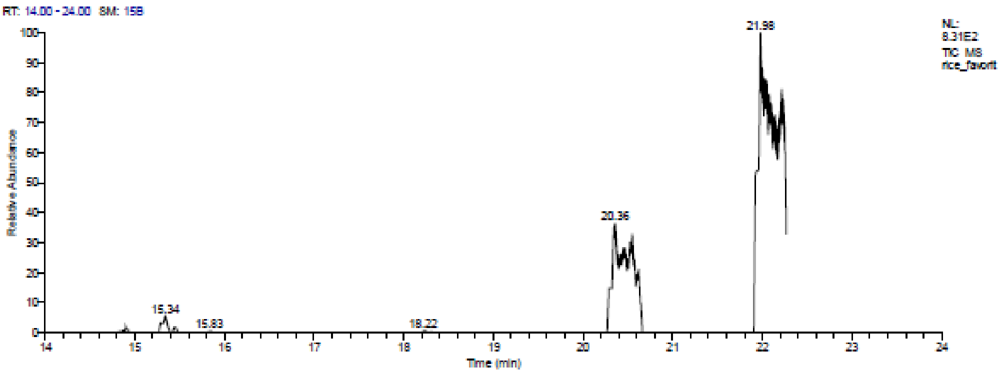

Component Name	Component Type	Expected RT	Component Found	Calculated Amount	Units
BHC,gamma	Target compound	15.73	Yes	1.67	mcg/ml
DDE,p,p	Target compound	20.50	Yes	1.59	mcg/ml
DDT,p,p	Target compound	22.12	Yes	2.79	mcg/ml
Aldrin	Target compound	N/A	No	N/A	mcg/ml
BHC,alpha	Target compound	N/A	No	N/A	mcg/ml
BHC,beta	Target compound	N/A	No	N/A	mcg/ml

Figure 4. Chromatogram obtained in the determination of pesticides in rice of the Favorit variety

Table 3. Content of persistent organic pollutants in rice varieties "Aikerim" and "Favorit"

Rice Varieties	The name of the Determined Pesticides	MPC mg/kg	Concentration of Pesticide Amounts mg/kg	Actual Values µg/ml
"Favorit"	HCH α-isomers	no more than 0.5 (In total)	-	not detected
	HCH β-isomers		-	not detected
	HCH γ-isomers		0.0001	1.67
	4.4 DDT	no more than 0.02 (In total)	0.0002	2.79
	4.4 DDE		0.0001	1.59
	Aldrin	-	-	not detected
"Aikerim"	HCH α-isomers	no more than 0.5 (In total)	0.0002	1.31
	HCH β-isomers		0.0002	1.63
	HCH γ-isomers		0.0002	1.67
	4.4 DDT	no more than 0.02 (In total)	0.0003	2.79
	4.4 DDE		-	not detected
	Aldrin	-	0.0001	1.56

Comparison of the results of analyzes of the content of pesticides in rice grains with maximum permissible concentrations showed that the content of persistent organic pollutants in rice, which were used in the fields for a long time in the last century, does not exceed the established norms. However, given the cumulative ability of pesticides in the human body, and the fact that rice is a regularly consumed crop among the indigenous population, the pesticides contained in rice undoubtedly contribute to the spread of ecopathologies in the region.

Determination of cadmium, lead, arsenic and mercury in rice grains of "Aikerim" and "Favorit" varieties. The data obtained as a result of the study on the content of heavy metals in rice grains "Aikerim" and "Favorit" are reflected in Table 4.

Table 4. The content of heavy metals in rice grains "Aikerim" and "Favorit"

Metal	MPC mg/kg	Name of Rice Varieties	
		Aikerim	Favorit
Cd	0.1	0.036	0.014
Pb	0.5	0.015	0.013
As	0.2	not found	not detected
Hg	0.03	not found	not detected

Studies have shown that both varieties of rice grains contain cadmium (Cd) and lead (Pb): rice variety "Aikerim" contained Cd – 0.036 mg/kg and Pb – 0.015 mg/kg; rice "Favorit" –Cd– 0.014 mg/kg and Pb – 0.013 mg/kg. Arsenic (As) and mercury

(Hg) were not detected in rice samples "Aikerim" and "Favorit".

Despite the fact that, according to the accepted MPC standards, the content of heavy metals does not exceed the permissible concentrations, their presence, as well as pesticides, is a threat to public health.

5. CONCLUSIONS

Thus, the assumption was confirmed that the rice farming in the Kyzylorda region is irrational in the use of water resources, contributes to an increase in the greenhouse gas methane into the atmosphere and poses a threat to public health, since the final product contains a number of toxic substances. In fact, it was found that rice cultivation for the entire 2020 growing season had the following adverse environmental impacts in the calculation: the volume of greenhouse gas emissions methane – about 21,220 tons; expenditures of water resources for irrigation of rice fields – 2.163941 km^3, or 2,163,940,722.84 tons of water.

The following types of toxic compounds, persistent in the environment, hazardous to public health, were found in rice grain: organochlorine pesticides; in rice variety "Aikerim" HCH α-isomers – 0.0002 mg/kg, HCH β – isomers – 0.0002 mg/kg, HCH γ – isomers – 0.0002 mg/kg, 4.4DDT – 0.0002 mg/kg, aldrin – 0.0001 mg/kg; pesticides HCH γ-isomers – 0.0001 mg /kg, 4.4 DDT – 0.0002 mg/kg, 4.4 DDE – 0.0001 mg/kg were detected in the Favorit rice. heavy metals: rice of the "Aikerim" variety contained Cd – 0.036 mg/kg and Pb – 0.015 mg/kg; rice "Favorit" – Cd – 0.014 mg/kg and Pb – 0.013 mg/kg.

The implications of the research highlight the importance of developing sustainable rice cultivation practices that mitigate the negative environmental impacts of rice cultivation while ensuring the long-term sustainability of rice cultivation in the region. The practical significance of the study is that its results can be used to develop and implement effective strategies that promote sustainable rice cultivation and minimize the negative impact of rice cultivation on the environment.

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