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Spatial differentiation of regulatory monetary valuation of agricultural land in conditions of widespread irrigation of steppe soils

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Abstract

The article presents results of quality class determination and regulatory and monetary valuation of agricultural land in the steppe soils irrigation zone using the Karmanov's methodology of soil and climatic quality class determination and author's methodology of ecological, agro-ameliorative and climatic soils quality class determination. Based on the results of spatial modeling, a series of maps was created and characteristics of ecological, agro-ameliorative and relief and climatic components of soils quality class were presented based on the example of the Kherson Region, Ukraine. According to the results soil and climatic quality class determination, it is established that the value of the class varies from 25 to 46 points; the regulatory and monetary value of agricultural land varies from USD 490 per 1 ha for dark chestnut and chestnut alkaline soils up to USD1,360 per ha for ordinary chernozem. According to the results of ecological, agro-ameliorative and climatic soils quality class determination, it is established that the value of the class varies from 6 to 59 points; the regulatory and monetary value of agricultural land varies from USD145 per 1 ha for degraded and highly saline chestnut soils up to USD2,060 per ha for irrigated southern chernozem. The suggested methodology of soil quality class calculation can have multiple purposes. It is intended to be used for different physiographic conditions of land use to develop adaptive soils protection measures at different territorial levels of agricultural production management with the overall objective of ensuring sustainable land use.

Key words: *ecological and agro-ameliorative indices, GIS technologies, irrigation, methodology, modelling, regulatory and monetary valuation, relief and climatic conditions, soil quality class*

INTRODUCTION

At the end of the 20th century, anthropogenic impact on the environment has exceeded its capacity for sustainable development. This has led to the global environmental crisis of landscape and aquatic ecosystems [PICHURA *et al.* 2017]. The situation requires the introduction of territorial management, including a comprehensive evaluation of multi-level territorial structural units to develop an action plan for the restoration of the natural balance in accordance with local conditions in specific physiographic zones.

Spatial and temporal differentiation of agro-climatic conditions and farming standards determine a qualitative status of agricultural landscapes and the change of ecological, ameliorative and agrochemical properties of soil fertility. These are components taken into account while determining a zonal soil quality class and providing a regulatory and monetary valuation of agricultural land [BEZNITSKA 2017; DUDIAK *et al.* 2019b; 2020]. Stocks of nutrients and their availability to plants, as well as reserves of productive moisture (sum of precipitation and irrigation) are closely dependent on natural and climatic conditions of agro-landscapes (features of relief, soil-forming rocks, climate, hydrogeological conditions, etc.) and the system of agriculture which ultimately determines the volume and quality of crops [DOMARATSKY *et al.* 2018; MEDVEDEV *et* *al.* 2006]. Ecological, ameliorative and agrochemical properties of agricultural landscapes are characterized by high spatial heterogeneity of distribution within the same soil with differences of 50–70%. It is the result of the soil formation process and farming standards [MEDVEDEV 2009; ZELENSKAYA *et al.* 2018].

An assessment of the rate of pedogenesis under natural conditions [JENSENA *et al.* 2020; LISETSKII 2012] has shown that the soil develops slowly and can be considered an almost irreparable resource under the economic planning horizon. This determines the great importance of assessing the quality of soils both in a utilitarian (resource) aspect and in terms of environmental functions performed by the pedosphere.

Climate is the most important abiotic factor of the geographical environment, which is functionally linked to most of its components and determines soil formation processes in zonal soils [LI *et al.* 2020; PICHURA *et al.* 2019]. In particular, the spatial differentiation of climate impacts is caused by morphometric characteristics of the agro-landscapes relief, the ratio of natural components (biocenoses, water resources, wetland ecosystems, etc.) and developed landscapes (arable land, settlements, roads, etc.) [BURYAK *et al.* 2014; STORIE 1978].

The soil quality class determination is the basis of the regulatory and monetary valuation of agricultural land. It is based on soil characteristics and its spatial differentiation in terms of its production quality and fertility. The quality class expresses the properties of the soil and its suitability for the growth and development of agricultural plants. The results of the soil quality class determination are used for rational planning of economic activities. This allows to take into account the natural and climatic potential of soils and the degree of anthropogenic degradation of the soil cover. This is obligatory to establish all cause and effect relationships in agro-landscape ecosystems, including the impact of relief, as a general integral function which largely determines the spatial differentiation of soil cover and soil formation processes [LISETSKII, CHEPELEV 2014; LISETSKII *et al.* 2017b; RASMUSSEN *et al.* 2007].

The soil quality class determination is a logical continuation of comprehensive land surveys and the basis for monetary valuation of agricultural land. The main objective of the soil quality class determination is to establish the relative quality of soil based on its fertility and to compare soils natural and acquired properties [DUDIAK *et al.* 2019b].

In this context, there is a need to provide an objective valuation of agricultural land and create spatially coordinated thematic maps of soils and climatic soil quality class distribution. Soils quality class maps contribute to a spatially discrete model needed to develop adaptive soil protection measures at different territorial levels of agricultural production management and to ensure sustainable land use.

The purpose of the research is to determine ecological, agro-ameliorative and climatic patterns of spatial differentiation of regulatory and monetary valuation of agricultural land in the steppe soil irrigation zone by applying advanced methodology of zonal soils quality class determination and GIS technologies.

DATA AND METHODS

The soil quality class determination in the steppe soils irrigation zone has been based on the example of the Kherson Region, Ukraine (Fig. 1), and the application of the comparative study and I.I. Karmanov's soil and climatic quality class determination model [KARMANOV 1980; KARMANOV, BULGAKOV 2012; KARMANOV *et al.* 2013] and the author's advanced ecological, agro-ameliorative and climatic model.

The Kherson Region encompasses seven natural agricultural areas. The area of agricultural land of the Beryslavsky natural-agricultural district is 415.2 thous. ha. The soil cover of the district consists mainly of southern black soil, which is characterized by a humus profile with of 53–54 cm and the humus content of 3.4–4.2%. The Nyzhnosirogozhsky natural-agricultural area includes about 490.3 thous. ha of agricultural land. More than 80% of the area is occupied by highly productive southern saline black soils, which are under the influence of deflation, so the humus content is in the range of 2.7–3.4%.

Within the Belozersky natural-agricultural district, the area of agricultural land includes 104.8 thous. ha. The soil cover of the district is represented by dark-chestnut soils in a complex with saline soils, which occupy about 70% of arable land. Soils are characterized by a developed humus profile of 52–58 cm, a small amount of humus (1.9–2.7%), and they are constantly exposed to deflation. The area of agricultural lands in the Oleshkovsky natural-agricultural district is 47.3 thous. ha. Dominated by saline black soils mainly of a sandy mechanical composition, characterized by low humus content (about 0.96%), strong soil profile, low absorption capacity, poor structure, high permeability, low moisture content and a low nutrient supply. The Skadovsky natural-agricultural district includes 272.2 thous. ha of agricultural land. The soil cover consists mainly of dark-chestnut soils and their complexes with saline soils. Soils are characterized by light mechanical composition, low and medium humus content (0.83–1.7%), well-developed humus profile with a weak structure characterized by significant water permeability on slightly saline soils. Within the Chaplynky natural-agricultural district, the area of agricultural lands is 236.7 thous. ha. The area of agricultural land of the Genichesky natural-agricultural district is 349.5 thous. ha. The soil cover of the districts consists of dark-chestnut soils and their complexes with saline soils, which are characterized by a humus profile with a thickness of 40–48 cm, significant salinity, insignificant humus content (2.8–3.0%), and a weak structure of the arable layer.

The agricultural soil quality class was determined based on climatic data, their value for agricultural production, morphometric characteristics of relief, distribution of solar radiation balance, in accordance with ecological, agro-ameliorative and climatic conditions of soils.

The study of the spatial climatic heterogeneity of the region was carried out according to data from the World -Clim global climatic rasters (http://worldclim.org) and the Kherson Regional Center of Hydrometeorology (Ukr. Hersons'kyy oblasnyy centr z gidrometeorologii). Agro-

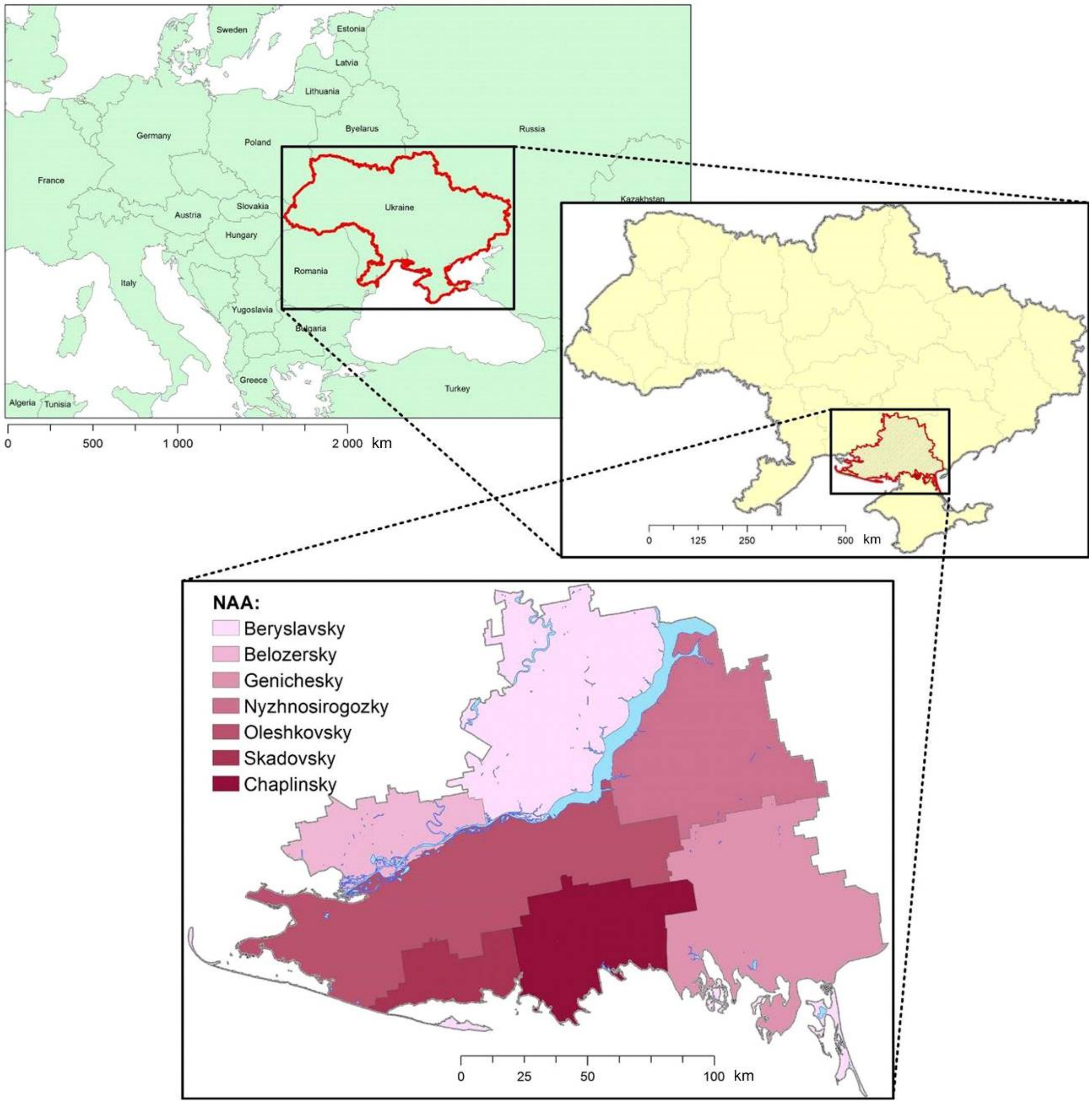


Fig. 1. The Kherson Region and its division into natural agricultural areas (NAA); source: own elaboration

chemical condition of agricultural land has been determined according to data from 296 stations of tour XI (2013–2017) examination by the Kherson branch of the State Institution "Soils Protection Institute of Ukraine" (Ukr. Instytut okhorony gruntiv Ukrayiny). The assessment of the soil agrochemical condition was performed for the 0–20 cm layer and included the following indicators: humus (%), nitrification nitrogen (mg·kg^{-1}), mobile phosphorus (mg·kg^{-1}), exchangeable potassium (mg·kg^{-1}) content. The residual of spatial models has been determined by the standard error distribution. The validity of spatial modelling is as follows: in terms of humus content – 92.0%, nitrification nitrogen – 85.8%, mobile phosphorus – 87.8%, and exchangeable potassium – 91.4%, content (%).

The ecological and ameliorative condition of soils (groundwater level and degree of soil salinization) was determined according to data from Kakhovka hydrogeological and ameliorative expeditions to the Kherson region in 1966–2019.

The evaluation of the soil and climatic potential (*SB*) was conducted using I.I. Karmanov's quality class determination model for growing a group of cereals, which occupy 57% of the agricultural land of the region, according to Equation (1):

$$SB = 8.2V\frac{\sum T \geq 10°\ HF}{CC+70} \tag{1}$$

Where: V = the raster of weight coefficients of agro-groups according to I.I. Karmanov's method; $\Sigma T \geq 10°$ = the raster of the average annual sum of active temperatures ≥ 10°C; HF = the raster of the humidity factor according to M.M. Ivanov; CC is the raster of the continentality coefficient.

The continentality coefficient (*CC*) is calculated according to the following formula:

$$CC = \frac{360(T_{\max} - T_{\min})}{\varphi + 10} \quad (2)$$

Where: T_{max} = the average monthly temperature of the warmest month; T_{min} = the average monthly temperature of the coldest month; φ is the latitude.

The humidity factor (*HF*) is calculated according to Equation (3):

$$HF = P/E \quad (3)$$

Where: *P* = the average annual precipitation (mm); *E* = the average annual evaporation ($g \cdot cm^{-2}$).

Spatial modelling of ecological, ameliorative and climatic zonal soils (*BAL*) quality class determination is carried out on the basis of the author's model:

$$BAL = 8.2V \frac{\frac{(R-9.9289)}{0.0121(P+IN)} K_K \, L \, W \, S_S}{0.94R(CC+70)} \quad (4)$$

Where: *V* = the raster of correction factors corresponding to the soil type; R_s = the raster of the radiation balance on an inclined surface ($kcal \cdot cm^2 \cdot y^{-1}$); *P* = the raster of the average annual amount of precipitation during vegetation (mm); *IN* = the raster of the actual annual average irrigation rate for cereals (mm); *L* = the latent heat of vaporization equal to 597 $cal \cdot g^{-1}$; *CC* = the raster of the coefficient of continentality; K_K = the raster of the complex coefficient of agrochemical soil properties; *W* = the raster of groundwater level correction factors; S_S = the raster of the type of soil salinization correction factors.

The calculation of the spatial differentiation of the balance of solar radiation (*R*, $kcal \cdot cm^{-2}$), taking into account the unevenness of the surface, is made according to the following formula:

$$R = R_0 \frac{\cos(s)\sin(h) + \sin(s)\cos(h)\cos(\psi_S - e)}{\sin(h)} \quad (5)$$

Where: R_0 = the value of the radiation balance of the horizontal surface for each month of the year ($kcal \cdot cm^{-2}$); *h* = the daily average height of the sun for each month (rad); ψ = the azimuth of the projection of the normal to the slope on the horizontal plane (rad); *s* = the raster of slopes (rad); *e* = the raster of directions (rad).

The raster of the complex coefficient of soil agrochemical properties is calculated according to the statistically normalized values of the weighted average amount of microelements content in the soil layer 0–20 according to Equation (6):

$$K_K = \frac{\sum_{i=1}^{n} (M_i / M_{\max})}{n} \quad (6)$$

Where: M_i = value of the *i* microelement of soil for plant development; M_{max} = the maximum value (reference value) of the spatial sample of the *i* soil microelement; *n* = the number of soil microelements.

The groundwater level and type of soil salinization correction factors were assigned according to Tsybikdorzhiev's classification [TSYBIKDORZHIEV *et al.* 2009] (Tab. 1).

Table 1. Negative ecological and ameliorative soil properties correction factors

Degree of the negative impact	Complexity group	Correlation coefficient
Bogginess		
Absent (non-boggy soil)	1	1.00
Mild (C horizon gleization with groundwater discharge in lower part of the crossover)	2	0.90
Medium (B and C horizon gleization with groundwater discharge at the depth of 75–100 cm)	3	0.80
Increased (groundwater in soil crossover at the depth of 55–70 cm)	4	0.65
High (groundwater at the depth of 0–50 cm)	5	0.20
Extremely high (groundwater level at the soil surface)	6	0.10
Salinization		
Non-saline soils	1	1.00
Sodium-carbonate and mixed salinization:		
– mild	2	0.85
– medium	3	0.70
– high	4	0.40
– extremely high	5	0.25
Sulphate and chloride-sulphate salinization:		
– mild	2	0.88
– medium	3	0.75
– high	4	0.45
– extremely high	5	0.29
Sulphate-chloride and chloride salinization:		
– mild	2	0.90
– medium	3	0.72
– high	4	0.48
– extremely high	5	030

Source: TSYBIKDORZHIEV *et al.* [2009].

The raster of distribution of quality class points enabled to calculate spatial differentiation of the regulatory and monetary valuation of agricultural land conducted separately by the type of agricultural land: arable land, perennial plants, hayfield, pastures, and fallows.

The regulatory and monetary valuation of agricultural land is determined in accordance with the standard capitalized rental income in the Kherson region (Tab. 2).

The scale of the regulatory monetary valuation (*RMV*) of agro-production groups of agricultural soils was carried out according to Equation (7):

$$RMV = \frac{SCRI \, B_{NAA}}{\overline{B}_R} \quad (7)$$

Where: *SCRI* = the standard of capitalized rental income on the respective agricultural land of the natural agricultural area in the region (UAH per ha); B_{NAA} = the soil quality class point of the agro-production group of soils of the respective agricultural land of the natural agricultural area; $\overline{B}_R$ = the quality class point of soils of the respective agricultural land of the natural agricultural area.

The raster of regulatory and monetary valuation is the basis for determining the real value of agricultural land plots, taking into account their condition and differentiation of tax per hectare of agricultural land. In this regard, a spatial simulation was performed using geostatistics methods and map algebra of ArcGIS 10.1 software.

Table 2. Standards of capitalized rental income on agricultural lands of natural agricultural areas in the Kherson Region

Name of the natural agricultural area, area code	Area	Standards of capitalized rental income $\left(\frac{UAH}{USD}\right)$			
		arable land, fallows	perennial plants	meadows	pastures
Beryslavsky	Beryslavsky	27 954.34 1 118.17	44 201.45 1 768.06	8 696.44 347.86	22 859.53 914.38
	Velykooleksandrivsky				
	Vysokopilsky				
	Novovorontsovsky				
Nyzhnosirogozky	Velykolepetysky	27 954.34 1 118.17	49 904.86 1 996.19	7 730.17 309.21	
	Verkhnorohachytsky				
	Hornostaivsky				
	Nyzhnosirogozky				
Belozersky	Belozersky	25 804.01 1 032.16	49 904.86 1 996.19	8 696.44 347.86	
	Kherson city				
Oleshkovsky	Holoprystansky	18 636.23 745.45	17 110.24 684.41	3 140.38 125.62	
	Oleshkovsky				
	Kakhovsky				
	Nova Kakhovka city				
Skadovsky	Skadovsky	20 786.56 831.46	35 646.33 1 425.85	4 589.79 183.59	
Chaplinsky	Chaplinsky	22 936.89 917.48	35 646.33 1 425.85	5 556.06 222.24	
	Kalanchatsky				
Genichesky	Genichesky	18 636.23 745.45	35 646.33 1 425.85	4 106.65 164.27	
	Novotroitsky				
	Ivanivsky				

Source: Kabinet Ministriv Ukrayiny [2016].

RESULTS AND DISCUSSION

The total area of the Kherson Region is 2,846.1 thous. ha (Fig. 2), of which agricultural land is 1,971.0 (69.25%) thous. ha, including arable land of 1,777.6 thous. ha (90.2%).

In 1980–2020, a sustainable use of agricultural land was observed with minor increase of 0.3%. The region represents 20% of the irrigated land in Ukraine; its area is about 426.8 thous. ha (21.65%). According to recent data from the State Agency for Water Resources of Ukraine (Ukr. Derzhavne agentstvo vodnykh resursiv Ukrayiny) (2019), irrigated land used in the irrigation mode accounted for 312.4 thous. ha (73.2 %), while 114.4 thous. ha (26.8 %) remain unused. The area of rice irrigation systems is 8.1 thous. ha [BREUS *et al.* 2019]. The main types of soil in the Kherson Region are southern chernozem and dark chestnut soils, which account for 43.7% and 30.7% of the total area of agricultural land respectively (Fig. 3a).

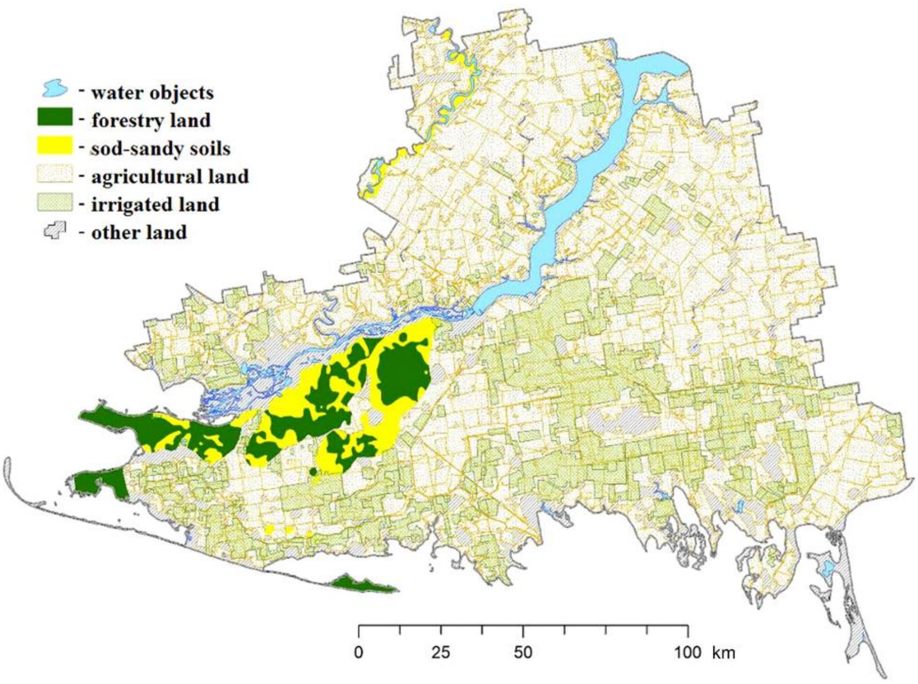


Fig. 2. Agricultural development of the Kherson Region; source: own study

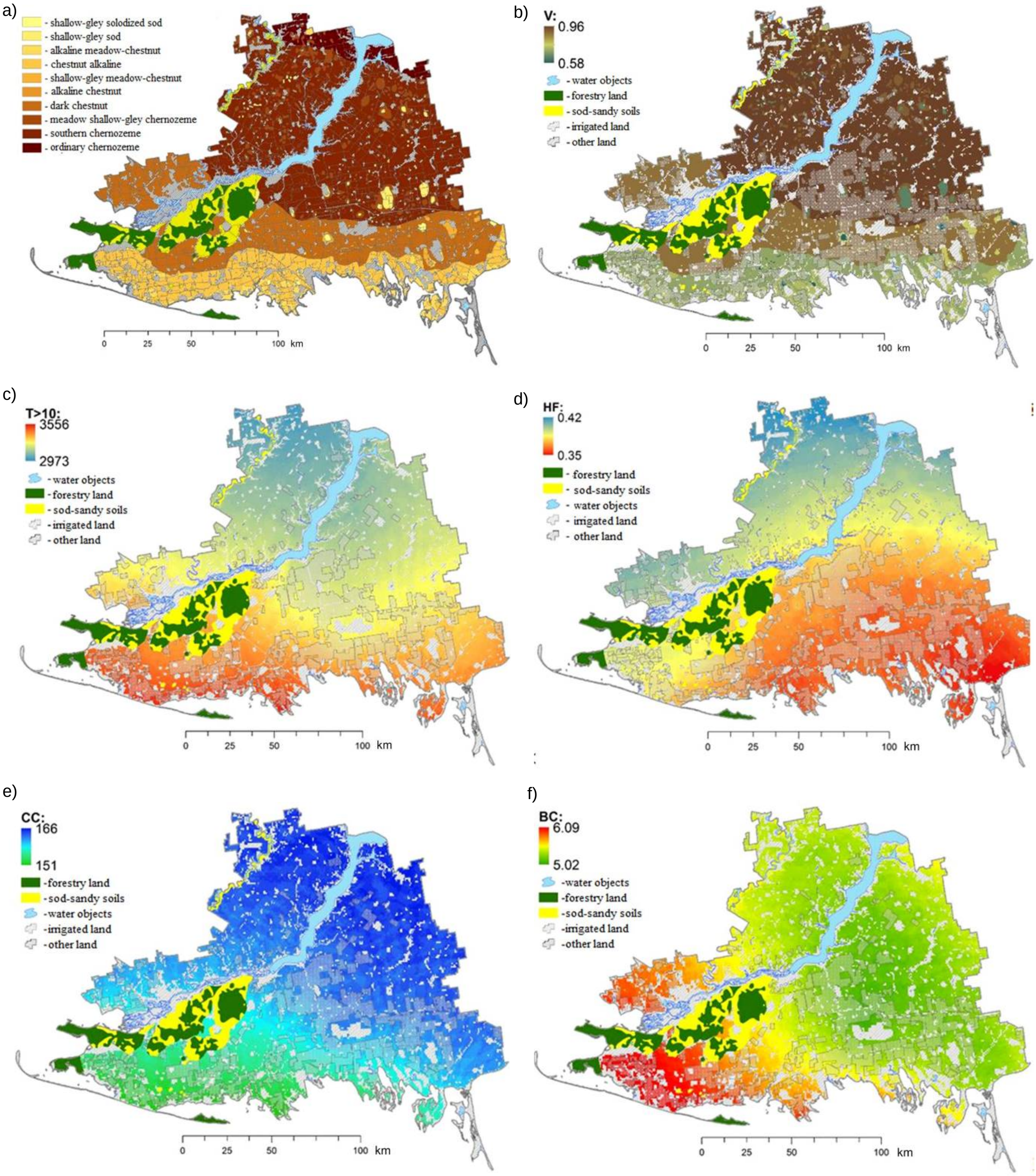


Fig. 3. Spatial distribution of soil components and climatic soil quality class in the Kherson Region: a) types of soils; b) coefficient of the total soil properties indicator (*V*); c) average annual air temperature above 10°C; d) Ivanov's humidity factor (*HF*); e) coefficient of continentality (*CC*); f) distribution of climatic quality class (*BC*); source: own study

To determine the spatial differentiation of soil and climatic quality class point of soils according to I.I. Karmanov's method, a weight coefficient of agricultural value of soils has been assigned to each agro-group, which varies from 0.58 (within sod-sandy boundaries) to 0.96 (ordinary chernozem). The resulting raster (Fig. 3b) of coefficients distribution enables to specify the quality class point for a given soil type according to the yield of agricultural crops.

Spatial differentiation of the bioclimatic potential of the territory is caused by the distribution of natural humidity, solar radiation and air temperature above 10°C (Tab. 3), which influences the processes of biochemical accumulation and migration of substances in the soil.

Table 3. Statistical characteristics distribution of the properties of bioclimatic indicators in the territory of the Kherson region

Bioclimatic indicators	Min	Max	Range	Mean	*SD*
Active temperatures above 10°C	2972.8	3555.8	583.0	3252.7	129.1
Humidity factor (*HF*)	0.354	0.422	0.068	0.383	0.015
Coefficient of continentality (*CC*)	151.63	166.18	14.55	161.25	3.28
Climatic quality class (*BC*)	5.02	6.09	1.06	5.37	0.22

Explanations *SD* = standard deviation.
Source: own study.

The sum of active temperatures above 10°C decreases from the south to the north of the Kherson Region from 3556°C to 2973°C (Fig. 3c). The humidity factor (*HF*), calculated according to M.M. Ivanov's method, characterizes the ratio of annual precipitation to annual evaporation from the relief surface and characterizes the supply of plants with water.

The value of *HF* in the region decreases from south -east to northwest from 0.35 to 0.42 (Fig. 3d), which means that landscape ecosystems function in extremely arid climatic conditions. Steppe soils belong to the area of risky agriculture with a low rate of soil formation and significant manifestations of deflationary processes.

The coefficient of climate continentality (*CC*) has the reverse value. At high values, it is characterized by high amplitude of air temperature and low level of precipitation. In the region, the *CC* value varies between 151 and 166 (Fig. 3e). The highest value of the quality class point (6.09) is typical for the southwestern territory of the region with chestnut and sod-sandy soils (Fig. 3f). More than 50% of the landscapes have the climatic quality class within 5.02–5.55 points for ordinary chernozem soils.

The relief of the territory is one of the main characteristics for the spatial extrapolation of climatic conditions, soil type and fertility. The application of relief data and its morphometric characteristics (steepness of slopes and their direction) significantly increases the reliability of estimates of agricultural landscapes, microclimate conditions and distribution balance of solar radiation and zonal soils quality class determination. The relief also affects the agrolandscape water supply which is determined by the heterogeneity of precipitation redistribution and moisture loss due to evaporation from slopes of different steepness and direction. High solar radiation on southern slopes leads to intense snow melting, water erosion of soils and reduced melt water uptake by up to 20–70% [DUDIAK *et al.* 2019a]. In particular, the absorption of melt water on the slopes facing north is 70–100%. In the mixed forest area with abundance of water, the redistribution of spring precipitation is as follows: 25–30% on southern slopes, 30–40% on northern slopes, and up to 100% at the foot. In forest--steppe and steppe areas, precipitation redistribution in spring is as follows: 15–25% on southern slopes, 25–30% on northern slopes.

The digital elevation model was created on the basis of sonar data from the shuttle radar topography mission (SRTM) with a spatial resolution of 30×30 m (Fig. 4a) and its morphometric analysis was conducted, including the determination of the spatial differentiation of slope steepness (Fig. 4b) and direction (Fig. 4c). The slope steepness in the Kherson Region ranges from 0° in the plain to 20.4° in the river coast territories. Territories located on a plateau account for 13.3% of arable land, territories with slope steepness from 0° to 1° account for 78.3%, whereas 1–2° 6.6%, 2–3° 1.3%, 3° and more account for 0.5%.

One of the main morphometric indicators for slopes is their direction (Fig. 4c), which characterizes heat supply from solar energy. This affects most types of economic activity, erosion and soil formation processes. On agricultural land in the Kherson Region, areas with different direction of slopes are distributed as follows: 5.6% (northern) to 12.4 % (western). Soils on the slopes facing north occupy 24.1% of arable land and are characterized by an increased degree of water supply. Soils on slopes facing south occupy 35.2% of arable land; they are prone to more intensive erosion as a result of snowmelt and spring showers.

It is established that the value of the solar radiation balance (R, kcal·cm^{-2}), depending on the morphometric characteristics of the relief in the region varies within 38.4–47.2 kcal·cm^{-2} (Fig. 4d). The solar radiation balance increases the soil quality class point when determining the sum of active temperatures, and lowers it when determining the humidity coefficient.

In 1966–2019, during vegetation periods, a positive trend-cyclical pattern of temperature regime change was observed. Two periods of air temperature formation are determined (T, °C): period I (1966–1996) – stable with average value $\overline{T}$ = 16.54 ± 0.16, variation level V = 5.4% and slight trend of $T = -0.168 \ln(t) + 16.96$; r = 0.16 type; period II (1997–2019) – rapid rise in the value of the average vegetation air temperature by 1.6°C with an average value $\overline{T}$ = 18.12 ± 0.31, variation level V = 7.4% and a significant trend component $T = 16.403\ e^{0.0102t}$; r = 0.76.

The main component of energy expenditure for soil formation and formation of soil quality class points is the total precipitation (P, mm). In areas of irrigation and amelioration, the total water supply is additionally determined by the irrigation rate (IN, mm). Between 1966 and 2019, the average value of the total precipitation in the Kherson Region varied from south to north between 155 and 330 mm during vegetation. In particular, the total water supply ($P + IN$, mm) on the irrigated lands was 345–410 mm (Fig. 5a), which led to an increase in energy expenditures for soil formation compared to the non-irrigated lands by 335 MJ·m^{-2} (up to 850 MJ·m^{-2}) and increase in the irrigated soil quality class. The total amount of energy expenditure for soil formation in the region varied from 265–765 MJ·m^{-2} on non-irrigated land to 790–910 MJ·m^{-2} on irrigated land during the vegetation period. The annual cycle of natural water supply necessitates the adjustment of the irrigation standard in order to obtain stable yields of agricultural crops (Fig. 5b).

The main soil quality class index reflects the soil agrochemical condition which is characterized by major macronutrition components, such as humus, nitrification nitrogen, exchangeable potassium and mobile phosphorus (Tab. 4).

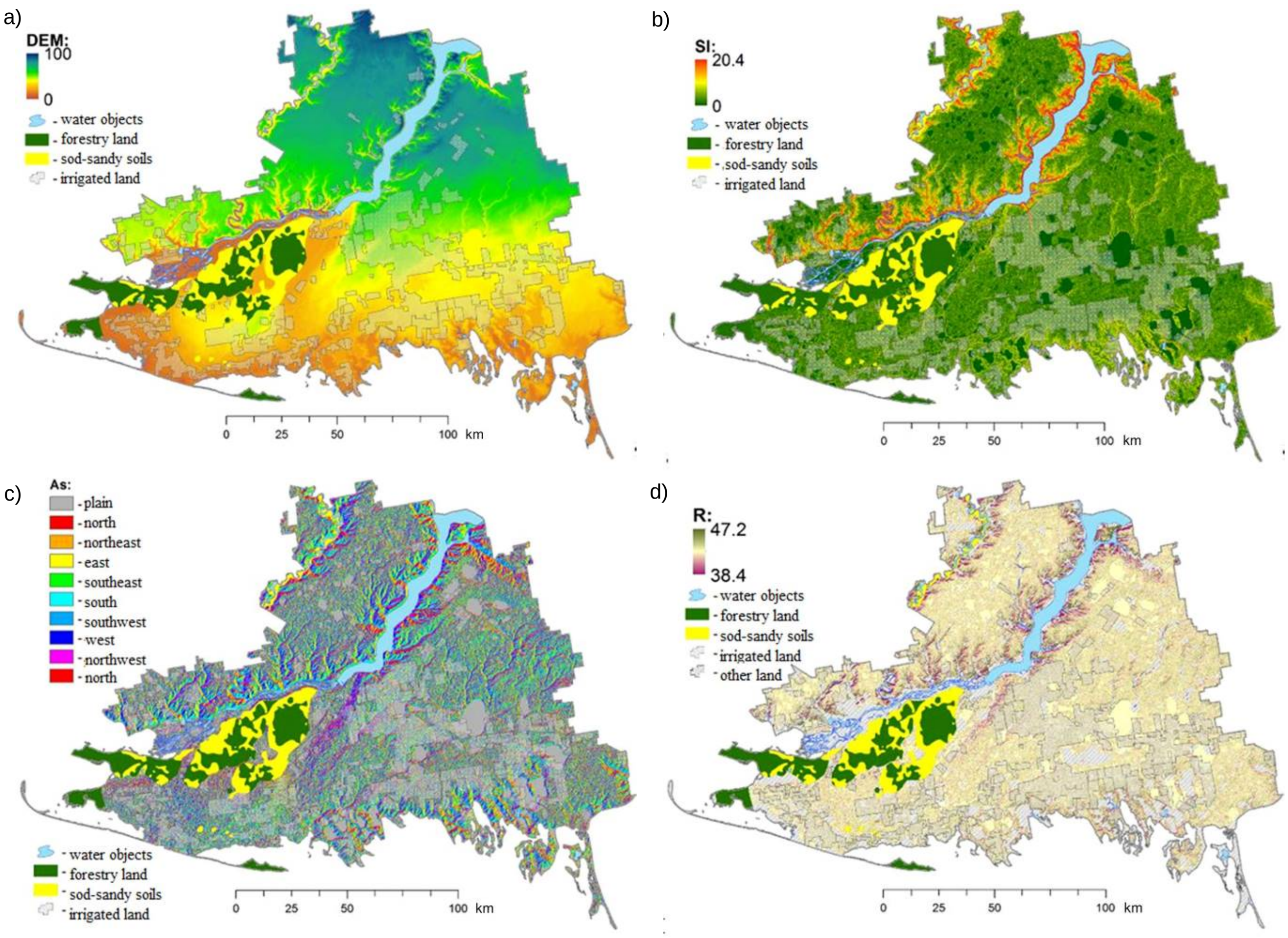


Fig. 4. Morphometric characteristics of the Kherson Region: a) digital elevation model (DEM), m; b) slope steepness (*Sl*), degree; c) slopes direction (*As*); d) surface radiation balance (*R*), kcal·cm^{-2}·y^{-1}; source: own study

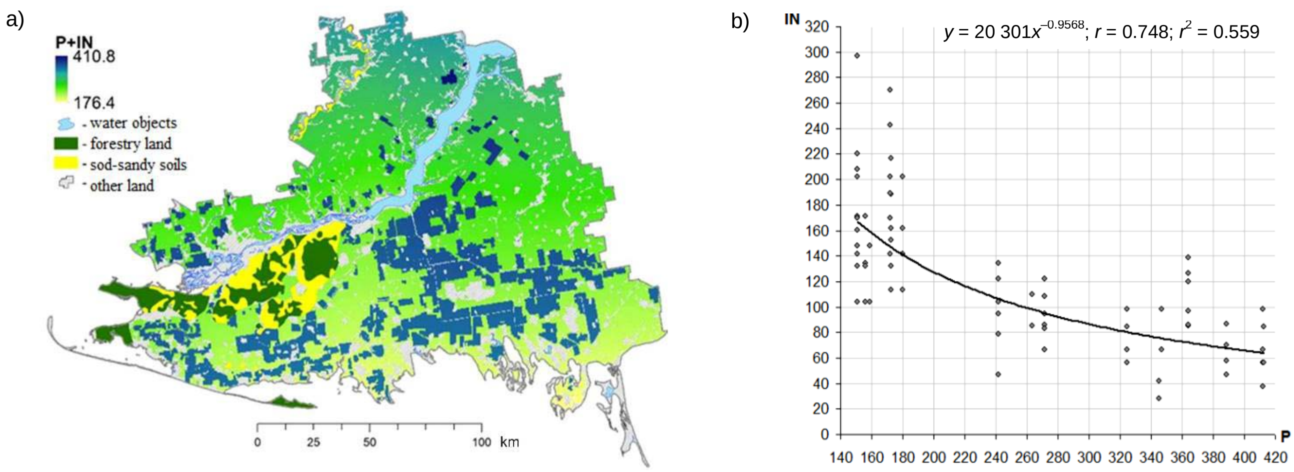


Fig. 5. Total water supply ($P + IN$, mm) on agricultural land of the Kherson Region during vegetation in 1966–2019 (a) and dependence of spatiotemporal differentiation of *IN* and *P* (b); source: own study

The soil cover of the Kherson Region is characterized by low-humus soils with humus content within 0.30–3.85% (Fig. 6a). The spatial heterogeneity of the humus content is determined by the complexity of the soil structure, which is determined chiefly by zonal factors of soil formation and heterogeneity of hydrothermal conditions, as well as by the development of gley processes in groundwater due to their sporadic excessive water saturation by melt and rain water, and by an intense process of alkalinization and salinization in shallow groundwater.

Features of the soil cover determine the initial humus content, which undergoes dynamic changes as a result of economic activity. This is determined by farming intensity and standards within land plots (crop rotation fields) and land use. In irrigation conditions, humus content in different soil types in the region (layer 0–20 cm) on average is

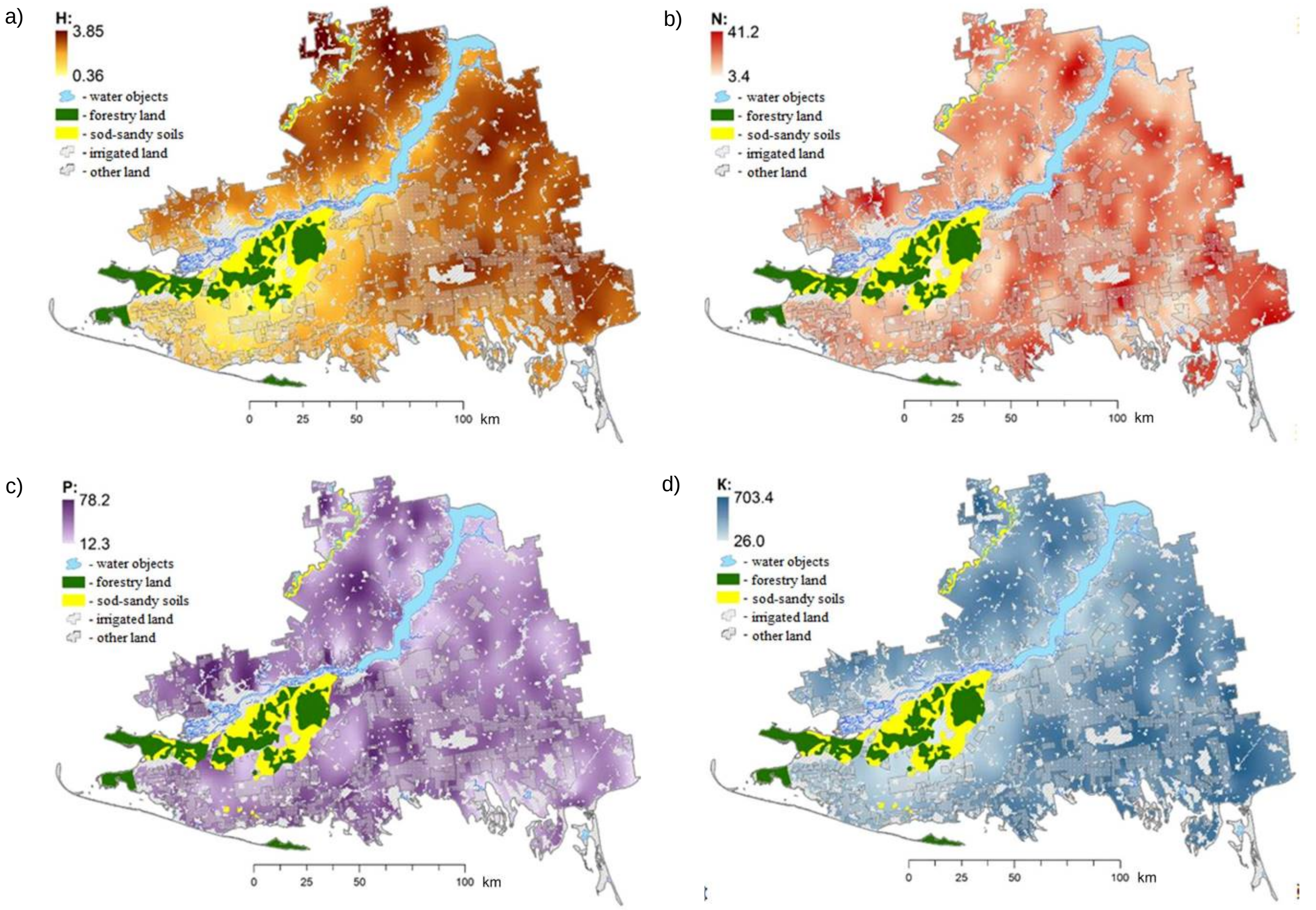
Table 4. Statistical characteristics distribution of the properties of agrochemical indicators in the territory of the Kherson region

Agrochemical indicator	Min.	Max.	Range	Mean	*SD*
Humus (H)	0.36	3.85	3.49	2.44	0.64
Nitrification nitrogen (N)	3.39	41.23	37.84	20.52	5.05
Exchangeable potassium (K)	25.99	703.42	677.42	401.84	134.44
Mobile phosphorus (P)	12.29	78.23	65.94	41.27	9.73

Explanations: *SD* = standard deviation.
Source: own study.

0.1–0.5% less than that for non-irrigated lands. This is determined by the intensity and technological features of irrigated meliorations (water quality, irrigation standards, crop rotations, etc.).

Dehumification of soils is explained by an increased mineralization of organic matter as a result of intensive treatment and imbalance of production and soil formation processes, insufficient intake of crop residues and organic fertilizers within the arable horizon, increase in the proportion of tilled crops, reduction in the proportion of perennial grasses in field crop rotations, dominating use of mineral fertilizers (especially their physiologically acid forms), insufficient use of crop residues as organic fertilizers, stubble burning, frequent burning of residual straw, water erosion, including irrigation erosion, and soil deflation, as well as the result of a long-lasting irrigation [LISETSKII *et al.* 2017a].



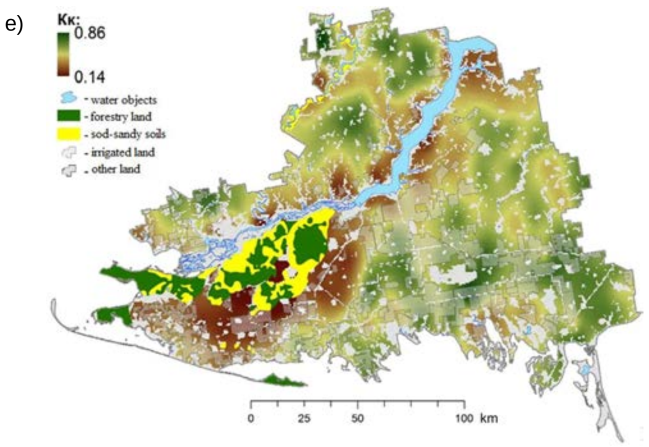


Fig. 6. Agrochemical condition of agricultural lands in the Kherson Region (2013–2017): a) humus content (*H*, %); b) nitrogen content by soil nitrification capacity (N, mg·kg^{-1} of soil); c) mobile phosphorus content (P, mg·kg^{-1} of soil); d) radiation content of exchangeable potassium (K, mg·kg^{-1} of soil); e) raster of the correction factor of the soil quality class point by agrochemical properties (K_K); source: own study

Over the last 50 years, the intensification of negative degradation processes in the soil cover has resulted in the decrease of the humus content in steppe soils by 0.36% (from 2.56 to 2.20%). At the same time, a high spatial heterogeneity of the humus distribution is observed on irrigated dark chestnut soils in the southern part of the Kherson Region (59.3% of irrigation area). Thus, a specific degradation of soils has been taking place, which is the result of excess irrigation of agricultural land.

The humus content in the soil (Tab. 5), which meets quality gradations of medium and increased content (>2.1%), is typical for 72.5% of the agricultural land in the Kherson Region.

Table 5. Distribution of humus content in soils of agricultural lands in the region

Humus content		Distribution of agricultural lands	
class	%	thous. ha	%
Extremely low	<1.10	124.4	6.3
Low	1.10–2.09	418.3	21.2
Medium	2.10–3.09	1 182.3	60.0
Increased	3.10–4.09	246.0	12.5
	Total	1 971.0	100.0

Source: own study.

The highest weighted average value of humus content of 3.04% was recorded in the ordinary chernozem soil located in the northern part of the region, the lowest humus content of 0.88% was found in sod-sandy soils. Nitrogen is an important biological element and plays an exceptional role in the life of plants. In 1998–2017, there was a negative trend in the nitrogen content formation in the arable layer (0–20 cm) of soil in the Kherson Region ($NO_3 = –0.53t^2 + 0.966t + 16.74$; $R^2 = 0.24$), which led to the decrease of its content by 17.0% (from 23.0 to 19.1 mg·kg$^{–1}$). Nitrogen content in soils (Fig. 6b, Tab. 6), which meets quality gradations from medium to increased content (>21.0 mg·kg$^{–1}$), characterizes 47.4% of the agricultural land area. The highest share of agricultural land with a medium-to-increased nitrogen content and nitrification capacity was noted in the central and eastern parts of the region.

Table 6. Distribution of nitrification nitrogen content in soils of agricultural lands in the region

Nitrification nitrogen content		Distribution of agricultural lands	
class	mg·kg$^{–1}$	thous. ha	%
Extremely low	<10.0	64.0	3.2
Low	11.0–20.0	972.1	49.3
Medium	21.0–30.0	881.5	44.7
Increased	31.0–45.0	53.4	2.7
	Total	1 971.0	100.0

Source: own study.

In addition, phosphorus is an important and scarce nutrient. It is a compound of nucleoproteins, sugar-phosphates, phosphatides and other compounds, is actively involved in metabolism and protein synthesis, determines the energy of cells, and affects plant growth. Over the last 50 years, in the Kherson Region, the content of mobile phosphorus in the soil layer of 0–20 cm has decreased by 34.17% (from 62.0 to 40.8 mg·kg$^{–1}$) and has a negative tendency to decrease the content: $T = –10.59 \ln(t) + 62.31$; $R^2 = 0.98$. The content of mobile phosphorus in soils (Fig. 6c, Tab. 7) from increased to extremely high content (>31.0 mg·kg$^{–1}$) is typical for 87.3% of agricultural land. The vast majority of the region's land (56.2%), mainly in irrigated areas, are characterized by high and extremely high levels of mobile phosphorus.

Table 7. Distribution of mobile phosphorus content in soils of agricultural lands in the region

Mobile phosphorus content		Distribution of agricultural lands	
class	mg·kg$^{–1}$	thous. ha	%
Medium	16.0–30.0	250.0	12.7
Increased	31.0–45.0	1 064.4	54.0
High	46.0–60.0	599.7	30.4
Extremely high	>60.0	56.9	2.9
	Total	1 971.0	100.0

Source: own study.

The presence of different forms of potassium in the soil related to the primary and secondary minerals has been determined together with features of their transformation. Over the past 50 years, in the Kherson Region, the exchangeable potassium content in the 0–20 cm soil layer decreased by 18% (from 442.4 to 363.8 mg·kg$^{–1}$) and keeps the downward trend: $T = –36.87 \ln(t) + 437.75$; $R^2 = 0.97$. The spatiotemporal heterogeneity of the decrease in potassium in soils from 50 to 210 mg·kg$^{–1}$ (from 10% to 50%) is determined by the absence of regular, uniform flow of mineral fertilizers, water erosion, including irrigational erosion, and soil deflation, as well as the result of long-lasting irrigation. The content of exchangeable potassium in soils (Fig. 6d, Tab. 8) from medium to extremely high content (>200 mg·kg$^{–1}$) is typical for 85.8% of agricultural land. The high content of exchangeable potassium in excess of 400 mg·kg$^{–1}$ in soil is recorded in the northwestern and southeastern parts of the region.

Table 8. Distribution of exchangeable potassium content in soils of agricultural lands in the region

Exchangeable potassium content		Distribution of agricultural lands	
class	mg·kg$^{–1}$	thous. ha	%
Extremely low	<100	70.6	3.6
Low	101–200	211.2	10.7
Medium	201–300	459.8	23.3
Increased	301–400	572.6	29.1
High	401–600	596.3	30.3
Extremely high	>600	60.5	3.1
	Total	1 971.0	100.0

Source: own study.

The raster of agrochemical properties complex factor (K_K) was created to clarify the spatial differentiation of the steppe soils quality class point. It has been found that the value of K_K varies from 0.14 to 0.86 (Fig. 6e). The most productive soils in terms of agrochemical properties are agricultural lands with the ordinary chernozem soil in the northern part and southern chernozem of the eastern and western parts of the region. The least productive soils for growing agricultural crops are lands with dark chestnut and chestnut alkaline soils located in the southwestern part of the region.

Additional components for determining the soil quality class point in the irrigation area are indicators of the ecological and ameliorative condition of the land, i.e. groundwater level and the degree of soil salinization, which negative manifestations affect the level of agricultural crop failure. Depending on groundwater levels (GWL) and the degree of soil salinization, agricultural crop losses reach up to 60%. Therefore, it is suggested to include correction factors in the methodology for the calculation of the soil quality class in the irrigation area. These factors should take into account the deterioration of the ecological and ameliorative condition of irrigated and adjacent lands and the reduction of the soil quality class level.

As a result of spatiotemporal studies, a periodic flooding of irrigated lands and adjacent territories has been observed in the last 20 years (Fig. 7).

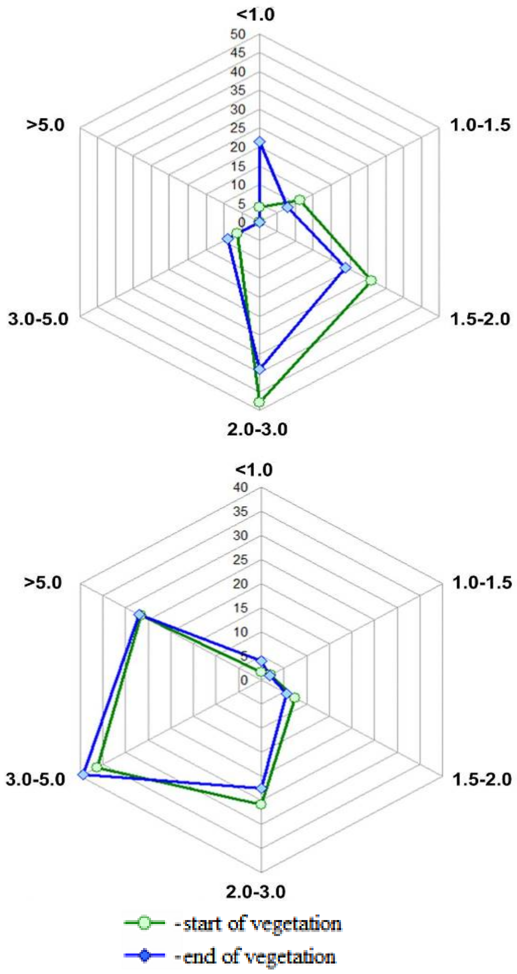


Fig. 7. Distribution of irrigated and adjacent lands in the Kherson Region in 2000–2019: a) rice systems; b) non-rice systems; source: own study

Changes in groundwater levels depend on the total precipitation, mode of irrigation, infiltration of irrigation channels and the efficiency of collector and drainage systems. The most regular flooding (GWL < 2 m) occurs on territories occupied by rice systems (Fig. 7a) at the start and at the end of vegetation, respectively 46.3% and 73.3%. Areas without rice systems are 11.2% flooded (Fig. 7b).

As a result of spatial modelling, periodic flooding has been observed on agricultural land occupied by rice in the Kherson Region (Fig. 8a). Flooding takes place along the edges of irrigation areas at the lowest geodetic marks, at the depth of groundwater, in areas located along the irrigation canals, coastal areas of the Black and the Azov Seas. Territories with the GWL less than 2 m make up 4.7% of agricultural land, from 2 to 3 m – 10.9%, within 3–5 m – 22.3%, and 5 m and more – 62%. According to the group of bogginess complexion, corresponding correction factors from 0.8 (flooded territories) to 1.0 (non-flooded territories) were assigned to soils in the region and the raster of negative impact of the GWL on soil fertility properties was created (Fig. 8b).

Alkalinization and re-salinization of agricultural land occurs in natural conditions of arid regions due to excess irrigation, low natural outflow of mineralized groundwater and poor drainage and overflow network of the irrigation system. This results in a capillary rising of brackish and saline water, degradation of soil and increase in space concentrations of alkaline soils. They have low fertility rates and are poorly suited for growing most agricultural crops due to their agrophysical and chemical properties.

According to salt imaging and studies at the saline stations of the Kakhovka Hydrogeological and Ameliorative Expedition to the Kherson Region, an appropriate interpretative map was created and the spatial distribution of land by degree of salinization was determined (Fig. 8c).

About 80% of the territory of agricultural lands in the region are non-saline and non-saline with soda content soils; 9.6% are saline, 7.0% are medium saline, and 3.4% are highly saline soils. The main part of the land with manifestations of soil salinization is located on the irrigated area in the southern part of the region. According to the group of soil salinization complexity, soils in the region were matched with corresponding correction factors from 0.4 (highly saline) to 1.0 (non-saline) and the raster of negative impact of salinity level on soil fertility properties was created (Fig. 8d).

According to the abovementioned characteristics and soil fertility properties, rasters were created reflecting spatial distribution of steppe soils quality class using two calculation methods: soil and climatic quality class determination by I.I. Karmanov, where the quality class varies from 25 to 46 points (Fig. 9a) and a modified model of ecological, agro-ameliorative and climatic soil quality class determination, where the quality class varies from 6 to 59 points (Fig. 9b).

The spatial division of areas using two methods of soil quality class determination is given in Table 9. Each point is equal to the unit of potential crop yield ($0.1\ Mg \cdot ha^{-1}$). The application of the method modified by the authors allows for objective soil quality class determination for grain crops cultivation. It also enables to take into account additional parameters of modern agrochemical soil condition,

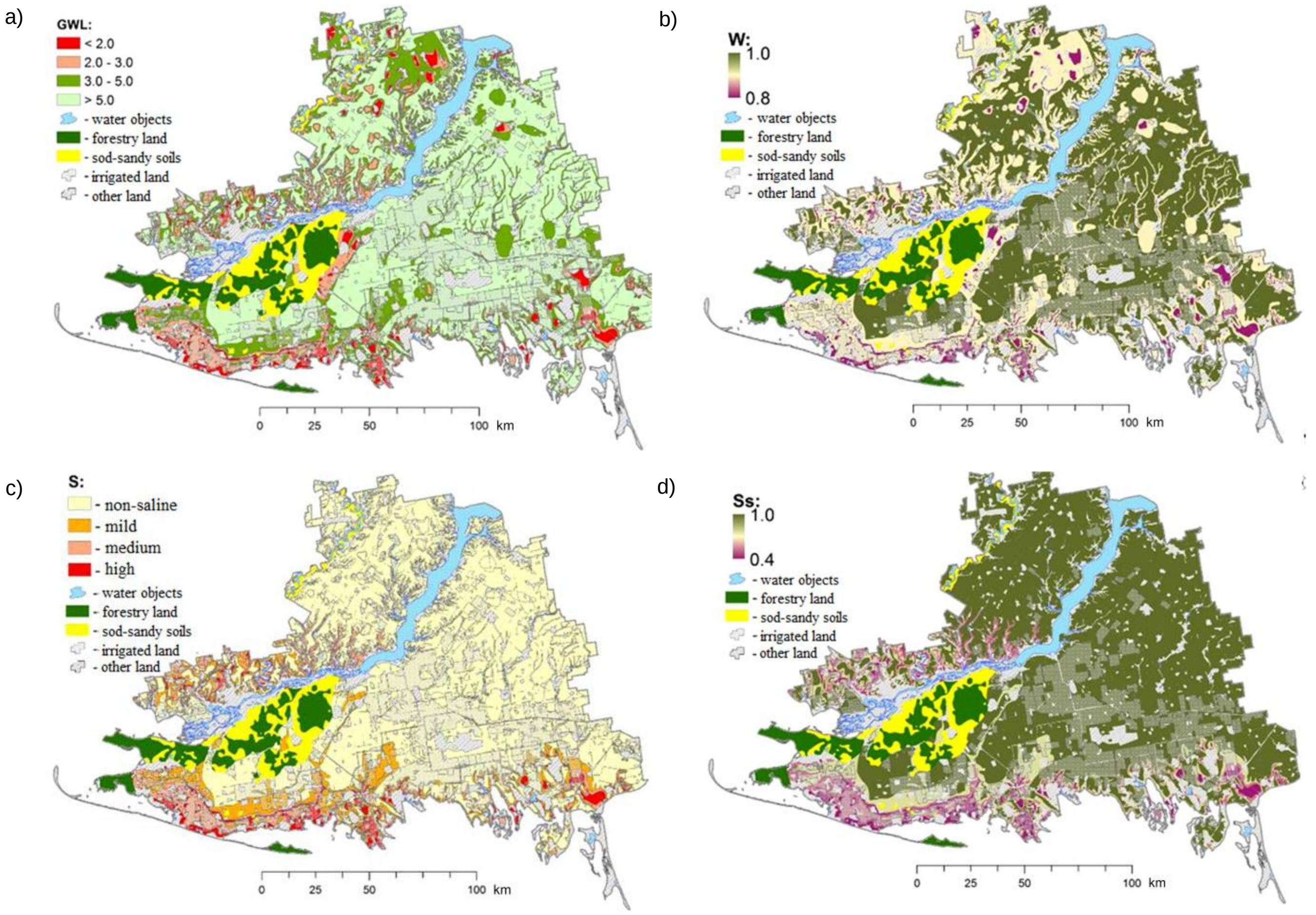


Fig. 8. Spatial differentiation of ecological and ameliorative condition of soils in the Kherson Region: a) groundwater level (*GWL*, m); b) groundwater level correction factors (*W*); c) degree of soil salinization (*S*); d) soil salinity correction factors (*Ss*); source: own study

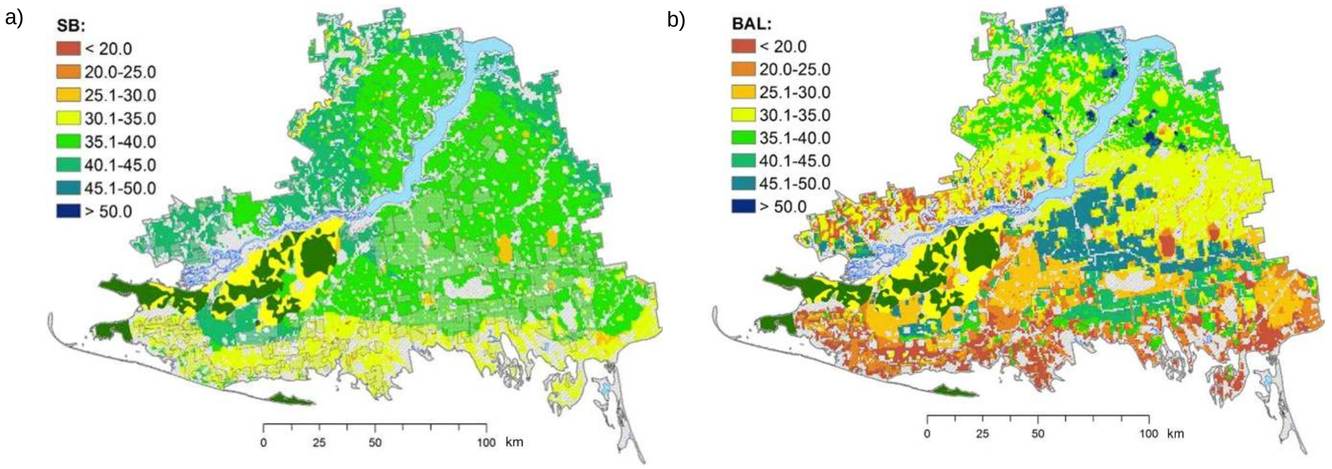


Fig. 9. Spatial differentiation of soil quality class in the Kherson Region for grain crops cultivation: a) soil and climatic quality class determination (*SB*, Eq. (1)), point; b) ecological, agro-ameliorative and climatic soil quality class determination (*BAL*, Eq. (4)); source: own study

morphometric characteristics of the relief, distribution of solar radiation, irrigation rates and the ecological and ameliorative soil condition.

The comparison of raster models of soil quality class point differentiation gives an opportunity to establish a reliable regulatory and monetary valuation and objectively determine the amount of tax in the steppe soils irrigation zone.

The application of the standard of capitalized rental income from arable land in the region and the spatial differentiation of the regulatory and monetary valuation of agricultural land on irrigated and non-irrigated steppe soils were based on *SB* and *BAL* rasters. Based on soil and climatic conditions (*RMVsb*, Fig. 10a), the value of agricultural land in the Kherson Region varies from USD490

Table 9. Distribution of agricultural land in the Kherson Region by soil quality class point

Point	I.I. Karmanov's soil and climatic quality class determination (method 1 – M1)		Modified model of ecological, agro-ameliorative and climatic soil quality class determination (method 2 – M2)		M2 – M1 (%)
	thous. ha	%	thous. ha	%	
<20	3.7	0.2	227.5	11.5	+11.3
20–25	9.5	0.5	219.4	11.1	+10.6
25–30	39.4	2.0	319.5	16.2	+14.2
30–35	331.4	16.8	518.2	26.3	+9.5
35–40	1 125.3	57.1	310.9	15.8	–41.3
40–45	461.6	23.4	162.5	8.2	–15.2
45–50	–	–	203.7	10.3	+10.3
>50	–	–	9.4	0.5	+0.5
Total	1 971.0	100	1 971.0	100	–

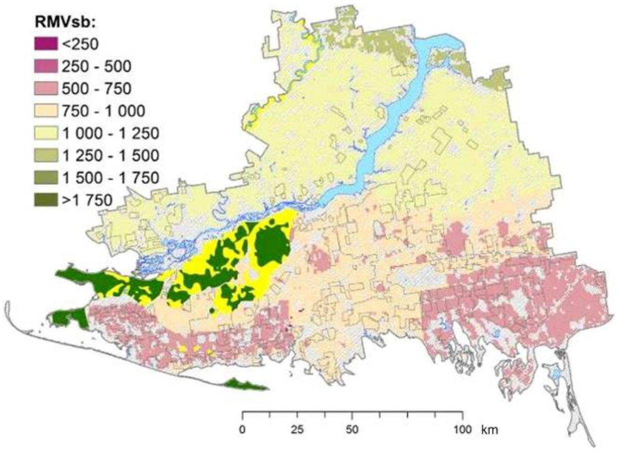
Source: own study.

(dark chestnut and chestnut alkaline soil) to USD1,360 per 1 hectare (ordinary chernozem soil), whereas based on ecological, agro-ameliorative and climatic conditions (*RMVbal*, Fig. 10b), from USD145 (degraded and highly saline chestnut soils) to USD2,060 per hectare (irrigated southern chernozem soils). The spatial differentiation of changes in the regulatory and monetary valuation of agricultural land depending on the method of soil quality class determination is presented in Figure 10c.

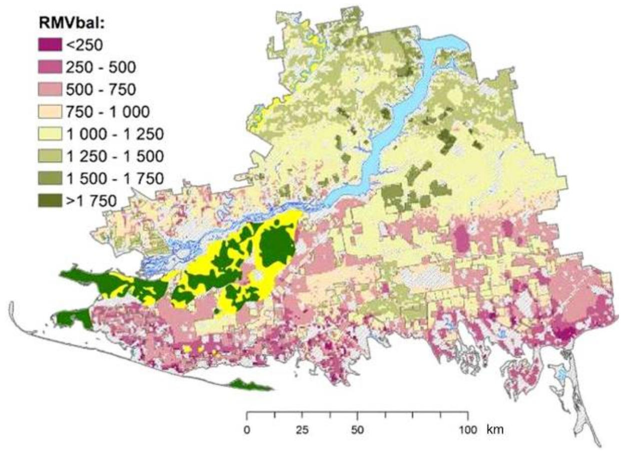
Based on the regulatory and monetary valuation, the total value of agricultural land in the Kherson Region is USD26.46 m according to the *RMVsb* model, and USD29.91 m according to the *RMVbal* model.

To increase information and define the quality class point in order to conduct the regulatory and monetary valuation of land in the steppe soils irrigation zone, it is necessary to introduce a geo-information and analytical system for soils monitoring using official data from relevant research government agencies and satellite images. It also enables to develop a complex of ameliorative measures to improve soil fertility properties. The system of spatial differentiation of soil protective measures should include: organizational and economic ameliorative measures, i.e. creation of a system of soil-protective crop rotations, mosaic structure of lands, conservation of degraded land, etc.; hydro-ameliorative measures, i.e. sustainable irrigation, erosion prevention ponds, water protection areas, reconstruction and modernization of irrigation and collector and drainage systems etc.; agro-ameliorative measures, such as a limited use of heavy tillage machinery, creation of buffer strips of perennial grasses, soil protection technologies, reduction of the amounts of pesticide application, cross plowing of slopes, etc.; forest-ameliorative measures, i.e. field protection, drain regulation and spur forest strips; and continuous afforestation of slopes etc.

a)



b)



c)

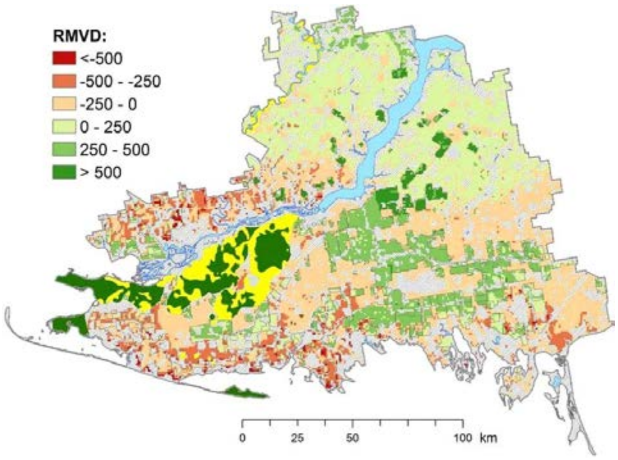


Fig. 10. Spatial differentiation of regulatory and monetary valuation of agricultural land (RMV) in the Kherson Region: a) RMV using soil and climatic quality class determination (*RMVsb*, USD); b) RMV using ecological, agro-ameliorative and climatic quality class determination (*RMVbal*, USD); c) difference "*RMVbal – RMVsb*" (USD); source: own study

CONCLUSIONS

The article provides a comparison between I.I. Karmanov's methodology of soil and climatic quality class determination and the methodology of ecological, agro-ameliorative and climatic soils quality class determination modified by the authors. The research was conducted on the example of the Kherson Region, Ukraine. The approval of the authors methodology and results obtained for the steppe zone soils have ensured the objective spatial differentiation of the agricultural land regulatory and monetary valuation in the irrigation area. The study developed raster models and established spatial distribution patterns of soil quality class. In particular, the components of the soils quality class include total soil property index, moisture coefficient, coefficient of climate continentality, average annual sum of active temperatures over 10°C, differentiation of solar radiation balance, average annual sum of precipitation and irrigation rate during vegetation, indicators of agrochemical soil properties, groundwater level and soil salinization type. Rasters of steppe soil quality class spatial distribution were created using two calculation methods. According to the results of I.I. Karmanov's soil and climatic quality class determination, it is established that the value of the class varies from 25 to 46 points; the regulatory and monetary value of agricultural land varies from USD490 per 1 ha for dark chestnut and chestnut alkaline soils up to USD1,360 per ha for ordinary chernozem. According to the results of ecological, agro-ameliorative and climatic soils quality class determination, the value of the class varies from 6 to 59 points; the regulatory and monetary value of agricultural land varies from USD145 per 1 ha for degraded and highly saline chestnut soils up to USD2,060 per ha for irrigated southern chernozem. The advanced methodology of soils quality class calculation suggested by the authors can have multiple purposes and can be suitable for different physiographic conditions of land use. It increases information and improves an objective determination of the ecological and agro-ameliorative condition of agricultural land. It improves the process of zonal soils quality class determination, increases the objectivity of regulatory and monetary valuation and tax rate on the use of agricultural land. This enables to substantiate the spatial differentiation of soil protection measures, the need for state and regional grants for the implementation of projects promoting sustainable land use. This will also ensure the zonal adjustment of irrigation standards to increase yield, save irrigation water and reduce the profile of soil degradation in irrigated areas.

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