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Sławomir Klatka *, Magdalena Malec *, Marek Ryczek *, Edyta Kruk *

Use of the synthetic index of agricultural environment quality for evaluation of soils degraded as a result of stone coal exploitation

Zastosowanie syntetycznego wskaźnika jakości środowiska rolniczego do oceny gleb zdegradowanych w wyniku eksploatacji węgla kamiennego

** Dr inż. Sławomir Klatka, dr inż. Magdalena Malec, dr hab. inż. Marek Ryczek, dr inż. Edyta Kruk - Department of Land Reclamation and Environmental Development, Agriculture University of Krakow, Mickiewicza 24/28 St, 30-059 Krakow, Poland; phone: +48 12 662 40 15, e-mail: rmklatka@cyf-kr.edu.pl*

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Abstract
In the work, evaluation of agricultural production space of the area at the Węglowa street in Jastrzębie Zdrój is presented. The method of the synthetic indicator proposed at the Institute of Soil Science and Plant Cultivation in Puławy was used in the calculation. The determined synthetic indicator of agricultural production space of the investigated area classifies it as the area of mean conditions for agricultural production. Geomechanical and hydrological degradation of soil increasing in time may cause changes of values of this indicator and also high deterioration of environmental conditions of agricultural production.

Streszczenie
W pracy dokonano waloryzacji rolniczej przestrzeni produkcyjnej terenu w rejonie ulicy Węglowej w Jastrzębiu Zdroju. W obliczeniach wykorzystano metodę syntetycznego wskaźnika opracowaną w Instytucie Upraw Nawożenia i Gleboznawstwa w Puławach. Wyznaczony syntetyczny wskaźnik jakości rolniczej przestrzeni produkcyjnej badanego terenu klasyfikuje go jako obszar o średnich warunkach do produkcji rolnej. Nasilająca się w czasie degradacja geomechaniczna i hydrologiczna gleb może powodować zmiany wartości tego wskaźnika i znaczne pogorszenie się warunków środowiskowych produkcji rolniczej.

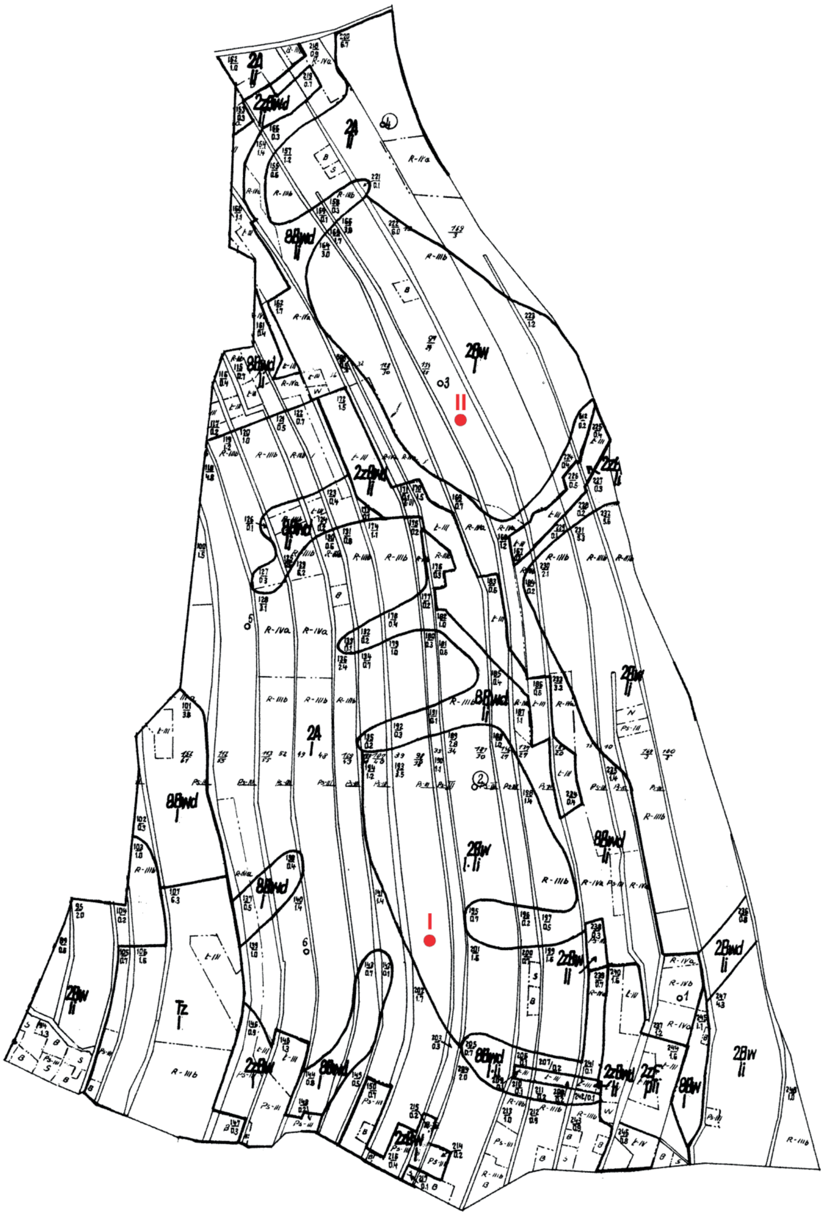
1. INTRODUCTION

Mining of every mineral resource causes various transformations of biologically used sites. The changes are visible in both soil cover and geological structure, as well land shape and land use [Szafrański et al. 2011]. In areas of intensive industrial exploitation, which are, for example, regions of hard coal mining, almost every element of natural environment undergoes degradation. In Poland, the highest degradation is observed on the area of the Upper Silesia, where high concentration of mine plants caused formation of the largest transformations of areas agriculturally used [Boroń and Klatka 1997]. Degradation of agricultural production space on former mining areas is mainly caused by geomorphological transformations as a result of surface settlement. For evaluation of agricultural areas on former mining sites, various indicators were used [Klatka et. al 2014]. In the used methods, most often agricultural space is evaluated taking into account a group of natural or anthropogenic factors. Natural factors decide mainly a form of land use for a particular agricultural use [Dudzińska 2011]. In Poland, three basic forms of agricultural soil evaluation were undertaken so far. They are: (i) soil suitability classification, (ii) complexes of agricultural usefulness and (iii) numerical and description evaluation methods [Koreleski 1993]. The first method allows to compare agricultural uses of lands taking into account their productivity. The second method supplements the first one, excluding lack comparability of soil suitability classes regarding nature. The third method combines the first two and additionally introduces the next elements of environment (climate, relief and water conditions) enabling determination of synthetic indicators of quality of agricultural production space [Klatka et al. 2011].

The aim of the work was evaluation of agricultural productivity space of the chosen area being the part of exploitation site of the Hard Coal Mine ‘Borynia – Ruch’ in Jastrzrębie Zdrój using the method of synthetic indicator proposed by Witek [1981].

2. MATERIALS AND METHODS

Investigations were carried out on the area of Jastrzębie Zdrój at the Węglowa street. This area undergoes high-mine anthropopressure exerted by the Hard Coal Mine ‘Ruch – Borynia’, and its result is surface settlement reaching this area with a mean of 1.0 m. In the framework of field investigations, two openings with description of morphological parameters were carried out and material for laboratory investigations was taken. Location of openings was presented on Fig. 1. The areometric Cassagrande’s method in Prószyński’s modification for the



Legend: I, II - soil openings

Figure 1. Soil map of the investigated area.

laboratory determination of texture and determination of physical properties by the ring method were chosen. Granular groups and subgroups were determined based on the Polish Standard PN-R-04033. Reaction using the potentiometric method in 1 n KCL and water as well as electric conductivity using the conductimeter method were carried out. Results of investigations were presented in Tables 1, 2 and 3.

The actual quality and agricultural usefulness of the investigated area were evaluated by the method of synthetic indicator elaborated in the Institute of Soil Science and Plant Cultivation in Puławy [Witek 1981]. The method allows to evaluate of natural conditions of agricultural production. It is based on four diagnostic properties that characterize agricultural production space: soil, relief, climate conditions and soil-water conditions. For all of the properties, proper numerical values were obtained. The sum of points for the particular elements gives the synthetic indicator of agricultural quality of agricultural production space *S*, in theoretical interval of 0–120 points.

$$S = W_b + W_{rz} + W_k + W_{SW} \quad \text{[points]}$$

where:

S is the synthetic indicator of quality of agricultural production space [points]

W_b the indicator of soil suitability [points]

W_{rz} the indicator of relief [points]

W_k the indicator of agroclimate [points]

W_{sw} the indicator of soil water conditions [points]

Table 1. Texture of investigated soils.

Opening no	Layer	Particle content [%]			Symbol PN-R-04033
		2-0,5 mm	0,05-0,002 mm	<0,002 mm	
I	0-28	36	42	22	g
	29-76	32	44	24	g
	77-150	48	43	9	g
II	0-30	46	24	30	gs
	31-62	62	12	26	gs
	63-96	64	16	20	gs
	97-150	59	20	21	gs

Table 2. Physical and water-physical properties of investigated soils.

Opening no.	Layer [cm]	Wm [% mas.]	Wv [% vol.]	ρo [Mg·m^{-3}]	ρo ‘ [Mg·m^{-3}]	ρs [Mg·m^{-3}]	Po [% obj.]
I	0-28	28,42	39,65	1,42	1,81	2,55	44,15
	29-76	22,56	33,05	1,48	1,86	2,61	42,27
	77-150	19,67	30,19	1,52	1,94	2,64	41,54
II	0-30	31,15	42,69	1,38	1,82	2,61	45,18
	31-62	26,15	39,25	1,51	1,84	2,66	42,18
	63-96	22,56	35,68	1,55	1,91	2,64	41,39
	97-150	18,15	31,26	1,58	1,88	2,65	40,18

Identification:
Wm – mass water content, Wv – volumetric water content, ρo – bulk density, ρo ‘ – actual bulk density, ρs – specific gravity, Po – total porosity

Table 3. Physical-chemical properties of investigated soils.

Opening no	Layer [cm]	pH_{H2O}	pH_{KCL}	Electric Conductivity [mS·cm^{-1}]
I	0-28	6,5	6,7	0,025
	29-76	6,4	6,8	0,042
	77-150	6,3	6,7	0,018
II	0-30	6,2	7,1	0,026
	31-62	6,4	6,7	0,019
	63-96	6,2	6,8	0,015
	97-150	6,3	6,4	0,019

The indicator of soil suitability is calculated as the arithmetic mean of sum of points for soil suitability class and complex of agricultural usefulness, based on ratios elaborated by the Institute of Soil Science and Plant Cultivation in Puławy [Witek 1981]. The indicator of relief was determined based on analysis of the percentage share of distinguished types of relief within agricultural uses and proper points according to Witek [1981]. The indicator of agroclimate was based on assumption of uniformity of all of climatic factors of the environment. This indicator is expressed on a 10-point scale.

Het indicator of soil water conditions was determined based on the yield risk and field as well as laboratory investigations. Taking into account the fact that water conditions were partially taken into consideration in suitability classes and complexes of agricultural usefulness, the scale for this indicator is 5-point scale [Witek 1981].

In summary, the evaluation of natural conditions of agricultural production on the investigated area was carried out for 98 soil-agriculture contours, presented on the soil-agriculture map (Fig. 1).

3. RESULTS

Based on the soil-agriculture map on a scale of 1:5000, it was stated that in the region of the Węglowa street in Jastrzębie-Zdrój, typically brown and leached-brown soils prevail in majority. The analysis of soil science investigations and laboratory determination led to the conclusion that, according to Systematic of Soils in Poland [PTG 2011], the investigated soils are in the order: brown forest soils, type: typical brown eutrophic and subtype: leached eutrophic brown. These are soils similar to the brown soils but have another reaction – lightly acid and neutral. These are the results of determination of chemical soil properties (tab. 3). Analysis of texture showed that that loam occurs in within opening 1 and medium loam within opening 2. They are soils medium heavy, of poor permeability, high retention and poor air-water properties. Soils of that kind are particularly susceptible to hydrological degradation caused by flooding [Klatka et al. 2011]. Solid phase density amounted between 2.55 and 2.66 [$Mg \cdot m^{-3}$] and was similar to the one occurring most often for Polish soils [Mocek 2015]. Values of bulk density amounted on average 1.49 [$Mg \cdot m^{-3}$]. The lowest values of bulk density were stated in organic matter layer of soil. In bottom layers, these values attained a maximum value of 1.58 [$Mg \cdot m^{-3}$] as the compaction increased. Total porosity was determined as above 40% (from 40.18% to 45.18%) in upper parts of soil profile, while as depth increases, values decrease up to about 40%. The determined values were nearing the ones characteristics of soils of a given subtype [Mocek 2015]. Values of pH measured in water were between 6.2 and 6.5, while the ones measured in 1 N KCl were between 6.4 and 7.1. According to Mocek [2015], the most advantageous reaction for majority of plants is from light acid to neutral; that is why it is possible to state that that the investigated soils have optimum reaction. Electric specific conductivity does not exceed limited permissible value for non-irrigated soils [Nowosielski 1974].

Analysis of the soil-agriculture map shows that on the investigated area arable lands are classified to soil quality classes IIIb and IVa, while grasslands to classes III and IV. Arable lands are classified to a complex of agricultural suitability 8, that is cereals-pasture strong, while grasslands to complex 2z, which pertains to medium grasslands.

In point evaluation of indicator of soil suitability (W_b), the investigated site obtained 86 points, out of the maximum possible 120. A comparison of the obtained results with values obtained for voivodships of the southern Poland shows that this is quite a high value. For example, for the śląskie voivodship, the indicator W_b was 46.8 points, for małopolskie 53.6 points, while for the dolnośląskie 56.9 points [Stuczyński et al. 2007]. In the evaluation of the relief indicator (W_{rz}), the investigated area obtained 4.5 points, which corresponds with relief of low-wave and low-hilly types. The obtained value is higher than the one for the śląskie voivodship, which attained a value of 3.6 [Stuczyński et al. 2007].

Evaluation of the agroclimatic conditions (W_k) for the Jastrzębie Zdrój community was determined changing mean yield expressed in cereals units into point evaluation of agroclimatic condition and then they were compared with literature data [Central Statistical Office 2015].

For the śląskie voivodship yield expressed in cereals units amounts was 32 $t \cdot ha^{-1}$, which corresponds to 9 points in agroclimate evaluation, but for the Jastrzębie Zdrój community it fluctuated between 9.3 and 9.6 points. For calculation, the value of W_k=9.4 points was taken.

Because during investigation of openings, excessive moisture was not included, and the determined physical properties showed optimum quantities, and the indicator of soil water conditions (W_{sw}) was taken as 5.0 points. The obtained result is higher that the one for the śląskie voivodship (2.6), małopolskie voivodship (4.0) and dolnośląskie voivodship (3.8) [Stuczyński et al. 2007].

Summing up the point values for the particular diagnostic properties, the synthetic indicator was determined that the characteristic quality of the agricultural production space of the investigated area cumulatively is 86.3 points for a maximum of 120. The obtained value allows to determine the investigated area in Jastrzębie Zdrój, at the Węglowa street as the area of mean conditions for agricultural production. Comparing the value of the determined indicator with points for the śląskie [Stuczyński et al. 2007] voivodship, amounting an average of 64.2 points one can state that this value is higher than the mean one [Stuczyński et al. 2007]. The obtained result is close to the one for the dolnośląskie voivodship [Stuczyński et al. 2007]. Such state is influenced by high soil quality classes and complexes of agriculture suitability. One can state that during the next years values of the synthetic indicator of agricultural production space will decrease as a result of hydrological degradation of soil. Because water conditions are partially taken into consideration in the soil quality classification and complexes of agriculture suitability, this change will cause a decrease of classes and complexes. The indicator of soil water conditions will change as well as, influencing the final result of the investigations. Similar phenomenon was observed on the exploitation area the Hard Coal Mine in Knurów, where as a result of hydrological degradation, most soils were changed to agricultural use [Klatka 2004].

The quality of agricultural environment on the former mine activity sites may be determined based on soil quality classes and complexes of agriculture suitability as well as on plant yield [Reith 1982]. The more exact result of evaluation may be obtained considering many elements, such as soil properties and form as well as kind of surface degradation [Porter at al. 1988].

Taking into consideration the fact that soil in the investigated area undergoes geomechanical and hydrological degradation, for determining the future the synthetic indicator, the soil water conditions should be determined very exactly. On the areas of former mining activity, as a result of degradation, the soil water conditions are represented by change of their types and subtypes. This fact should be reflected in value of the water conditions indicator W_{sw}, which apart from actual moisture state should regard prognostic values as a result of surface settlement changes.

4. CONCLUSIONS

1. Near the Węglowa street in Jastrzębie Zdrój, soils were classified according to the Systematics of Polish Soils [PTG 2011] and found to have the following order: brown forest soils, type: typical eutrophic brown, subtype: eutrophic leached brown, of loam and medium loam texture. Soils of this type have poor permeability, but have high retention abilities and poor air-water properties and because of their strong anthropressure caused by mining activity are specially susceptible to hydrological degradation.
2. The determined physical properties of these soils do not differ from the ones occurring commonly in Polish soils. In

turn, physico-chemical properties of these soils do not show degradation caused by acidification, alkalization or salinity. However, the predicted changes of groundwater level as a result of surface settlement and hydrological degradation will cause changes in the physical properties of soils.

3. The calculated synthetic indicator of agricultural production space amounted to 86.30 points, which classifies the investigated area as the one having average conditions for agricultural production. However, intense hydrological degradation of soil in time will cause changes of the indicator and high deterioration of environmental conditions for agriculture production. One can state that in future, potential conditions for agriculture production in the investigated area will deteriorate.
4. The evaluation of agricultural production space carried out in the work points to the fact that that the determination of the synthetic indicator according to Witek [1981] used in the study does not reflect actual state of soil water conditions. In areas of where mining activity was undertaken in the past, the geomechanical and hydrological degradation of soil-water conditions may differ essentially from the point classification used by the authors of the method. That is why while evaluating mining sites, actual and prognostic soil water management should be added to source element of the method.

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