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Soil quality index for agricultural areas under different levels of anthropopressure**

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A b s t r a c t. Different individual soil parameters or simple indices are widely used in soil quality evaluation, but this approach has many limitations. The aim of the study was to determine an integrated soil quality index in agricultural soils as affected by different levels of anthropopressure. The soil quality index was calculated through: the selection of the appropriate indicators for a minimum data set, score assignation for selected indicators and the integration of indicators in an index. The study was carried out in two areas under agricultural use with similar soil cover but with a different history and intensity of exposure to pollution input. Soil samples collected from the surface layer (0-30 cm) were analysed for physicochemical (*i.e.* texture, fractional composition of soil organic matter, pH), and biological (respiration, dehydrogenase activity, microbial biomass and nitrification) properties and the levels of contaminants (16PAHs and heavy metals). The level of anthropopressure was assessed on the basis of pollutants emission indices. A statistical evaluation based on principal component analysis enabled the selection of indicators of significant importance to soil quality. The level of anthropopressure was found to be an important factor influencing soil quality; higher soil quality index values (0.50) were determined for the area of low anthropopressure.

K e y w o r d s: soil quality, anthropopressure, minimum data set, agricultural soils, soil quality index

INTRODUCTION

The term “soil quality” first appeared in the scientific literature in the 1980s and since that time it has received much attention. A variety of definitions have been proposed for the term ‘soil quality’, ranging from the purely agricultural point of view to a more environmental perspective (Bastida *et al.,* 2008; Epelde *et al.,* 2014; Vasu *et al.,* 2016). Soil quality may be defined as ‘the capacity of soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health’ (Garrigues *et al.,* 2012; Mukherjee and Lal, 2014; Rahmanipour *et al.,* 2014). From an environmental perspective soil quality is ‘the capacity of the soil to promote the growth of plants, protect watersheds by regulating infiltration, and prevent water and air pollution by buffering potential pollutants such as agricultural chemicals, organic wastes, and industrial chemicals’ (Bünemann *et al.,* 2018). Soil contamination is a widespread threat to proper soil functioning and its quality. The most important functions and services listed in the EU soil framework directive that may be affected, include biomass production, water flow and retention, solute transport and retention, physical stability support, retention and nutrient cycling, buffering and filtering potentially toxic metals, and the maintenance of biodiversity and habitat (Garrigues *et al.,* 2012; Volchko *et al.,* 2014). The maintenance of soil quality is critical for ensuring the sustainability of the environment, because only a healthy soil can potentially enable the entire ecosystem to function properly. Typically, the concept of soil quality is considered in order to evaluate the productivity of soils. In recent times, soil quality assessment has been increasingly incorporated into sustainable land management, environmental risk assessment, monitoring environmental change and land restoration (Bünemann *et al.,* 2018). To date, soil quality assessment has remained a challenging issue, because soils present a high degree of variability in their properties and functions.

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Several methods of soil quality evaluation have been developed, including soil card design and test kits, geostatistical methods or soil quality index methods (Rahmanipour *et al.,* 2014; Bünemann *et al.,* 2018**)**. In general, soil quality assessment is carried out by selecting a set of soil properties which are considered to be indicators of soil quality (Vasu *et al.,* 2016). The use of different individual soil parameters (*e.g.* total organic C, texture) or single indices (*e.g.* the metabolic quotient, the metabolic ratio) is a common approach utilized for the evaluation of soil quality. However, the use of one individual indicator or indices integrating only two parameters has many limitations and provides insufficient information about soil quality and degradation (Bastida *et al.,* 2008; Masto *et al.,* 2015). Therefore scientific attention has recently focused on the derivation of complex, multiparametric indices combining different parameters. A soil quality index (SQI) could be defined as a minimum set of parameters that provides numerical data concerning the capacity of a soil to carry out one or more functions (Garrigues *et al.,* 2012; Asensio *et al.,* 2013). The selection of a minimum soil data set (MDS) is based on either expert opinion (subjective), or mathematical and statistical (objective) methods (Bastida *et al.,* 2008; Bünemann *et al.,* 2018). In recent times, statistical data reduction by using multivariate techniques such as principal component analysis (PCA), redundancy analysis, discriminant analysis and multiple regression have become more common. Soil quality indices have been used to evaluate the impact of agricultural practices, crop production, soil management (Armenise *et al.,* 2013; Rahmanipour *et al.,* 2014; Bera *et al.,* 2016; Vasu *et al.,* 2016), and to a lesser extent to assess soil exposed to anthropogenic pressure (*e.g.* contamination).

The aim of the study was to determine a soil quality index in agricultural soils affected by pollution which indicated different levels of anthropopressure. Different physical, chemical and biological soil properties were considered as potential soil quality indicators. Beyond basic soil characteristics (*i.e.* texture, pH, organic carbon content), the fractional composition of the soil organic matter and the level of pollution was included in the total data set. SQI was calculated by a weighted additive approach after the selection of a minimum soil data set.

MATERIALS AND METHODS

The study was carried out in 2013 in two agricultural regions with a similar soil cover (predominance of Cambisols and Luvisols), but with a different history and intensity of exposure to pollution. Area HAP (115 km^2), located in Upper Silesia (Czerwionka municipality, southwestern Poland), combines both typical urban, industrial, post-industrial and agricultural areas. Soil contamination in this region is mainly a result of fossil fuel combustion, waste recovery, road transport, long-term (over 100 years) coke production and previous coal mining activity. Area LAP (108 km^2), located in the Lublin region (Frampol municipality, eastern Poland), is a typical agricultural region, remote from pollution sources, where soils are predominantly used for agriculture and horticulture. The climate in the investigated areas is influenced by continental air masses. The average yearly precipitation and temperature are 719 mm and 8.9ºC for area HAP, and 640 mm and 7.8ºC for area LAP, respectively. Pollutant emission indices (Central Statistical Office, 2015) were used for the assessment of the anthropopressure level in both regions. A more detailed description of the study area may be found in Klimkowicz-Pawlas *et al.* (2017).

The soil samples (area HAP, n= 43; area LAP n=32) collected from the surface layer (0-30 cm) of the agricultural soils were analysed for physical, chemical and biological properties and for the content of selected contaminants: PAHs and metals. The soil materials were air-dried at a temperature of 20±2ºC, sieved through a 2 mm sieve-mesh and stored in the dark at 16-18ºC before chemical and physical analysis. Fresh soil samples for biological activity measurements were prepared according to the ISO 10381-6 (1993) method.

The soil particle-size distribution was analysed using the aerometric method (PN-R-04032, 1998), while the pH was measured potentiometrically in a 1:2.5 (m V^{-1}) suspension of soil in a 1 mol L^{-1} KCl solution (ISO 10390, 2005). The total nitrogen content (N_{tot}) was measured in a Vario Macro Cube CN analyser (Elementar Analysensysteme GmbH) after dry combustion. The total organic carbon (C_{org}) content was determined by sulphochromic oxidation (ISO 14235, 1998), and the fractional composition of the soil organic matter including humic acids (HA), fulvic acids (FA) and humins (HU) was analysed using an adapted ISO 12782-4 (2012) method approved by the International Humic Substances Society (Swift, 1996). The 16 PAH compounds from the US EPA list were extracted with dichloromethane in an Accelerated Solvent Extractor (ASE 200, Dionex) and analysed using gas chromatography with a mass spectrometer (GC-MS) (Agilent Technologies, Santa Clara, CA). The quality control procedures included the analysis of certified reference material (CRM 131), laboratory control samples and solvent blanks. The recoveries for individual PAHs from CRM 131 were within 62-84%, precision which was expressed in the form of a relative standard deviation (RSD) was in the range of 5-12%, and the method quantification limit (MQL) ranged from 0.02 to 2.10 μg kg^{-1}. The total concentration of three heavy metals (Z, Cd, Pb) was determined using an inductively coupled plasma mass spectrometry (ICP-MS) technique after the wet digestion of soil samples in aqua regia (ISO 11466, 1995). The accuracy for metal analysis was 10% and the MQL values were 0.85, 0.08 and 0.01 mg kg^{-1} for Zn, Pb and Cd, respectively.

The analysis of soil biological properties included four parameters. Basal microbial respiration (BR) was measured by titration method (ISO 16072, 2002), carbon dioxide evolution was measured after a 24 h incubation of the soil samples. The method of Casida *et al.* (1964), with triphenyltetrazolium chloride (TTC) as an electron acceptor, was applied to dehydrogenase (EC 1.1.1.1) activity (DHA) measurements. Microbial biomass (C_{mic}) was based on the substrate-induced respiration method (ISO 14240-1, 1997), in which CO_2 evolution was assessed 6 h after the addition of the readily degradable substrate. The potential of nitrification (NIT) was determined according to a method which was described in detail by Maliszewska-Kordybach *et al.* (2007). Soil samples were mixed for 24 h with a mineral medium containing ammonium sulphate as a substrate, the amount of NO_2^- formed was determined spectrophotometrically after the addition of a colour reagent containing sulphanilamide and N-(1-naphtyl)ethylene diamine dichydrochloride. All biological analyses were performed in triplicate and the results were expressed as an arithmetic mean of three measurements adjusted to the dry matter content of the soil.

The calculation of the soil quality index (SQI) included three steps: selection of the appropriate indicators for a minimum data set (MDS), score assignation for the selected indicators and the integration of the indicator scores into an overall index of soil quality (Rahmanipour *et al.,* 2014; Volchko *et al.,* 2014). The selection of indicators for the MDS was based on a principal component type of factoring (PCA) analysis, which was used as a data reduction tool. The varimax rotation of the factor loading matrix was applied, only the factors with eigenvalues ≥ 1 were considered in the selection of indicators. Only the soil parameters which had a higher correlation with the principal component (PC) in PCA were considered in the MDS. However, when more than one variable was selected within a single PC, multivariate correlation coefficients were used to check for redundancy and correlation between the variables. Of the significantly correlated parameters, only one variable with the highest loading factor was included in the MDS. In the second step selected parameters were transformed into numerical scores which ranged from 0 to 1 through a linear scoring method (Armenise *et al.,* 2013; Mukherjee and Lal, 2014). This scoring process was applied to the two regions (area LAP and area HAP) separately. Two types of assumptions were applied, the best soil functionality was associated with the high or low values of the indicator. For the 'more is better' parameters, each value of the indicator was divided by the highest observed value so that this value received a score of 1; for the 'less is better' indicators, the lowest observed value was divided by each observation such that the lowest value received a score of 1. After scoring the parameters, an SQI value was calculated using the weighted additive approach according the following equation:

$$SQI = \sum w_i S_i,$$

where: w_i is the weightage factor determined from the ratio of the total percentage of variance from each factor to the maximum cumulative variance coefficients of the principal component considered; S_i is the score of each parameter in the minimum dataset.

All statistical analyses including basic statistical parameters analyses (mean, standard deviation, range, and coefficient of variation), PCA analyses and the determination of correlation coefficients were carried out using the Statgraphics Centurion programme (version XV, Statpoint Technologies). The differences in SQI between regions were also evaluated using a one-way analysis of variance (ANOVA, Duncan test, $p \leq 0.05$).

RESULTS AND DISCUSSION

The level of anthropopressure in both regions was assessed on the basis of pollutant emission indices and the content of 16PAHs and three metals (Table 1). For the HAP area the anthropogenic indices amounted to 6 827 and 1 084 kg year^{-1} km^{-2} for total dust emission and dust emission from industrial sources, respectively (Central Statistical Office, 2015). Additionally this region was characterized by a high population density (366 persons *per* km^{-2}) (Maliszewska-Kordybach *et al.,* 2010; Klimkowicz-Pawlas *et al.,* 2017). The emission indices noted for the LAP area were several times lower (995 and 111 kg year^{-1} km^{-2}, respectively). Soils from both of the investigated regions did not differ significantly in their basic properties (texture, pH and nitrogen content). Most of the soils exhibited relatively high acidity values (average pH of 5.2-5.5), and low N_{tot} content (mean 1.72-1.83 g kg^{-1}). A high degree of variability was observed for C_{org} (CV up to 145%), as well as for metals and PAHs content (CV up to 375%) (Table 1). The total concentration of pollutants in the soils from the HAP area was much higher (5-fold for metals and over 15-fold for PAHs) compared to the LAP area and reached levels of 140.08, 1.09, 54.25, and 224.13 mg kg^{-1} for Zn, Cd, Pb and 16PAHs, respectively. Such content of pollutants in this region was connected with a high degree of anthropogenic pressure related to long-term intensive industrial activity, i.e. coal mining, energy production and waste recovery. A wider discussion of the potential sources of PAHs was presented in an earlier work of Maliszewska-Kordybach *et al.* (2010) and Klimkowicz-Pawlas *et al.* (2017). A large variability in total organic carbon was also observed, the C_{org} content in soils from the HAP area ranged from 6.97 to 187.16 g kg^{-1}. In the fractional composition of organic carbon the predominant fraction was HU (Table 1). Humins are the most stable fraction of humic substances, they are resistant to microbial degradation and demonstrate a high sorption capacity and ability to retain contaminants. Our observations were in line with the findings of other authors (Watanabe *et al.,* 2001; Tan 2014).

Table 1. Descriptive statistics of soil properties used for soil quality assessment

Parameters	Units	Area LAP (n = 32)					Area HAP (n = 43)				
		mean	min	max	SD	CV	mean	min	max	SD	CV
Sand	%	56	15	94	25	44	72	49	90	9	13
Silt	%	39	5	82	22	56	27	9	45	8	32
Clay	%	5	0	21	6	120	2	0	6	2	101
N_{tot}	g kg^{-1}	1.72	0.75	5.05	1.05	61	1.83	0.76	11.67	2.00	109
pH_{KCl}	-	5.5	3.5	7.3	1.2	22	5.2	3.8	7.8	0.9	18
C_{org}	g kg^{-1}	15.77	6.37	55.48	11.15	70	26.98	6.97	187.16	39.08	145
FA	g kg^{-1}	2.89	1.58	6.01	1.20	42	2.77	0.60	8.79	1.76	64
HA	g kg^{-1}	5.84	0.64	20.12	4.08	70	7.28	0.61	17.12	3.43	47
HU	g kg^{-1}	7.04	0.30	32.54	7.93	112	16.92	0.15	164.93	36.72	217
DHA	µgTPFg^{-1} dw	48.68	4.21	97.89	22.42	46	25.42	3.44	73.88	15.10	59
NIT	µgNO_2^- g^{-1} dw h^{-1}	3.78	0.03	21.50	4.73	125	2.50	0.04	7.67	2.07	83
BR	µgCO_2 g^{-1} dw h^{-1}	3.40	0.79	9.72	2.14	63	2.72	0.72	7.68	1.77	65
C_{mic}	µg g^{-1} dw	73.48	37.86	114.71	21.97	30	71.00	22.12	166.59	28.89	41
Zn	mg kg^{-1}	27.83	4.01	48.15	10.85	39	140.08	20.88	1092.22	205.04	146
Cd	mg kg^{-1}	0.24	0.06	0.58	0.11	44	1.09	0.06	9.33	1.57	144
Pb	mg kg^{-1}	14.00	6.52	27.57	4.55	32	54.25	15.40	416.68	70.72	130
16PAH	mg kg^{-1}	0.65	0.10	4.35	0.88	134	11.27	0.38	224.13	42.28	375

N_{tot} – total nitrogen content, C_{org} – total organic carbon content, FA – fulvic acids, HA – humic acids, HU – humins, DHA – dehydrogenase activity, NIT – potential of nitrification, BR – basal respiration, C_{mic} – microbial biomass; Zn, Cd, Pb and 16PAHs – zinc, cadmium, lead and polycyclic aromatic hydrocarbons content, respectively; SD – standard deviation, CV – coefficient of variation (%), LAP – area of low anthropopressure, HAP – area of high anthropopressure.

Significant differences were found between the biological activities of the soil from the two regions studied. Dehydrogenase and nitrification activity was lower in the HAP area, on average by 48 and 34%, respectively. Active microbial biomass and soil respiration was affected to a lesser extent (Table 1). Biological and biochemical soil properties are considered to be the essential factors affecting the fertility and quality of soils (Bastida *et al.,* 2008; Epelde *et al.,* 2014; Masto *et al.,* 2015; Muhlbachova *et al.*, 2015). Soil microorganisms participate in many soil processes and due to their short generation time and high surface-to-volume ratio they may react quickly to environmental changes (Maliszewska-Kordybach *et al.,* 2007; Asensio *et al.*, 2013; Bera *et al.,* 2016). Potential nitrification reflects the activity of autotrophic ammonium oxidizing bacteria, which are very sensitive not only to soil environment conditions (temperature, pH, substrate content), but also to soil contamination even at a very low concentration (Wyszkowska and Kucharski, 2004; Maliszewska-Kordybach *et al.,* 2007; Epelde *et al.,* 2014). Dehydrogenases are present in all living microbial cells, they rapidly degrade in the soil after the death of the cells and do not accumulate in soils, they provide a measure of the total oxidative activity of soil microorganisms (Bastida *et al.,* 2008; Muhlbachova *et al.*, 2015).

Different methods and approaches are reported in the literature as a tool for the selection of indicators for the minimum data set and calculation of soil quality indices. These methods are based either on expert opinion (Asensio *et al.,* 2013; Masto *et al.,* 2015), statistical and mathematical analysis (Armenise *et al.,* 2013; Bera *et al.,* 2016; Li *et al.,* 2018), or a combination of both approaches (Mukherjee and Lal, 2014; Vasu *et al.,* 2016; Bünemann *et al.,* 2018). In our study the identification of MDS and the calculation of SQI was based on the method described earlier by Rahmanipour *et al.* (2014) and Vasu *et al.* (2016). A minimum data set was established through a principal component analysis performed using seventeen different soil parameters: physical (soil texture), chemical (pH, N, C content, fractional composition of C_{org} and the level of soil contamination) and biological (enzymatic activity, nitrification potential, microbial respiration and biomass). The results obtained from PCA indicated four (LAP area) and five factors (HAP area) with eigenvalues ≥ 1 (Table 2) thereby explaining 81 and 84% of the total variation, respectively. Soil variables from each PC factor were considered for the minimum data set. Eight different soil indicators (N_{tot}, C_{org}, HA, HU, BR, C_{mic}, Cd and Pb) were selected from PC 1 for the LAP area, while for the HAP area only five indicators (sand, N_{tot}, C_{org}, HU, C_{mic}) were correlated with the first factor. However, a further analysis of multivariate correlation between

Table 2. Principal components, eigenvalues and component matrix variables

Parameters	Area LAP (n=32)				Area HAP (n=43)				
	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3	PC 4	PC 5
Eigenvalue	6.8	4.0	1.6	1.4	6.4	2.9	2.5	1.5	1.0
%Variance	40.2	23.5	9.2	8.2	37.4	16.9	14.7	8.8	6.2
Cumulative variance	40.2	63.8	73.0	81.2	37.4	54.3	69.0	77.8	84.0
Factor loadings (Rotated component matrix)									
Sand	-0.267	-0.264	<u>**-0.891**</u>	-0.013	**-0.676**	0.190	-0.408	-0.039	-0.189
Silt	-0.289	0.123	**0.884**	0.014	-0.366	-0.022	-0.019	0.167	<u>**0.864**</u>
Clay	-0.141	**0.553**	0.438	**-0.545**	0.223	-0.013	-0.450	-0.041	**0.762**
N_{tot}	<u>**0.980**</u>	0.019	0.020	0.073	**0.819**	0.109	0.490	-0.106	-0.181
pH_{KCl}	0.009	**0.862**	0.225	0.111	-0.145	0.089	0.033	<u>**0.908**</u>	0.163
C_{org}	**0.973**	-0.043	-0.054	0.107	**0.920**	0.239	0.193	-0.102	-0.091
FA	0.427	-0.438	-0.211	-0.030	0.217	0.131	**0.798**	-0.216	-0.227
HA	**0.790**	-0.024	-0.219	0.326	0.321	0.266	**0.638**	-0.302	-0.227
HU	**0.956**	-0.015	0.017	0.033	<u>**0.938**</u>	0.223	0.108	-0.070	-0.065
DHA	0.349	0.164	0.067	<u>**0.754**</u>	-0.422	0.324	0.378	-0.358	-0.337
NIT	-0.027	<u>**0.877**</u>	0.166	-0.144	0.023	0.066	-0.150	**0.880**	-0.045
BR	**0.731**	**0.598**	-0.027	0.139	0.265	0.115	<u>**0.821**</u>	0.088	0.002
C_{mic}	**0.641**	0.313	0.190	-0.369	**0.610**	0.221	**0.617**	0.054	-0.172
Zn	0.403	0.419	**0.724**	0.036	0.019	<u>**0.971**</u>	0.132	0.042	0.009
Cd	**0.952**	-0.050	0.150	0.044	0.064	**0.929**	0.173	0.033	-0.107
Pb	**0.835**	-0.161	0.356	-0.063	0.115	**0.950**	0.161	-0.015	-0.124
16PAH	-0.087	-0.063	0.043	**0.728**	0.392	**0.651**	-0.052	0.144	0.241

PC – principal component; bold factor loadings were considered highly weighted and underlined bold values are selected in minimum data set. Other explanations as in Table 1.

Table 3. Pearson correlation coefficients for highly loaded parameters in PC 1 (example of HAP area, n = 43)

	Sand	N_{tot}	C_{org}	HU	C_{mic}
Sand	1				
N_{tot}	-0.710*	1			
C_{org}	-0.593*	0.913*	1		
HU	-0.577*	0.880*	0.994*	1	
C_{mic}	-0.539*	0.817*	0.707*	0.658*	1

*Values statistically significant at $p<0.001$. Explanations as under Table 1.

these parameters indicated their close interrelationship and only N_{tot} and HU which have the highest factor loadings were retained in the MDS. An example of the correlation matrix for selected parameters within the first PC is shown in Table 3. A similar analysis was carried out for other factors – data not shown, which allowed for additional indicators such as NIT, sand and DHA for soils from the LAP area, and Zn, BR, pH and silt from the HAP area (Table 2) to be included in the MDS. The ‘more is better’ assumption was used for assigning a score to N_{tot}, HU, NIT, DHA, BR, pH and silt, and ‘less is better’ for sand and metals content.

Generally, the soil quality in the typical LAP agricultural region was mainly affected by total nitrogen, NIT and DHA, *i.e.* parameters which describe soil organic matter quality, the functional capability of the soil to supply nutrients to plants, and the microbial activity relevant to N cycling and the oxidation of organic compounds (Bünemann *et al.,* 2018). In the HAP area of high anthroporessure, the highest factor loadings were for organic matter composition (mainly HU – the most stable fraction of organic matter), soil acidity, texture and the level of soil pollution. As stated by Masto *et al.* (2015), Vasu *et al.* (2016), and

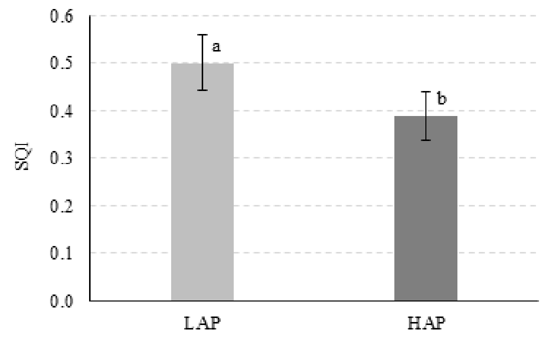

Fig. 1. Soil quality index (expressed as a mean value) for the area of low (LAP) and high (HAP) level of anthropopressure. Different letters indicate significant differences in SQI values in both regions (ANOVA Duncan's test, $p < 0.05$).

Li *et al.* (2018) the most common indicator used in SQI evaluation is the total organic carbon content, while studies which include the fractional composition of soil organic matter into MDS are rather rare (Asensio *et al.,* 2013). Soil pH and texture (mainly clay content) are also frequently considered in the quality assessment of agricultural soils (Bastida *et al.,* 2008; Armenise *et al.,* 2013; Rahmanipour *et al.,* 2014; Bünemann *et al.,* 2018), however literature data concerning the use of the concentration of contaminants for SQI assessment are rather insufficient (Volchko *et al.,* 2014). Soil pH affects the solubility and availability of nutrients and contaminants and affects microbial activity, in contaminated areas soil acidity may be an additional stress factor for soil microorganisms and increase their sensitivity to pollution (Maliszewska-Kordybach *et al.,* 2007). The clay fraction influences carbon sequestration in soils, the adsorption and desorption of nutrients, the stability of soil aggregates and the retention of contaminants (Armenise *et al.,* 2013); the low content of the clay fraction may result in a reduction in pollutant sorption, which increases their leaching and transport to the deeper soil layers and enhances their bioavailability (Maliszewska-Kordybach *et al.,* 2010). Additionally, the soil quality in the HAP area was related to soil respiration, which reflects the oxidative capacity of soil microorganisms and is influenced by the energy sources present in soils (Epelde *et al.,* 2014; Muhlbachova *et al.*, 2015). Soil processes *i.e.* nutrient cycling, organic matter decomposition, filtering and buffering are driven by the biochemical properties of the soil. Therefore, these properties are important indicators with which to monitor soil processes as they are more sensitive to changes in the environment than soil physical and chemical parameters (Bastida *et al.,* 2008; Bera *et al.,* 2016). Soil respiration, alongside parameters such as microbial biomass, enzymatic activity or process-level based assays (nitrification), is the most commonly used indicator both in assessing soil quality and environmental risk (Myśków *et al.,* 1996; Muhlbachova *et al.*, 2015; Bünemann *et al.,* 2018). However, soil biological properties are most frequently utilized as individual indicators in soil quality assessment (Epelde *et al.,* 2014; Muhlbachova *et al.*, 2015) and are rather seldom included in multiparametric quality indices (Myśków *et al.,* 1996; Wyszkowska *et al.,* 2013).

The parameters selected for the minimum data set were independent of each other, and after the assignment of a score and weighting value they were integrated into SQI (Fig. 1). The values of the soil quality index were in the range of 0.20-1.35, with mean values of 0.50 for the LAP area and 0.39 for the HAP area. The results of ANOVA (Fig. 1) showed that the anthropopressure level significantly affected the SQI; higher values of this index (+22%) were found in soils from the agricultural LAP area. However, the observed differences were rather small, which indicates that despite the high level of pollutants (Table 1) in the HAP area, soil quality in this region is also influenced by biological and physicochemical properties. Volchko *et al.* (2014) and Li *et al*. (2018) have both proposed soil classifications based on SQIs (Table 4), they distinguished five classes of soil quality: very poor, poor, medium, good and very good depending on the values of SQIs. In general, the quality of soils from the two regions varied from low to high, but the percentage share of soils in the individual quality grades differed distinctly (Fig. 2). Most soils from the area of high anthropopressure (HAP) had very low SQI values with an average value of 0.28 and were of very poor (72%) and poor (9%) quality according to the proposed system of Li *et al.* (2018). The soils classified in the good quality category consisted of only 14% of the total area (Fig. 2). In contrast, in the typical rural region of the LAP area soils of moderate (22%) and good (31%) quality prevailed. The soil quality index is a product of a few selected soil indicator properties and is a useful method with which to differentiate between the degradation status of various soils (Masto *et al.,* 2015). Our studies revealed that the quality of soils should be determined by analysing both physicochemical and biological soil characteristics, and in the agricultural regions exposed to anthropogenic activity the level of contamination should be incorporated into the SQI evaluation.

Table 4. Classification criteria of the soil quality for the minimum data set (Li *et al.* 2018)

Indicator	Soil quality grade				
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
	Very high	High	Moderate	Low	Very low
SQI	>0.60	0.55-0.60	0.45-0.54	0.38-0.44	<0.38

SQI – soil quality index.

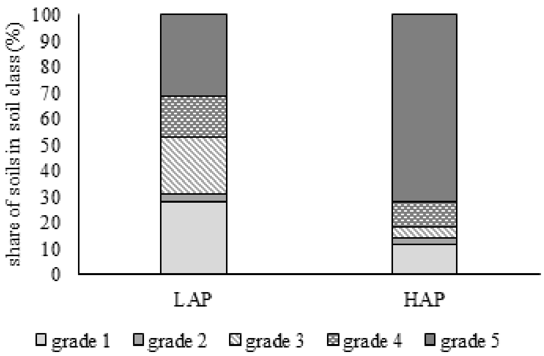

Fig. 2. Classification of the SQI values for the area under study, percentage share of soils in specific soil quality grades according to the criteria proposed by Li *et al.* (2018), LAP – area of low anthropopressure, HAP – area of high anthropopressure.

CONCLUSIONS

1. The soils from the regions investigated differed significantly in their biological activity and levels of pollution (heavy metals ad PAHs content).

2. Different soil descriptors were included in the minimum data set; total nitrogen content, potential of nitrification, sand content and dehydrogenase activity for the area of low anthropopressure, and humins, Zn content, basal microbial respiration, pH and silt for the area of high anthropopressure.

3. The level of anthropopressure was an important factor influencing soil quality; significantly higher soil quality index values (average of 0.50) were determined for the area of low anthropopressure.

4. The majority (80%) of the soil samples from the region of high anthropogenic pressure was classified as low quality soil.

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