Soil Environmental Quality Assessment in Sustainable Rehabilitation of Mine Waste Area: Establishing an Integrated Indicator-based System

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Abstract: - Soil environmental quality is the capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health'. In the long-term, vegetative rehabilitation of mining wastes aims at, as far as possible, the proper ecological integration of the reclaimed area into the surrounding landscape, which is sustainable and requires minimal maintenance. This article presents here an indicator-based system of soil environmental quality that evaluates sustainable rehabilitation of mine waste through a set of 2 subindicators, chemical fertility and stocks of organic matter, and further combines them into a single general Indicator of Soil Quality (GISQ). The design and calculation of the indicators were based on sequences of multivariate analyses. Principal component analysis (PCA) was used to assess soil quality overall. A GISQ combined the different subindicators providing a global assessment of soil environmental quality. Our findings provide evidence that selected indicators can provide a definitive, quantitative assessment of soil environmental quality and lend credence to the value of our approach in quantifying relationships between soil function and indicators for specific areas.

Key-Words: - Soil environmental quality; Sustainable rehabilitation, Mine waste area; Indicator-based

1 Introduction

Establishment and monitoring soil environmental quality in rehabilitation of mine waste area is quite often a difficult task. The efficiency of the scheme selected can be substantially improved by using adequate simple indicators system so that trends can be plotted, elucidated and assessed. Exploitation of mineral resources has caused devastation in large areas and serious environmental problems. Ecological restoration and mine reclamation are considered today as very important [1]. Sustainable revegetation indicators should take into account soil environmental quality. Soil environmental quality is the capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health. In the long-term, vegetative rehabilitation of mining wastes aims at, as far as possible, the proper ecological integration of the reclaimed area into the surrounding landscape, which is sustainable and requires minimal maintenance [2, 3]. A certain succession pattern is therefore needed. Recent ecological concepts recognize the role of the substrate's quality and nutrients in affecting the rates and directions of succession patterns [4]. Although pedogenesis and eventually soil quality in mine waste are not well known, monitoring of soil environmental quality parameters in Fuxin mine tailings reveal a remarkable establishment and or improvement of specific soil environmental quality indicators.

During the same time the vegetative cover's total functionality as well as reproductive ability improved. Functions of soil, and thus soil quality, can be assessed at the field, farm, ecosystem, pedosphere, and global scale. It is recognized, however, that management of soil becomes increasingly difficult at larger scales, but for demarcated mine waste sites it is possible to ameliorate and manage and assess soil functions and quality. Therefore the significance of the study is the following: soil functions and quality become inseparable from the idea of system sustainability, and are considered as key indicators of ecosystem sustainability on rehabilitated mine tailings material.

Several soil quality indicator sets have been developed for different purposes. Nortcliff [5] suggested a general SQI set within standardised soil quality attributes. The National Soil Resources Institute (NSRI) developed a typical minimum dataset of physical, chemical and biological indicators for soil quality based largely on agricultural experience [6]. Tzilivakis et al. [7] used the SQI set to assess the risk to soil functions in the context of general soil evaluation; Huinink [8] did so for the calculation of the heavy metal concentration threshold values; Schipper and Sparling [9] used the set to compare soil quality for different natural and semi-natural land uses; Larson and Pierce [10] compared conventional and organic farming to assess soil quality in an agricultural context;

We consider here (1) soil hydraulic properties that determine the infiltration and storage of water in soils; (2) chemical soil fertility that sustains plant production; (3) C sequestration in stable aggregates created by physical or biological processes assessed by a quantification of soil morphology; (4) participation of soils in climate regulation via carbon storage and (5) biodiversity, as indicated by the structure and abundance of macro invertebrate communities. These organisms are broadly accepted predictors of all biodiversity in soils and reflect their outstanding influences as ecosystem engineers.

Larson [10] and Lavelle [11] show that Chemical fertility is the ability of soil to provide the nutrients necessary for plant growth. Basic measurements of cation concentrations and pH allow the differentiation of soils with sufficient concentrations of all macronutrients from unfertile, nutrient-poor soils.

Marinissen [12], Pulleman [13] and Six [14] Show that Organic matter is an important attribute of soil quality for the variety of functions that it has in soils as cation reserve (an attribute of fertility) and agent of aggregate stabilization, site for carbon storage and sequestration and as an energy resource for heterotrophic biological activity. This component of soil quality is assessed through overall C and N concentrations, a density fractionation that separates the more ephemeral light fractions from persistent heavy fractions associated with clay and fine silt fractions together with respirometry activities in optimal laboratory incubations that indicate to what extent organic matter is accessible to soil microorganisms.

For soil quality assessment in current China, a lot of work has been focused on determining methods of membership degree of soil parameters and on assessing techniques such as grey system theory, fuzzy theory, PCA, artificial neural network, GIS/RS approaches and so on.

The overall objective of this study was to describe the relationship between measurable properties and soil environmental quality. Specific objectives addressed in this study were to: (i) identify soil indicators linked to sustainable rehabilitation of mine waste area; (ii) present a method for the evaluation of soil environmental quality; and (iii) assess the soil environmental quality in sustainable rehabilitation of mine waste area.

2 Materials and methods

2.1 Experimental site

The research area is Haizhou opencast coal mine (Fig. 1) in Fuxin, Liaoning Province. The region is with longitude between 121° 36′ E and 121° 42′ E, and latitude between 41° 56′ N and 42° 00′ N. It is a mountainous area, hills take up 58% of the total area, plains account for 23% and the sandlot occupies 8%. The ground above the elevation of 500 m is brown soil, cinnamonic soil and eluviation cinnamonic soil.

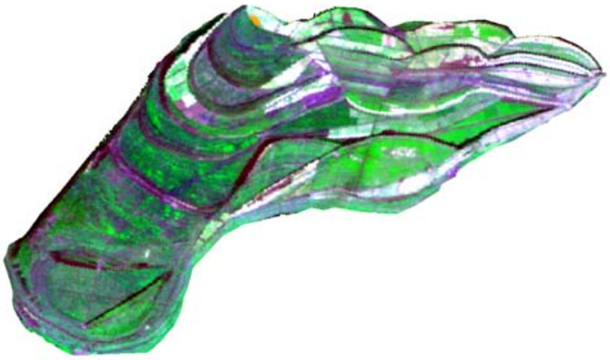

Fig.1 RS image of the study area

It belongs to warm temperature zone with semi-arid and semi-wetness continental monsoon climate characterized by four distinct seasons and sufficient sunshine. The winter in the region is long and cold, but the snowfall is less than the other areas. On the contrast, precipitation focuses in summer. Spring and autumn are transition seasons, and the temperature rises and falls rapidly within the periods. The annual average temperature is between 6.5°C and 7.5°C; the frost-free period covers 150 days. The gross amount of water resources is 970 hundred million m^3 in Fuxin colliery, and atmospheric precipitation is the main replenishment measure. The annual average amount of precipitation is 539mm, but the annual average amount of evaporation reaches 1717mm. Furthermore, the precipitation distributes asymmetrically in space and time, descending from south to north and focus on June to September. The Liao River and Dalin River consists of the direct surface runoff in the churchyard. The annual average direct runoff rate reaches 500 hundred million m3. Especially, the eastern Liao River drainage area is rich of ground water and surface water resources. However, the central and western areas, where industrial and mining establishments and a great mass of population concentrated, went short of water resource severely.

Coal mine exploitation has also disturbed the earth's surface seriously and a great amount of waste rocks, fly ash and slag were discharged during the exploitation process. All these wastes not only occupied a large land resource, but also polluted the air and water resources around the colliery. Coal mine exploitation has also disturbed the earth's surface seriously and a great amount of waste rocks, fly ash and slag were discharged during the exploitation process. All these wastes not only occupied a large land resource, but also polluted the air and water resources around the colliery. Finally, the fragmentation of landscape ecology pattern and the decrease of biodiversity lead to degeneration of zoology function and quality. It has been proved that some natural calamities like the water and soil loss, soil desertification, even mud-rock flow have a closed relationship with the frangibility of the colliery ecosystem.

Revegetation experiments on the surface of 4 different kinds of waste rocks, which have been disposed for more than 8 years, were carried out. It was found that at least 8 kinds of trees can survive on the surface of waste rocks in semi-arid area. The trees are dwarf elm, silver chain, cotton Chinese scholar tree, toon tree, amorpha, camphor pine, torch tree and arborvitae. So far, they have obtained a great success in reconstructing manmade forests in Wulong refuse dump, Gaode refuse dump, Haizhou refuse dump, Xinqiu refuse dump and some areas of subsidence. Generally, the survival percentage keeps above 70%.

2.2 Indicator selection

Identification of soil quality indicators and assessment approaches is complicated by multiple physical, chemical, and biological factors and their temporal and spatial variation. Practical assessment of soil quality, however, requires consideration of these multiple factors and their variation in time and space. Producers, researchers, and policy makers are interested in an integrative soil quality index to monitor changes over time. Obviously, there are numerous soil properties that change in response to changes in management practice and land use, some of which are highly sensitive, whereas others are more subtle. On the other hand, nematode faunae in agroecosystems and their relationship to soil processes suggest that they are potential bioindicators. For example, laboratory experiments and field studies have demonstrated that nematodes that feed on bacteria and fungi play important roles in influencing turnover of the soil microbial biomass and thus the availability of plant nutrients. However, the literature searched indicates that the effects of changes in agricultural practices on nematode community structure can produce contradictory results.

The work discussed below presents synthetic indicators (designed to permit quantification over a common range from 0.10 to 1.00) of the chemical fertility and stocks of organic matter in the upper 5 cm of the soil profile and the diversity and composition of soil macro invertebrate communities. These subindicators are then combined into a general index of soil quality. Our approach comprises evaluation of the different ecosystem services provided by soils using the relevant sets of variables [15]. We only choose Chemical fertility and Organic matter in our research area. Table 1 show specific soil environmental attributes that compose the subindicators and indicator suites.

Table1 Categories of indicator suites

Indictor suite	Component attributes (subindicators)
Chemical fertility	P, S, B, K, Cu, Fe, Mn, Zn, Ca, Mg, pH
Organic matte	OM (%), N-NH4+(mg/kg), N-NO3-(mg/kg), AA (cmol/L)

2.2.1 Chemical fertility

All soil physical and chemical variables were measured from soil taken from monoliths collected for faunal assessment or from undisturbed cores immediately adjacent to them, when necessary.

Chemical fertility was assessed through eleven properties: total P-total, S, B, K, Cu, Fe, Mn, Zn, Ca, Mg and pH. Cation contents were quantified by atomic absorption. Total phosphorus was measured by a colorimetric method with ammonium molybdate after acid digestion; the available P (P-Bray II), with ammonium fluoride and hydrochloric acid. Soil pH was measured in 2:1 water/soil slurry.

2.2.2 Organic matter

Soil samples used for chemical analysis were also analysed for organic matter. We measured OM, N-NH4+, N-NO3- , and AA by the dynamic closed chambers method [16]. Fifty grams of each soil (equivalent dry weight) were moistened with ultra-pure distilled water to 80% of their water-holding capacities, and put in closed jars incubated in an oven at 30℃ for 21 days. CO_2 in the jars was measured 4 (R1), 7 (R2), 14 (R3) and 21 (R4) days after the onset of the incubation, with an infrared CO_2 meter.

The Ludox method [17] was used to determine C contents in three density fractions: LL-light (>150μm, <1.13 g cm-3), IL-intermediate (>150μm, 1.13–1.37 g cm-3), and HL-heavy (>150 μm, >1.37 g cm-3). An air-dried soil sample (250 g) was gradually wetted, then flooded with 2:1 of water, thoroughly mixed and sieved through two superimposed sieves (top, 250 μm mesh size; bottom, 150 μm). The Ludox light (LL), intermediate (LM) and heavy (HL) fractions were obtained by density fractionation of the >150 μm size fraction in a colloidal silica suspension gravimetrically adjusted to 1.13 and 1.37 g cm-3, respectively. Ludox fractions were washed three times with 100ml deionised water before drying to constant weight at 40℃.

2.2.3 Physical state

Six variables were measured in the central zone of each plot using established methodologies: BD, real density (RD), P derived from the last two variables, moisture content (M) (% dry soil), SS and penetration resistance with a hand penetrometer Eijkelkamp (PR).

2.2.4 Soil morphology

This important attribute of soil quality was assessed by a simplified version of the Topoliantz et al. small volume method. A cube of soil, 5*5 cm down to 5 cm depth, was taken in the central zone of each plot. The natural components of the soil were gently separated: small, (< 1 cm); medium (1–3 cm); and large (> 3 cm) biogenic aggregates made by soil ecosystem engineers (earthworms, termites, Coleoptera, ants and Diplopoda); small, medium and large aggregates produced by physico-chemical processes, roots, leaf and shoot debris, invertebrates, gravels and stones, seeds and wood pieces. Separation was done by gently breaking the soil apart among its natural constituents. Depending on the soil and training of the operator, it took 1–3 h to process one sample. Separated items were quantified using a grid enumeration technique. Aggregates of a given category were arrayed over a grid of 0.5*0.5 cm^2 units and the total surface covered was measured. Root lengths or absolute numbers of, e.g., gravels or invertebrates were also used as measurements. This simple way of assessing the different units allows measurements to be made under field conditions. An alternative to this relative assessment may be given by weighing items of each class after drying to constant weight.

2.3 Statistical analysis

Analysis of variance (ANOVA) was performed to determine the effects of sewage treatment on soil quality parameters. For statistical analysis of data (PCA, correlations) Microsoft Excel and SPSS window version 15.0 packages were used. The PCA reduced the data and constructed linear combinations (principal components) of the original variables that explain a large part of the total original variability.

In data mining you often encounter situations where there are a large number of variables in the database. In such situations it is very likely that subsets of variables are highly correlated with each other. The accuracy and reliability of a classification or prediction model will suffer if you include highly correlated variables or variables that are unrelated to the outcome of interest. Superfluous variables can increase the data-collection and data-processing costs of deploying a model on a large database. The dimensionality of a model is the number of independent or input variables used by the model. One of the key steps in data mining is finding ways to reduce dimensionality without sacrificing accuracy.

Statistical techniques, especially the principal component analysis (PCA), have been widely employed among various approaches proposed to acquire MDS for soil quality assessment over the past decades. Through PCA analysis, the number of independent soil parameters could be reduced and the problem of multi-colinearity could be solved to some extent. In many cases, however, reducing the number of soil parameters for finally assessing purpose means the loss of information represented by those reduced parameters. Therefore, most of current assessing approaches are imbalanced between maximally reducing data redundancy and minimally losing information of soil quality included in soil parameters. In the MDS proposed by Andrews et al., for example, those soil parameters with factor loading within 10% of the highest factor loading in each principal component (PC, hereafter) are qualified into the final MDS, which will cause data redundancy. Parameter with the highest score sum (not factor loaded in PC) is chosen in each PC, thus perhaps resulting in information loss since the parameters with the highest score could not fully imply the soil phenomena characterized by other parameters in the same PC.

Principal component analysis (PCA) is a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables called principal components. The objective of principal component analysis is to reduce the dimensionality (number of variables) of the dataset but retain most of the original variability in the data [18-21]. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible [22].

Formulation of the general indicator of soil quality (GISQ) followed four different steps: (i) PCA analysis of each of the indicators allowed testing of the significance of their variation; (ii) identification of the variables that best differentiate the sites according to soil quality; (iii) creation of subindicators of soil chemical fertility and organic matter, with values ranging from 0.10 to 1.00; (iv) combination of all subindicators into a general one.

3 Results

Assessment and classification were done to the mine area rehabilitation situation by synthetic principal components analysis (PCA).As a result, the number of PCs was reduced to four (Fig.2). The variables with higher loadings (positive or negative) are those that contribute most to explain the meaning of each principal component. The four principal components have the largest percentage of total variance, (Table 2) explaining 33.556%, 20.412%, 13.575% and 7.751% of the total variance, respectively (totally 75.294%).

Table 2 Total Variance Explained

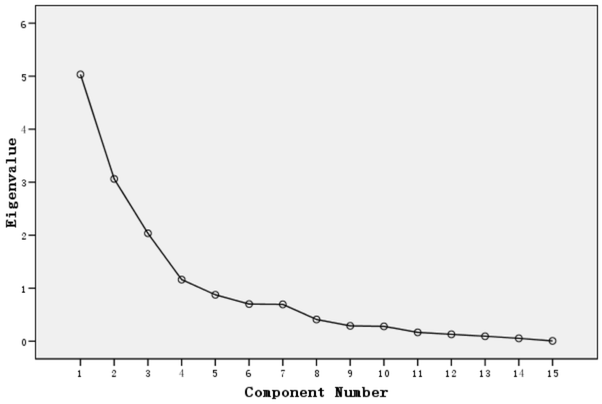

Fig. 2 Scree Plot of the indicators PCA

The relative significance of data set parameters and of overall soil environmental quality was assessed using PCA of the 15 retained variables. There (Fig.3) were four significant PCs that together explained 75.3% of the total variance (Table 3). In general, PC1, which accounted for 33.556% of the total variance, has high loadings for the OM, AA, pH and P. At the same time, PC1 is related to the toxic heavy metals, especially Fe. This indicates that organic matter and the heavy metal aspects of soil environmental quality were the most sensitive indicators of soil quality considered by this study.

Table3 Rotated Component Matrix (a)

	Component			
	1	2	3	4
pH	-.784	-.329	.339	.070
AA	.788	.067	.165	-.215
OM	.843	.161	.312	-.168
P	.758	-.117	-.152	.016
NH4-N	-.014	.975	-.023	-.060
NO3-N	-.006	.972	.033	-.041
S	.253	.538	-.208	.017
B	.024	.899	.115	.034
K	.593	-.005	.449	.135
Cu	.034	-.159	.359	.737
Fe	.881	.026	-.079	.179
Mn	.627	.543	.181	-.117
Zn	.561	.054	.572	.413
Ca	.110	-.065	.067	-.827
Mg	-.056	.009	.900	.066

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Principal component 2, which explained 20.412% of the total variance, included only three significant, positively weighted variables, NH4-N, NO3-N and B. Soils with high PC2 scores were organic matter.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.033	33.556	33.556	5.033	33.556	33.556
2	3.062	20.412	53.968	3.062	20.412	53.968
3	2.036	13.575	67.543	2.036	13.575	67.543
4	1.163	7.751	75.294	1.163	7.751	75.294
5	.876	5.842	81.136			
6	.701	4.676	85.812			
7	.696	4.637	90.449			
8	.410	2.734	93.183			
9	.290	1.931	95.114			
10	.280	1.868	96.982			
11	.168	1.117	98.099			
12	.130	.867	98.966			
13	.094	.630	99.596			
14	.054	.362	99.958			
15	.006	.042	100.000			

Extraction Method: Principal Component Analysis.

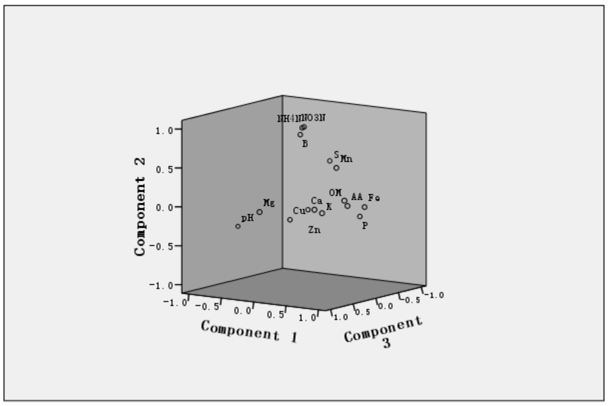

Fig. 3 Component Plot in Rotated Space

Significant PC3 and PC4 loadings, which explained 13.575 and 7.751% of the total variance, respectively, were associated with chemical parameters. The PC3 scores reflected Mg levels. Soils with high PC4 scores had relatively high Cu and Ca.

4 Discussions

The soil scientific community is aware of the complexity of soil quality evaluation. Many methods have been developed for different purposes, where a significant number of them are technical and require expert knowledge in order for them to be applied. In view of the highly varied types of end-users to which soil quality evaluation is directed, an applicable method for soil quality evaluation in urban areas must be flexible and easy to implement and upgrade. It should produce sensitive, effective, and clear results.

4.1 Indicators of soil environmental quality

The selection of soil quality indicators should be made carefully. The involvement of complex indicators could significantly improve the accuracy of the soil quality evaluation but it is likely that the procedure would then be much less applicable. It could also become costly, making unfeasible demandson time and knowledge. From the extensive list of possible soil parameters and measured soil data, a selection of the most important, generally applicable, and frequently measured SQI should be made, where these can be evaluated by using simple evaluation modules or pedotransfer functions.

Several soil quality indicators used in the evaluation may be mutually dependent. The high quality of many SQI can, to a certain extent, compensate for the low quality of one SQI. In situations when numerous SQI are evaluated and the quality is high for all of them but one, the resulting index value can still be relatively high (e.g., >0.5) in spite of the very low quality (low QD value) of only one indicator. Consequently, the soil should be interpreted as ‘quality soil’ and the significance of the single low quality SQI evaluated should be judged according to its importance or it should be determined by the legislated threshold values or by an additional risk-assessment procedure. Such situations often occur in urban areas when heavy metal soil pollution is defined in terms of threshold values. In reality, the quality of other important soil properties with high evaluations (e.g., organic matter, clay content, etc.) to a certain extent compensates for the single parameter with a low evaluation; thus, the high ISQ values indicate the lower potential for heavy metals to be released into the environment. In such cases the risk of soil pollution should be further assessed using additional risk evaluation procedures.

Many different soil quality classes may be used. During practical work, the ten-class rating was found to be too detailed regarding the spatial resolution of data and the spatial variability of the soil parameters, while three classes were found to be less suitable for the evaluation. It is justifiable to define the quality classes more precisely in cases when accurate and quality input about soil and land information is available, the spatial resolution of data enables/justifies the numerical precision of the evaluation, and separate SQI evaluation procedures are used, which give results of required precision. In this case, real values between 1 and 5, respectively (e.g., 3.5) can be used. Soil quality indictor weights (IW values) may be integers (1, 2 or 3) or real. An adequate definition of the soil quality class and indicator weight values for local environments and land uses primarily depends on local expert knowledge.

A large number of soil quality indicators have been proposed in the scientific literature in response to the growing needs for evaluation and monitoring of soils worldwide. Most indicator systems however only propose large lists of properties to measure (some of them redundant) focused on the resolution of rather specific questions [23-25].

Part of the indicators are based on biotic and abiotic parameters [26, 27], others on soil biochemical and microbiological quality [28, 29], organic matter stratification ratio [30], or chemical properties [31].

4.2 Soil environmental quality evaluation

The GISQ methodology is applicable to any group of sites that need a comparative evaluation. Methodological problems may however exist in selecting variables when the indicator has to respond to a large diversity of objectives.

For example, comparing the efficiency of different techniques in an attempt to rehabilitate degraded soils, evaluating the effects of different land use systems on soil ecological functions or assessing a general policy for natural resource and biodiversity protection [32].

The soil resource is affected during urban expansion of the city by the physical destruction of the soil (the spatial decrease in the active soil surface—soil sealing), and by the negative impacts caused by construction activities on the soils adjacent to the construction sites. Urban planning practices oriented towards more sustainable urban planning should take into consideration the evaluation of the loss of the soil resource and the assessment of the negative effects on the performance of the environmental soil functions resulting from urban expansion. The main purpose of Procedure B is to obtain a notion of: (i) how the active soil area will decrease as a result of the land use change; i.e., what the loss of the soil resource will be; and (ii) how the performance of soil functions will decrease (or increase in the event of remediation) with the land use change.

Building activities often degrade the soil adjacent to the actual construction site (e.g., the soil is mixed and/or compacted, and topsoil may be removed, polluted, or the quality lowered in some other way). This degradation is taken into consideration by adapting the ASAe to ASAp values in the evaluation procedure. For the final evaluation of the land use change impact on the soil, the ASAp value is used.

The assessment of two or more different planning areas at the same time enables a comparison of the API and I values. The I values calculated for different optional land uses may be used in scenario modelling. This information derived from the soil quality ndicators can be useful in guiding planners in the selection of a planning option which, from a soil protection point of view, would result in a lower negative impact on the soil resource and a lower decrease in soil function performance within the planning area.

High ISQ values can be used to detect the irrational use of soil (e.g., soil with high environmental value is environmentally too good to be sealed by extensive shopping centres). A comparison of the quantified results of Procedure B can be used to reconsider or adjust planning decisions towards more “sustainable urban design” (i.e., appropriate urban planning) and to “foster land use policies, which avoid urban sprawl and reduce soil sealing”.

The applicability of the method is facilitated and promoted also by means of the careful preparation of a set of instructive documents adapted to end-user needs and knowledge. In any case, the general pre-defined input parameters presented in this evaluation method should be included in the introductory stage of the method supplemented by local experts to best meet the specific needs of the local conditions [33].

In developing an end-user oriented method, a typical trade-off situation is frequently encountered:

the simplicity of the method used might entail a loss of scientific accuracy regarding the method, but this is compensated for by greater applicability and, above all, acceptability. If the method is recognized and accepted by planners it might contribute to better soil quality management in urban areas and more sustainable urban planning.

The diversity of cities and local conditions do not facilitate the elaboration of an evaluation method based on inflexible set of fixed parameters (i.e., threshold values of soil quality parameters), or the determination of a universally applicable PTF. The concept of the method itself is applicable within different cities but users are encouraged to supplement and tailor the method to meet the national/local legislation requirements, analytical procedures and interpretation, data availability, local planning practices, and other special circumstances. Local expert knowledge is indispensable to improving the evaluation accuracy, applicability, and feasibility of the soil quality evaluation. The selection of the appropriate PTF depends mainly on data availability and data suitability for local use [34].

This problem is resolved in GISQ since the methodology is rather adaptable and specific subindicators can be added as required, provided a minimum set of variables are measured to describe this effect in the reference data base. These could include such properties as the concentrations of pesticide residues and other pollutants as well as socio-economic parameters. The quality of an indicator largely relies on the quality of raw data used to build it and their currency. Most indicators available in the literature have not been validated nor their sensibility been tested in a wide range of situations.

5 Conclusion

This study allowed for the first time the formulation of an indicator of soil environmental quality that will allow accurately detection of any problem in soil function. This will facilitate the identification of sustainable mine rehabilitation practices and measurement of soil ecosystem services.

Evaluating and monitoring soil quality is a complex undertaking. It has become an important activity, because of the need to protect soil and its ability to sustain its functions. The soil-quality evaluation is considered a prerequisite for the agro-ecological sustainability of soil use and management. Depending upon the nature of the soil function under consideration in soil-quality evaluation, the selection of soil indicators will vary. These soil attributes can be classified in three broad groupings: physical, chemical or biological indicators. Most of the soil physical and chemical parameters, which are the main input land characteristics in land evaluation, are very fixed and permanent in time. However, the soil biological parameters are most variable and sensitive to management practices.

Soil-quality evaluation and agro-ecological land evaluation have many elements in common, and an approach is proposed that analyses soil physico-chemical indicators and soil biological indicators separately.

Organic management affects soil microbiological and chemical properties by increasing soil nutrient availability, microbial biomass and microbial activity, which represent a set of sensitive indicators of soil quality. The microbial biomass activity was not the only most sensitive reactions to different management because others soil chemical properties were affected (i.e. electrical conductivity, nitrate-N and phosphorus contents). The increased enzymatic activities in the organically managed soil expedite mineralization and mobilization of available nutrients, which may also estimate to be a potential of eutrophication for adjacent ecosystems.

Multivariate assessment of soil environmental quality indicated that chemical fertility and stocks of organic matter aspects of soils were the properties most altered by agronomic practices. Organic matter was the most sensitive indicator of soil environmental quality in this study. Use of multivariate scores as system descriptors may have minimized bias by preventing selective emphasis of ANOVA results.

Case studies in the different agro-ecological zones should be conducted on soil biological quality evaluation and monitoring, in order to provide detailed information on the effectiveness of the farming system, land-use practices, technologies and policies on soil protection.

These indicators will also assist in the design of adapted approaches to soil restoration and the monitoring of progress, once adequate interventions have been carried out. They will also be of great use in the assessment of general policies aimed at protecting or enhancing soil environmental equality. This is the case, for example, in the recently approved Chinese soil legislation that will require specific tools to verify the adequacy of soil environmental quality in relationship to requirements imposed by the law makers. Our different subindicators may also be considered as indicators of the performance of specific soil ecosystem services.

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