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Research paper

Method of Integral Assessment of Soil Quality in Rural-Urban Areas Based on the Fuzzy Logic

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Abstract

This article proposes a method of integral assessment of soil quality in rural-urban areas based on the fuzzy logic, both from the standpoint of the possibility of living in a given territory, and from the point of view of the possibility of keeping subsidiary farming. There are determined the linguistic variables describing the main soils components of rural-urban areas and terms describing the meaning of these variables. There are constructed the membership function that determine the ratio of the measured soil quality parameters to the terms and the rules of fuzzy inference. The authors developed an algorithm that describes this method.
This method of integral assessment of soil quality can be basis for the formation of well-founded control actions during the planning, construction and development of specific rural-urban areas.

Keywords: *method of integral assessment, fuzzy logic, assessment of soil quality, rural-urban areas.*

1. Introduction

Today, the construction of residential developments is one of the priority directions of the economy of the rapidly developing regions of the Russian Federation. Especially it should be noted the growth of private housing construction. The annual volume of housing commissioned by private developers in Russia in the last fifteen years has increased from 13 to 34 million m^2 (by 161%). There is intensive development of special components of urban agglomerations, whose population lives predominantly in low-rise residential developments. Such people can lead personal subsidiary farming on personal plots of land, and on the other hand actively participate in the economic and social life of the city. The authors use the phrase “rural-urban areas”. It means the territories of individual housing construction as well as workers’ settlement, rural settlement within the city and suburban areas characterized by the above specifics.
It should be noted that the planning, building and development of such areas in the Russian region is mainly carried out without assessing the dynamics of the quality of the natural sphere components state. Pollutants enter the soil directly from technogenic sources, through contacting environment (water, air), as well as with production and consumption wastes. Pollutants can spread along the soil body and accumulate in high concentrations in the upper layer. These processes significantly affect the health and life activities of population.
There is a connection between the effectiveness of the process of managing the planning, building, development of rural-urban areas, considering their environmental safety and development and research of effective methods and models for supporting decision-making in this area, including the methods and models for assessing the quality of the condition of these territories. On the basis of such methods and models, there can be obtained scientifically valid control actions. One of the modern methods of assessing the quality of area state is the application of data mining methods. [1-14]
The purpose of this work is to develop a method of integral assessment of soil quality in rural-urban areas as one of the main components of the rural-urban areas natural sphere. This method should be the basis for developing effective management impact in the planning, building and development of these areas and consider their main features, namely the predominance of low-rise residential development, keeping personal subsidiary farming, the special significance of soil conditions.

2. Methods of research

In this article, the authors propose to carry out a comprehensive assessment of the chemical soil condition both from the standpoint of the possibility of living in a given area, and from the point of view of the possibility of keeping subsidiary farming. This approach will provide an effective choice of management decision on the prospects for private housing construction in rural-urban areas.
The soil condition is described by a large number of dissimilar parameters both quantitative and qualitative . Tocarry out its comprehensive assessment, there is proposed to use a fuzzy logic. As a result, authors posed and solved the following problems:
- The definition of linguistic variables describing the different soils components of rural-urban areas;
- The definition of terms to which the values of these variables may be related with some degree of probability;
- The definition of membership functions, using which it is possible to determine the ratio of measured indicators of the soils condition in the rural-urban areas.
- The algorithm development for the integral assessment of soils in rural-urban areas.

The investigations were carried out in accordance with the terms of reference and the schedule of study "Research of the methods and processes modelling in biotechnology and plant systematic".

3. Results and discussion

The soils condition on the considered rural-urban areas can be represented as a linguistic variable:

$$\{SoilSt, T, SS, G, H\}, \quad (1)$$

Here, SoilSt is a name of the variable under consideration, describing the soils condition on the considered rural-urban area. T is a base term set, that is, the set of values of the linguistic variable. SS is the set of quantitative characteristics on the basis of which it is possible to determine whether the soil condition belongs to one or another value T. G is the set of syntactical rules for the formation of new values names of SoilSt, not included in the base term set. H is the mathematical rules that allow to specify the type of membership function.
To perform a comprehensive assessment of soils condition on considered rural-urban area, the SoilSt variable will be a composite one:

$$SoilSt = (SoilSt_з, SoilSt_{cx}), \quad (2)$$

Here, $SoilSt_з$ is a linguistic variable that characterizes the soils condition from the point of view of influence on the health of the population and the possibility of living in a given area;
$SoilSt_{cx}$ is a linguistic variable that characterizes the soils condition from the point of view of the possibility of cropping and keeping subsidiary farming. These variables similar to (1) and can be represented by this way:

$$\{SoilSt_з, T_з, SS_з, G_з, H_з\}, \quad (3)$$

$$\{SoilSt_{cx}, T_{cx}, SS_{cx}, G_{cx}, H_{cx}\}, \quad (4)$$

Here, $T_з$ and T_{cx} are the base term sets that set values of the linguistic variables $SoilSt_з$ and $SoilSt_{cx}$ respectively; T3 is on SS3, to the elements of which there are belonged the parameters of soil condition, characterizing its impact on public health; TCX is a fuzzy variable on the number set of SScx, to the elements of which there are belonged the parameters of soil condition, characterizing its suitability for agricultural exploitation.
Such as the assessment of soil quality in (3), (4), in turn, is determined on the basis of influence assessments of a large number of pollutants, so the variables $SoilSt_з$ and $SoilSt_{cx}$ are also composite:

$$SoilSt_з = (SoilSt_{з1}, SoilSt_{з2}, SoilSt_{з3}, \dots, SoilSt_{зj}, \dots, SoilSt_{зm}), \ j=\overline{1,J} \quad (5)$$

$$SoilSt_{cx} = (SoilSt_{cx1}, SoilSt_{cx2}, SoilSt_{cx3}, \dots, SoilSt_{cxi}, \dots, SoilSt_{cxn}), \ i=\overline{1,I} \quad (6)$$

Here, the variables $SoilSt_{зj}$ are estimates of the measured parameters affecting the soil condition from the point of view of the population health; and the $SoilSt_{cxi}$ variables are estimates of specific measured parameters affecting the soil condition from the point of view of its agricultural designation. When choosing these parameters, it is necessary to be guided by normative documents [15,17], the functional purpose of the considered area, and also the peculiarities of pollution sources that have a negative impact on the given area.
To describe the soils condition from the point of view of the impact on public health, the authors use following terms:
$T_з = \{ T_{з1}, T_{з2}, T_{з3}, T_{з4}, T_{з5}\}$,

Here, $T_{з1}$ is "clean" such an estimate of soil is given from the point of influence on the population health when the content of pollutants does not exceed the background level.
$T_{з2}$ is "permissible", such an estimate is given when the content of at least one pollutant exceeds the background level, but it is not above maximum permissible concentration (MPC) and the total pollution index $Zc < 16$.
$T_{з3}$ is "moderately dangerous", such an estimate is given when the content of at least one pollutant in the soil ranges from 1 to 2 MPC or the total pollution index $16 \le Zc \le 32$.
$T_{з4}$ is "dangerous", such an estimate is given when the content of at least one pollutant in the soil ranges from 2 to 5 MPC or the total pollution index $32 \le Zc \le 128$.
$T_{з5}$ is "extremely dangerous", such an estimate is given when the content of at least one pollutant in the soil exceeds 5 MPC or the total pollution index $Zc > 128$.
To describe the soils condition from the point of view of agricultural designation, the authors use the following terms:

$$T_{cx} = \{T_{cx1}, T_{cx2}, T_{cx3}, T_{cx4}, T_{cx5}\}, \quad (7)$$

Here, T_{cx1} is "clean", such an estimate of the soil is given in terms of the possibility of growing crops when the content of pollutants does not exceed the background level.
T_{cx2} is "permissible", such an estimate is given when the content of pollutants in the soil exceeds the background level, but not above MPC.
T_{cx3} is "moderately dangerous", such an estimate is given when the content of pollutants in the soil exceeds their MPC under the limited general sanitary, migration water hazard index and migration air hazard index, but below the permissible level by translocation index.
T_{cx4} is "dangerous", such an estimate is given when the content of pollutants exceeds their MPC with a limiting translocation hazard index.
T_{cx5} is "extremely dangerous", such an estimate is given when the content of pollutants exceeds the MPC in the soil for all hazard indexes.
Specific values of MPC degrees for the description of terms are determined by sanitary regulations and standards requirements to the soils quality in populated areas and agricultural soils quality.
The authors introduce the following terms for a comprehensive assessment of soils condition, which will be used in making management decisions about the possibility of building and directing the development of rural-urban areas.

$$T = \{T_1, T_2, T_3, T_4, T_5\} \quad (9)$$

T_1 is "clean", such an estimate is given when $SoilSt_з$ is "clean" from the point of view the effect of the soil condition on the population health and when $SoilSt_{cx}$ is "clean" from the point of view of the effect of soil condition on the population health. With such an estimate, the assessed area can be used both for living and for keeping subsidiary farming without restrictions;
T_2 is "permissible", such an estimate is given when both the estimates of $SoilSt_з$ and $SoilSt_c$ have a value "permissible" either when one of them has the value "permissible" and another has the value "clean". With such an estimate, it is also possible to live in the given area and grow crops providing certain measures to reduce the impact of pollution sources on the soil;
T_3 is "residence is limited". Such an estimate is given in the case when $SoilSt_з$ is "moderately dangerous" or "dangerous" but the $SoilSt_{cx}$ is "clean" or "permissible". With such an estimate, the living in such area can cause an increase in the level of general incidence, but the cropping is possible without significant restriction;
T_4 is "subsidiary farming is limited". Such an estimate is given in the case when $SoilSt_з$ is "clean" or "permissible", but $SoilSt_{cx}$ is "moderately dangerous" or "dangerous". With such an estimate, it is possible to live in a given area without significant influence on

population health, however, the soil of this area can be used only to grow crops that are not used as food;

T_5 is "extremely dangerous". Such an estimate is given in the case when $SoilSt_з$ is «extremely dangerous" and $SoilSt_{cx}$ is "extremely dangerous". With such an estimate, the soil is unsuitable for growing any crops and has a significant impact on the health of people living in this area.

To implement a fuzzy inference and obtain a comprehensive assessment of the soil condition in rural-urban areas, it is necessary to construct sets of logical rules of the form "if the condition", then "inference", for example, for the variable *SoilSt:*

If $(SoilSt_з = T_{з1})$ and $(SoilSt_{cx} = T_{cx1})$

Or $(SoilSt_з = T_{зi})$ and $(SoilSt_{cx} = T_{cxj})$ (10)

...

Then $SoilSt = T_k$,

Here, $T_{зi}$, T_{cxj} are the terms ("clean", "permissible", "dangerous", etc.) that are part of the basic term of the sets $T_з$, T_{cx} of dimension i, j. $T_k \in T$ from (9), $k=\overline{1,5}$. These terms give an estimate of variables $SoilSt_з$ and $SoilSt_{cx}$ respectively;

$SoilSt = T_k$ is the value of the integral assessment of soil quality in considered area. It is resulted from fuzzy inference, both from the point of view of the impact on the health population, and from the point of view of the possibility of keeping subsidiary farming and cropping.

Similar sets of rules should be constructed for the variables $SoilSt_з$, $SoilSt_{cx}$ to obtain the corresponding estimates.

To determine the degree of correspondence between each numeral value of the sets множеств $SS_з$ and SS_{cx} describing the soil condition in the considered area, the terms $T_{зi}$ and T_{cxj} use specially constructed for this case membership functions $\mu_{T_{зi}}$, $\mu_{T_{cxj}}$. The type and parameters of these functions should be determined according to the opinion of domain experts, regulatory documents and official statistics.

Figure 1 presents an algorithm of the method of the integral assessment of soil quality in rural-urban areas.

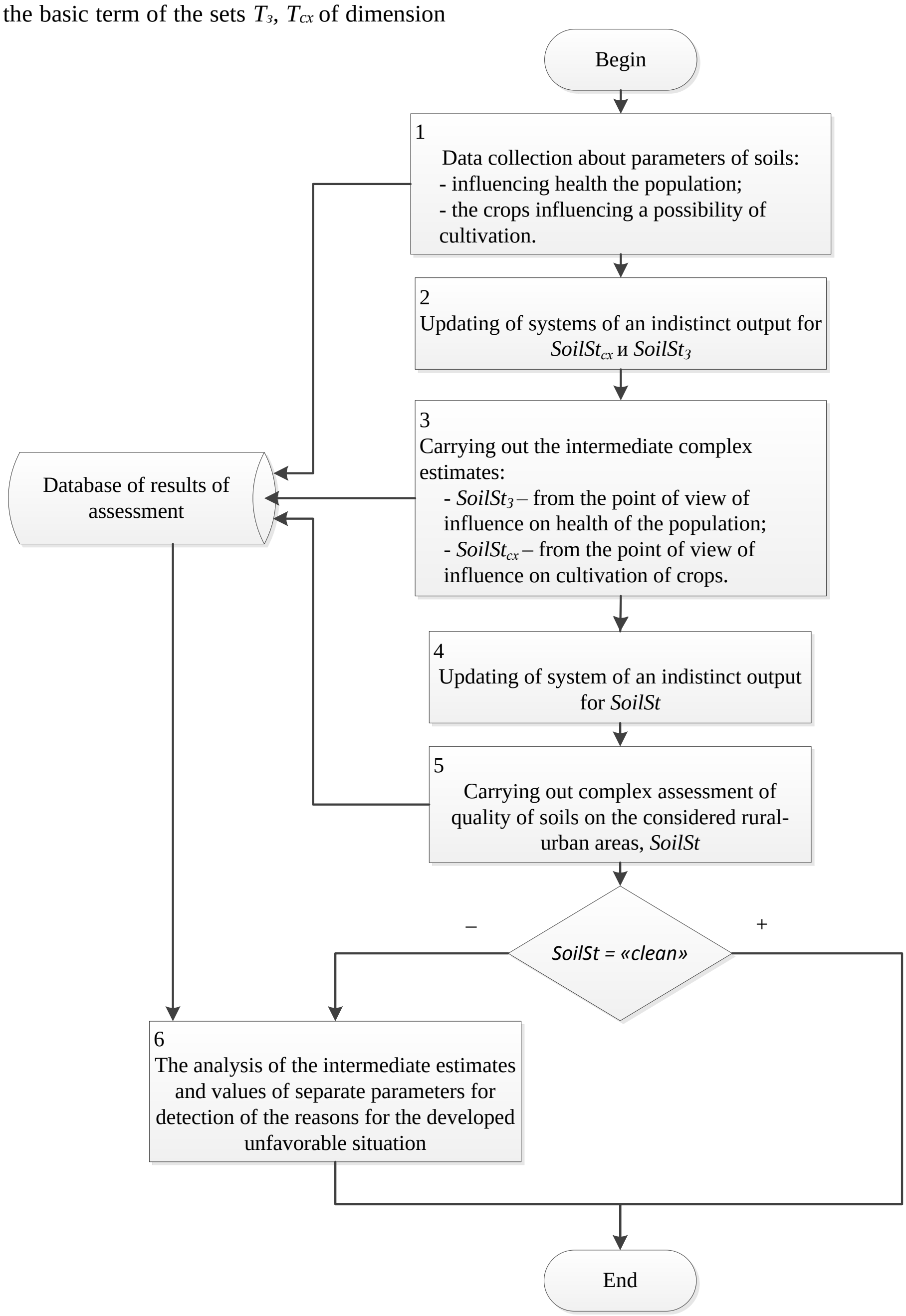

Fig. 1 - Algorithm of the method of the integral assessment of soil quality in rural-urban areas.

The first stage of this algorithm is the collection of data on soils parameters in rural-urban area. It should to collects information about the soil quality in the selected area according to a predetermined number of parameters. Data can be obtained both as a result of monitoring the current situation, and as a result of predictive modeling.

The second stage is the actualization of the fuzzy inference systems for $SoilSt_з$ and $SoilSt_{cx}$. The values of $SoilSt_{cxi}$ and $SoilSt_зj$ are determined based on the values obtained according to the developed rules system and in accordance with the identified membership functions.

Further, in the third stage, there is performed the procedure of fuzzy inference of the intermediate complex estimates of $SoilSt_{cx}$ and $SoilSt_з$ based on the values of the linguistic variables $SoilSt_{cxi}$ and $SoilSt_{зj}$. It should be noted that the intermediate estimates, as well as the values of soil parameters of the rural-urban areas, should be recorded in the database, which in future will allow to develop valid management decision.

In the stages 4 and 5 there is made a receipt of final comprehensive assessment the selected rural-urban area *SoilSt* similarly to the receipt of these intermediate assessment. Evaluator ends, if the resulting estimate corresponds to the term “clean”. If it does not, there is performed stage 6, which analyses all the intermediate results of the parameters estimation to identify specific causes that have a priority effect on the unfavorable soil condition.

4. Conclusion

The described method is the basis for developing implementing fuzzy models of the integrated assessment of soil quality in specific rural-urban areas considering their principal features. The final integrated assessment, as well as interim evaluations obtained during the operation of these models, can become the basis for the development of well-founded control actions in the planning, building and development of rural-urban areas and become a part of the automated management system for this type of areas.

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