CARTOGRAPHY AND AERIAL PHOTOGRAPHY

UDC 528

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USING A FUZZY IMPACT ASSESSMENT FOR THE ENVIRONMENT QUALITY EVALUATION

Purpose. The aim of the research is to develop fuzzy impact models of the natural and anthropogenic influence, which allows to integrate different physical factors, which makes it possible to bring them to a single environmental assessment system and comparison of different assessed areas. Methodology. The basis of the proposed modeling is a traditional approach on the development of such models, which includes conceptual, logical and physical modeling levels. The Unified Modeling Language (UML) is used for conceptual modeling level, which is recommended as the main modeling tool in the set of international standards in geographic information / geomatics and software that supports the interactive mode of UML diagrams creation Visio. The geospatial database and SQL-functions are implemented and the extension of the standard SQL-99 language with a new data type geometry and built-in functions which provides storage, processing and analysis of geospatial data in database management systems is used. The proposed models are realized in the environment of object-relational DBMS PostgreSQl / Postgis and geographic information system QGIS. Results. A review of the experience of using fuzzy logic to assess the state of the environment is done. Technological models for computation of indicators of administrative unit provision by social infrastructure objects, influence of greenery, industrial territories and transport on the environment are offered and realized. An example of approbation of the proposed approach based on OpenStreetMaps open data for the Popasnianskyi distinct of Luhansk region territory is given. Scientific novelty. Theoretical generalizations are made and practical results are received of resolving applied problem of the development of the fuzzy impact assessment model of various factors influence on the environment with use of GIS. Such assessment can be used at the stage of community spatial development strategies preparation to determine the most acceptable development version, as well as to unify the means of strategies implementation monitoring, organically linking local, national and global tasks. Practical significance. The application of the proposed approach of GRID modeling and fuzzy impact assessment use in assessing the quality of the environment allows to integrate different indicators, compare them, by bringing them into a single evaluation system.

Key words: geographic information systems; strategic environmental assessment; GRID modeling; environmental quality indicators; environmental management; environmental monitoring.

Introduction

The development of geographic information systems allows to use them to assess the state of the environment not only as a means of visualizing pollution sources, problem areas, etc. through thematic maps, but also to model relationships between these objects, assess or predict their possible manifestations.

During the development of urban planning documentation and strategic environmental assessment of this documentation there is a need to assess and compare planning alternatives and their impact on the environment by the set of indicators. For a quick, previous comparison of different planning versions and verification of the done conclusions, the need to develop indicators and/or systems for comparing the impact of spatial decisions is becoming necessary. To do this, it is proposed to use a geographic information model for fuzzy assess impact of potential pollution sources, recreational objects, social infrastructure, etc. on the quality of the environment of different administrative and planning units.

The application of fuzzy logic to assess the state of the environment was studied by the following authors Stanovskiy (2018), Olekh (2013), Lyashchenko (2012, 2010), Zaznobina (2008), Statyukha (2006), Adriaenssens (2006), M. Rudner (2007), Petry (2005), N. Vogiatzakis (2003), Enea and Salemi (2001), Mario (2001) and others. This approach is also used in open models of environmental quality assessment – InVEST Habitat Quality (InVEST).

In the works of Lyashchenko (2012, 2010) the application of GRID-models and fuzzy impact assessments taking into account environmental factors in the normative monetary assessment is considered, where examples of desirability functions for different components of man-caused load are given.The procedure of impact assessment on the environment using Harrington's functions is discussed in the article of Stanovskiy, which considers the assessment of the impact of physical factors on various components of the environment. The use of fuzzy logic is also used in open models of environmental quality assessment – InVEST Habitat Quality (InVEST), which considers the assessment of changes in habitat and its subsequent impact on biodiversity. The model assumes that the quality of habitat depends on the proximity of habitat to human land use and the intensity of use of these lands and uses two variants to calculate the impact of land use either on the basis of a linear function or on the basis of exponential. Analysis of previous work shows that the use of GRID modeling and fuzzy logic to assess the impact of natural and anthropogenic components is widely used to integrate disparate factors and can be extended to other problems based on specific inputs.

Purpose

The aim of the research is to develop fuzzy impact models of the natural and anthropogenic influence, which allows to integrate different physical factors, which makes it possible to bring them to a single environmental assessment system and comparison of different assessed areas. Such models allow not only to compare environments by different sets of factors, but also to compare the forecasts of the development of the same environment in the future.

The relevance of the research is due to the need of tools for assessing the environment state for cross-cutting application in the hierarchy of environmental management, including the assessment of sustainable development goals, assessment of ecosystem services, strategic environmental assessment and environmental impact assessment. This requires the development of convenient and objective methods for combining different properties and indicators of the natural and anthropogenic components impact on the environment into the integrated assessment system.

Methodology

To bring the dissimilar quality indicators of different environment elements to a single environmental assessment system, a fuzzy impact assessment based on the use of the GRID modeling and fuzzy sets based on Harrington's desirability functions was used [Liutyk, 2016; Harrington, 1965]. The main idea of using GRID modeling and fuzzy sets for qualitative assessment of the environment state consists in creation of the GRID geographical field of fuzzy estimates of the impact of various factors.

GRID-models (models of regular grids) in geoinformatics belong to the basic models of discrete representation of the spatial distribution of two variables functions $Z = f(X, Y)$ which is ordered by a set of values Zij in regularly arranged cells of the same size and shape [Lyashchenko, 2012]. Each cell of such GRID model can have a differential assessment of the state for each individual factor and/or integrated assessment – common to the group or all factors taken into account.

Harrington's generalized membership (desirability) function is based on the idea of converting all dimensional indicators into dimensionless quality indicators (desirability functions), which vary from zero (very low quality) to one (high quality), that is the natural values of individual indicators become dimensionless by unitary desirability scale and take values on the interval [0,1].

Using GRID modeling and fuzzy logic, the analysis of the environment quality of the settlements of Popasnianskyi district of Luhansk region was performed according to such criteria as provision by social services, impact and provision of greenery, impact of industry and transport.

To assess the social infrastructure provision of the Popasnianskyi district, social infrastructure facilities are divided into three main groups according to their priority on the basis of expert opinion (see Fig. 1).

Each group is assigned its maximum impact value (group weight), which in sum gives a value one for all groups. For each object in the group its service area (zone of influence) is defined in accordance with the requirements of DBN B.2.2-12: 2019, within which it serves the population. Note that these examples oriented on the implementation and testing of the approach based on available open data from OSM [https://www.openstreetmap.org], which served as a source of data in this research, and can be extended by criteria / objects, etc.

The general scheme of assess of the social facilities provision for each cell of the GRID-model and each settlement is presented as UML-diagram in Fig. 2. The basic approach is based on the fact that if the cell falls into the object influence zone in the group, then its influence on the cell is equal to 1 (True), otherwise the influence of the object is absent, so it is equal to 0 (False). The maximum impact of a group of objects is limited by the set value of the weight for this group (see Fig. 2). The total level of provision of the GRID-model cell with objects of all groups of social objects is defined as the sum of influence of all groups and varies from 0 to 1. For values from 0 to 0.2 the level of sufficiency is defined as unsatisfactory, for values from 0.2 to 0.3 – as low, from 0.3 to 0.5 – as below the base, from 0.5 to 0.8 – as base, from 0.8 to 1 – high.

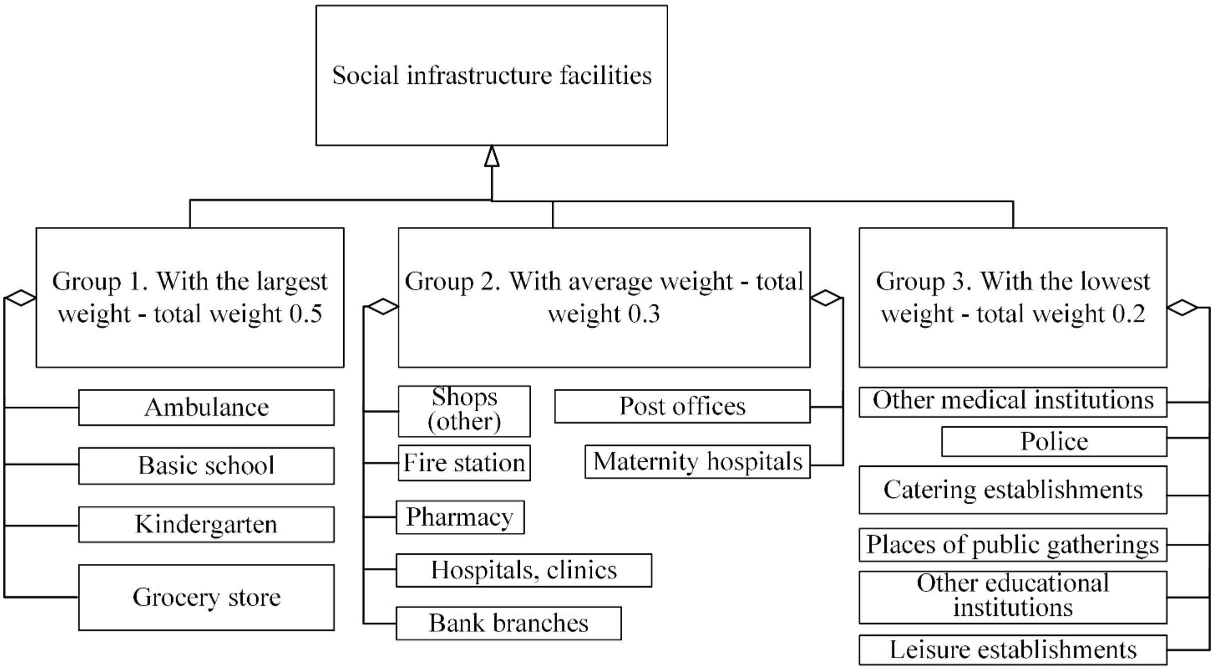

Fig. 1. UML – diagram of the social infrastructure objects classification by their priority

In order to evaluate the generalized provision of each settlement and compare the degree of their provision by social infrastructure, the ratio between the average value of the settlement social infrastructure provision and the average values of all settlements in the distinct is calculated (see Fig. 1).

To assess the impact of greenery and industrial facilities on the environment as a criterion the distance from these facilities to the cell and the degree of their impact on the cell, which is assigned to them on the basis of expert opinion, is used. Thus, for each cell of the GRID-model the impact of negative objects (industrial territories) is determined on the principle the closer to such an object the worse, and the impact of positive objects (greenery) on the principle the closer to such an object the better. Generalized technological schemes for calculating these impacts are presented as UML-diagrams in Fig. 3 and Fig. 4, respectively. To assess the impact of greenery, the distribution of green areas within the district was previously analyzed using the NDVI index (Chepanov, 2011) and Sentinel-2 images, open data from OSM. All territories of greenery were divided into three groups of impact, taking into account their area, in principle a larger area of greenery – more impact. In particular, the coefficients for assessing the level of greenery impact are divided into the following groups: from 0.8 to 0.9 – sufficient impact, from 0.9

to 1 – high impact, equal to 1 – intensive impact, equal to 0 – almost no impact.

The impact of industrial territories and transport is determined on the basis of the size of sanitary protection zones (SPZ) and hazard classes of objects according to DSP-173-96. The impact on the environment of each object is determined by a linear function:

$$b = \left\{ \begin{array}{l} if\ S_m \le S_{\min}, then\ b_m = k, \\ if\ S_{\min} < S_m \le S_{\max}, then \\ b_m = k + (0.8 - n) \cdot \frac{S_m}{S_{\max}}, \\ f\ S_m < S_{\max}, then\ b_m = 0.8 \end{array} \right\}, \quad (1)$$

where m – type of object (for example, industrial territories of the IV class of hazard, scrap heap, highways, etc.) from which impact is defined, Sm – the minimum distance from the object to the i-th cell; Smin, Smax – the minimum and maximum distances on which the impact from the object is taken into account; k, n – coefficients determined on the basis of expert opinion define the degree of impact for each type of object (type of impact), depending on the hazard class and the size of the SPZ.

The value of the transport and industry impact is divided into the following groups: from 0 to 0.2 – very bad, from 0.21 to 0.37 – bad, from 0.38 to 0.63 – satisfactory, from 0.64 to 0.8 – good, 1 – no negative impact.

Results

The proposed models are implemented as SQL-functions [ISO / IEC 13249-3: 2011] in the PostgreSQL/postgis database [https://www.postgresql.org/], the structure of which corresponds to the above algorithms (Fig. 2–4) with data visualization in the QGIS geographic information system [http://qgis.org].

Consider the physical implementation of these SQL-functions on the example of a function for calculating the social infrastructure provision.

The process includes the following steps (the following is a fragment of the SQL function for calculating the general level of provision of the cell by the objects of social infrastructure):

1. Creation of the function and variables declarations:

```
CREATE OR REPLACE FUNCTION cad_data.grid_soc_test()
RETURNS text AS
$BODY$
DECLARE
_o1 boolean;_o2 boolean; _o3 boolean; _o4 boolean; _g1 double precision; _g2 double precision; _g3 double precision; _o5 boolean;_o6 boolean; _o7 boolean; _o8 boolean; _o9 boolean; _o10 boolean; _o11 boolean; _o12 boolean; _o13 boolean; _o14 boolean; _o15 boolean;_o16 boolean; _o17 boolean; _o18 boolean; _gzal double precision; _geom geometry; i integer;
BEGIN
```

2. Selection of the cell:

```
FOR i in (SELECT id FROM cad_data.grid) LOOP
```

3. Determination of the cell entering into the zone of impact of different groups objects:

```
_o1=(case when (select coalesce(count(*),0) from cad_data.zones e where e.obj='emergency' and st_intersects(_geom, e.geom)=true)=0 then false else true end);
```

4. Determination of the total impact of the group:

```
_g1=0.5*((_o1+_o2+_o3)/4::double precision);
```

5. Determination of the total impact on the cell:

```
_gzal=_g1+_g2+_g3;
```

6. Calculation of the average value of the provision of cells with social infrastructure objects for the settlements of the district:

```
koef_gzagal=(SELECT AVG(c.gzal) FROM
(SELECT a.id,a.gzal, a.geom FROM cad_data.grid as a, cad_data.naspunkt as b WHERE ST_Intersects(b.geom,a.geom)) AS c);
```

7. Calculation of the ratio of the average value of settlement provision with social infrastructure objects in relation to other settlements of the district:

```
_koef_np=(SELECT AVG(c.gzal)/koef_gzagal FROM (SELECT a.id,a.gzal, a.geom FROM cad_data.grid as a, cad_data.naspunkt as b WHERE ST_Intersects(b.geom,a.geom) and b.id=i.id) as c);
```

The full text of the functions in the article is not given due to their volume and limited size of the publication. The key components of the function are given.

Approbations of the developed functions were performed using data from open sources, in particular OpenStreetMaps, for the above-mentioned territory of Popasnianskyi district of Luhansk region.

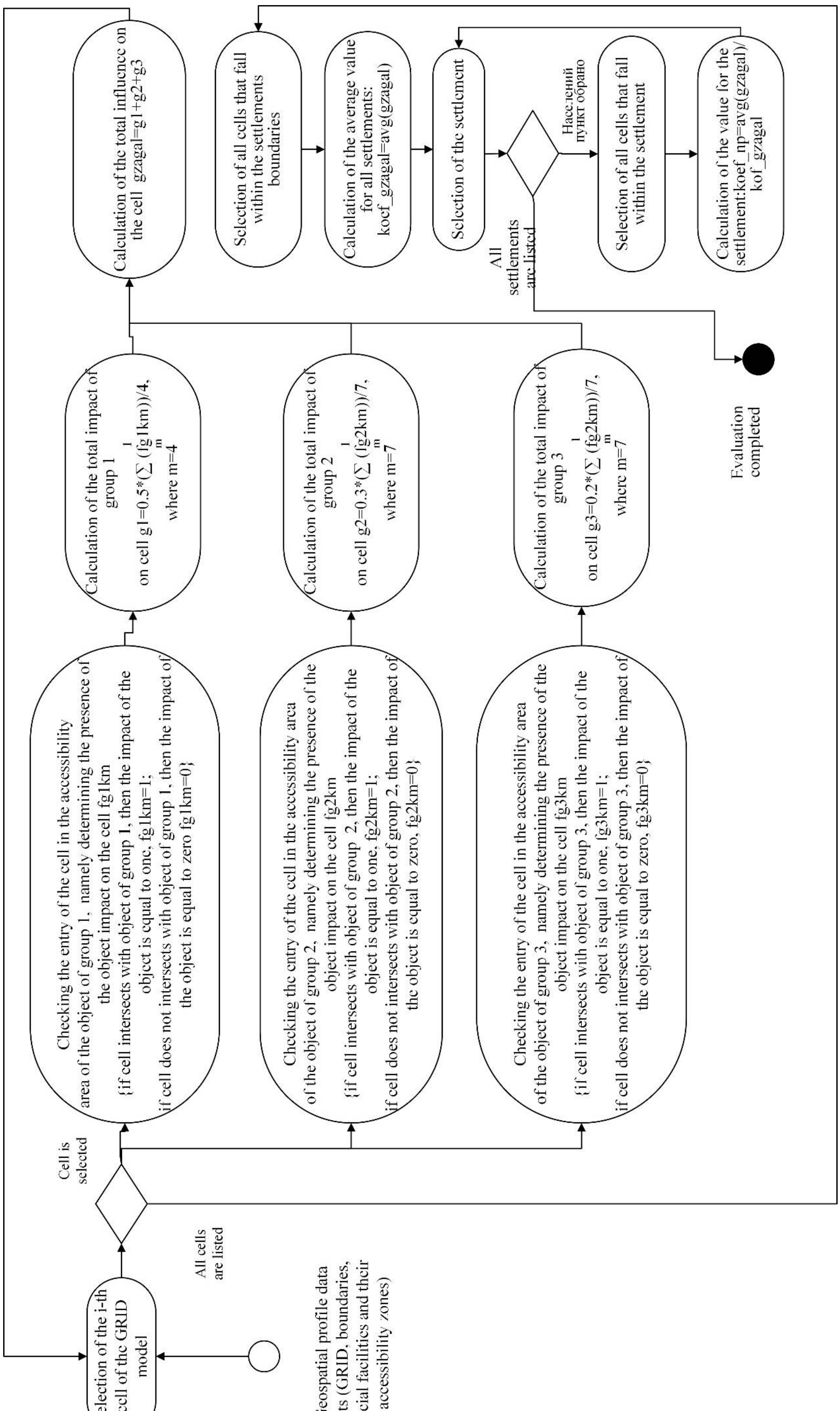

Fig. 2. Technological scheme for computation of the social infrastructure provision

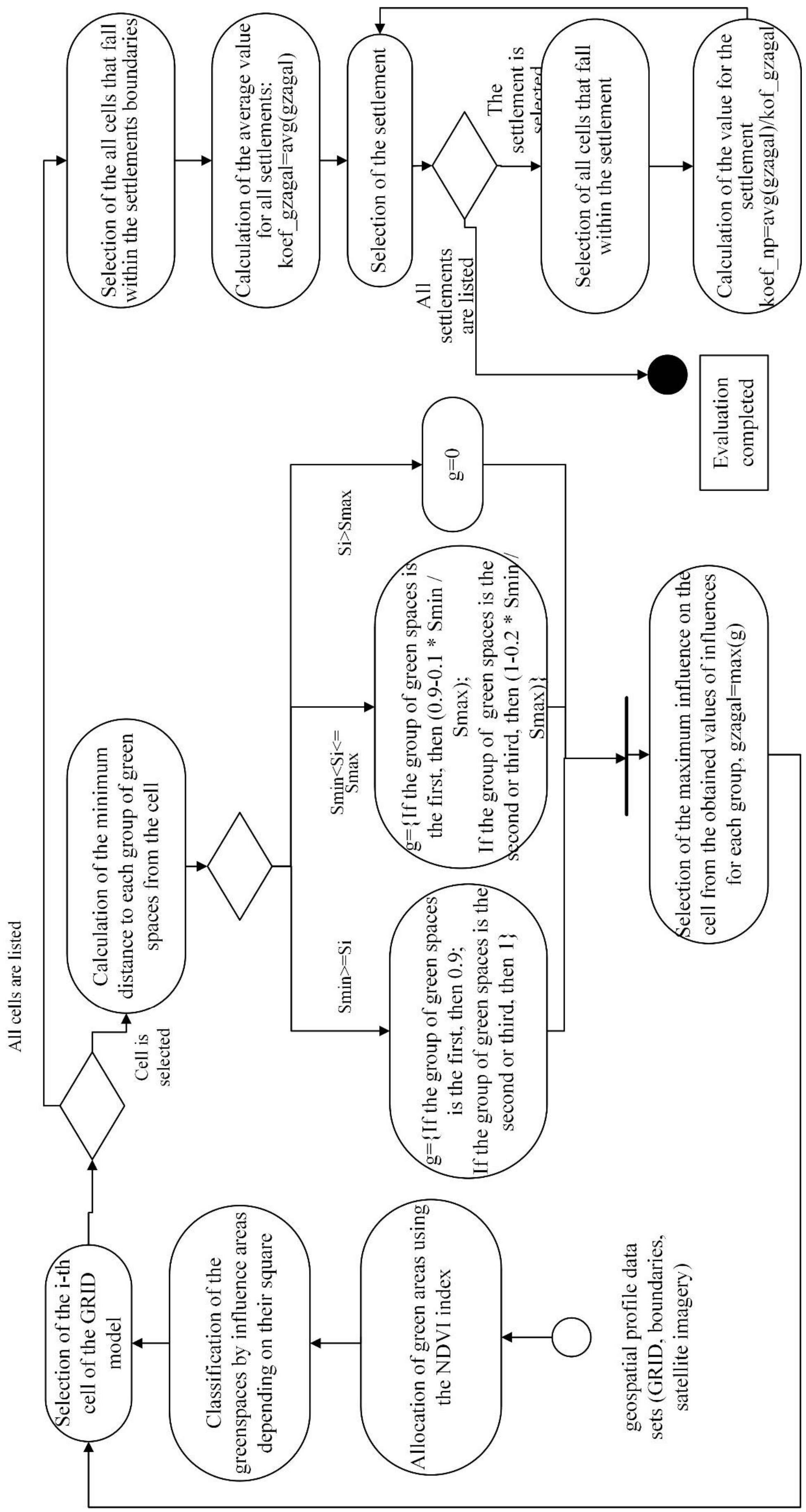

Fig. 3. Technological scheme for computation of greenery impact

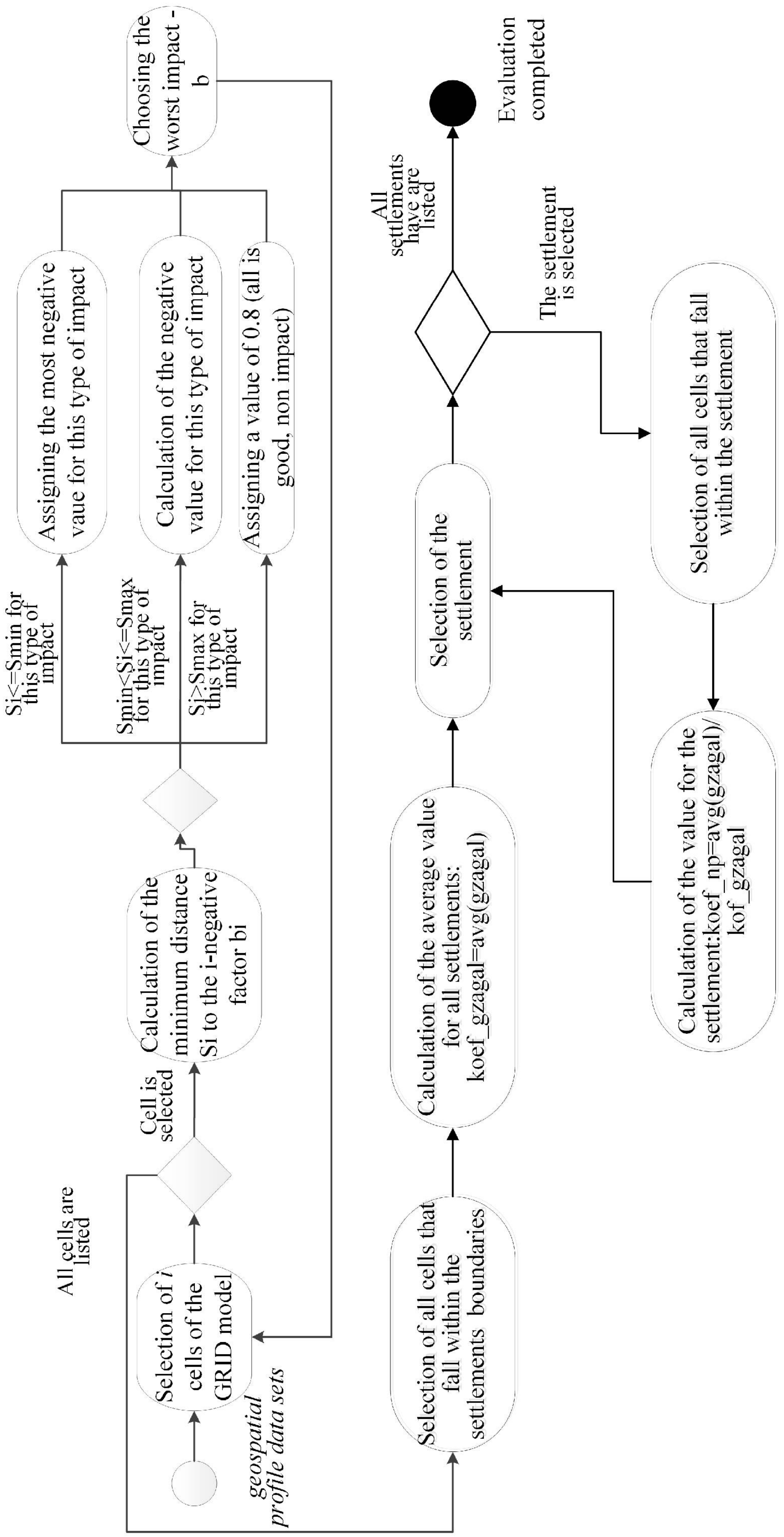

Fig. 4. Technological scheme for computation of industrial territories and transport infrastructure impact

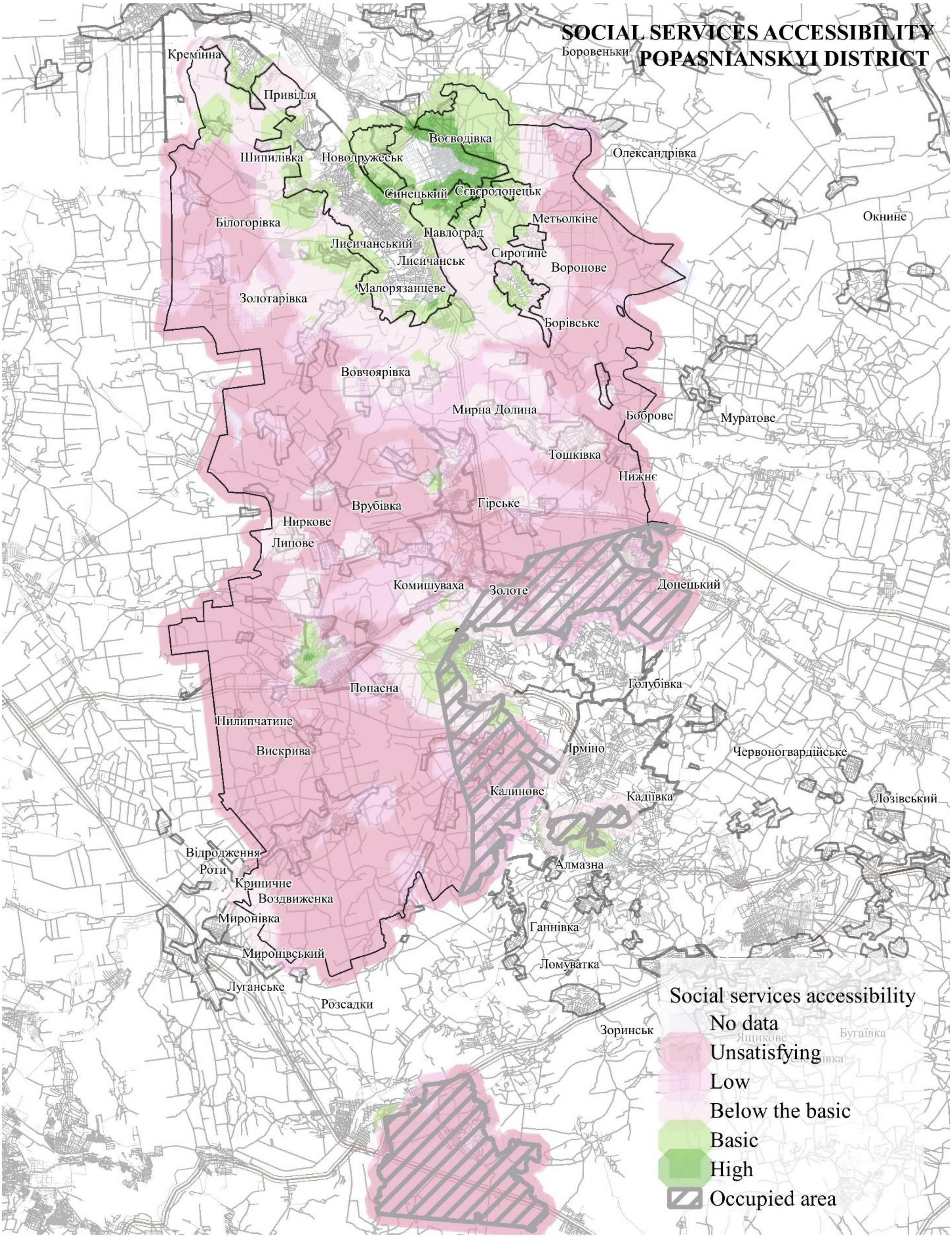

Fig. 5. Assessment of social services provision

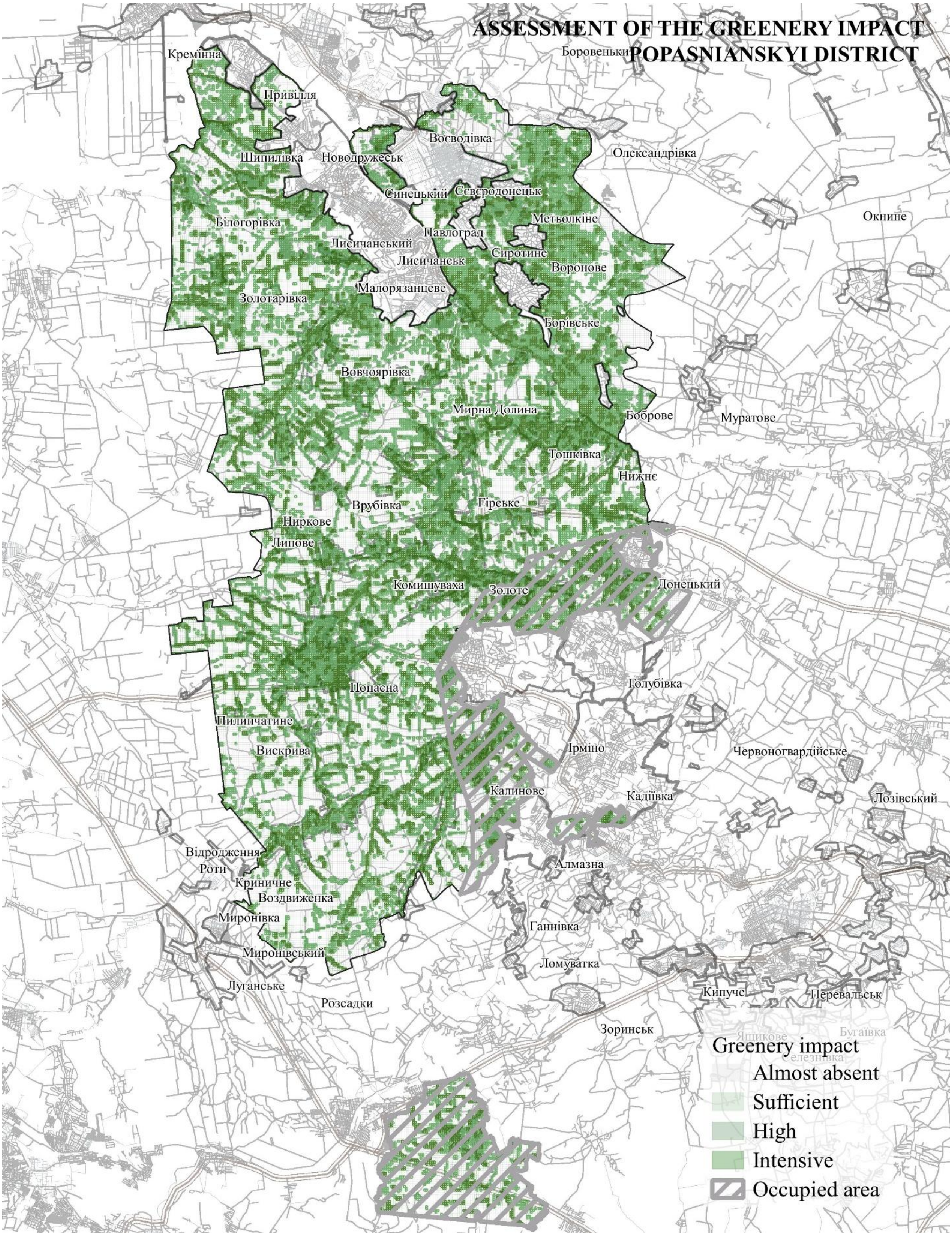

Fig. 6. Assessment of greenery impact

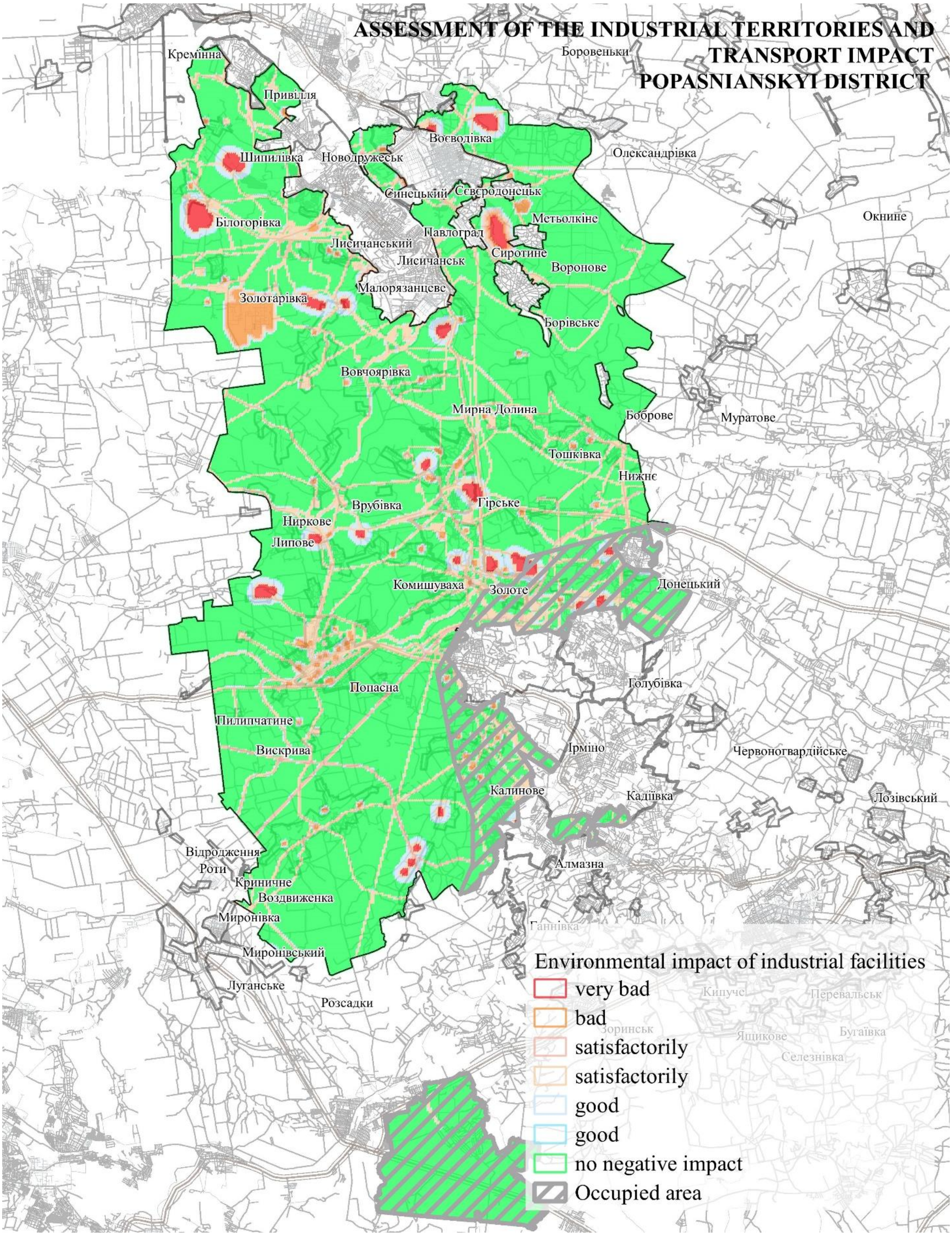

Fig. 7. Assessment of industrial territories and transport impact

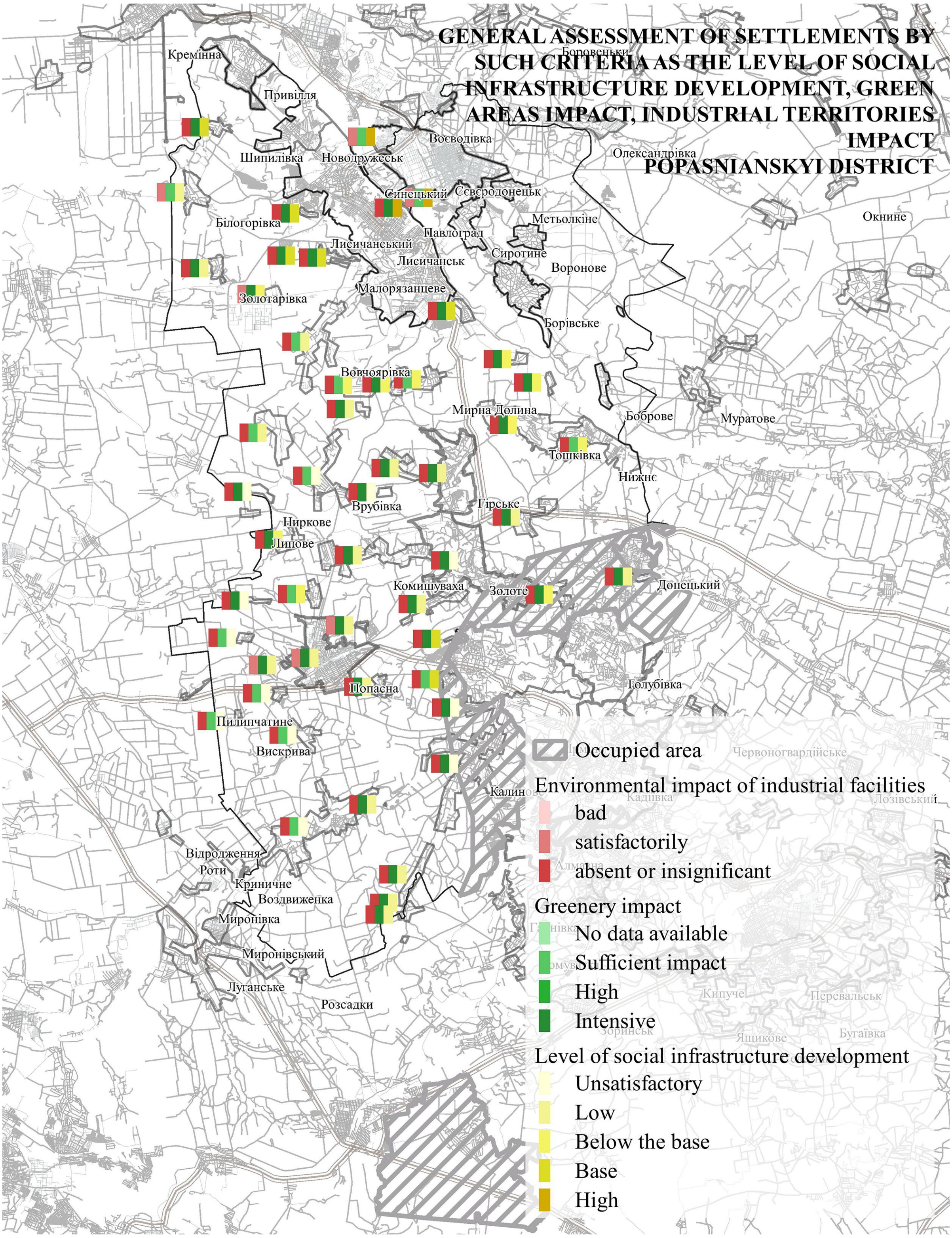

Fig. 8. Generalized assessment of settlements of Popasnianskyi district

According to the results of fuzzy GRID modeling thematic maps of geographical fields of integrated assessment of social services provision (Fig. 5), assessment of the greenery impact (Fig. 6), assessment of the industry and transport impact (Fig. 7) are prepared.

And also the thematic map of the generalized estimation of settlements by the listed indicators (Fig. 8) which reflects average values on each direction for all settlement is created.

Such assessment allows to identify places that need urgent attention, to determine development priorities for each settlement and to focus opportunities for their implementation.

Comparing the obtained results of GRID-modeling with the spatial distribution of objects in the research area, we can say that the obtained estimates reliably reflect the situation regarding the impact of the considered factors. On the maps on Fig. 5–7 examples of the distribution of the impact of anthropogenic factors due to planning decisions of the mid-twentieth century (social infrastructure, transport, industry) and natural factors (vegetation, water bodies) that are actively changing under the influence of current economic activity are shown.

Scientific novelty and practical significance

Theoretical generalizations are made and practical results are received of resolving applied problem of the development of the fuzzy impact assessment model of various factors influence on the environment with use of GIS. Such model is based on the use of independent impact assessments and GRID-modeling, which are widely used to assess the quality of the environment [Lyashchenko, Zaznobina, Olekh, Petri, Stanovsky and theirs], and has its own specific impact factors, weight of impact, and evaluation functions. Proposed assessment can be used at the stage of community spatial development strategies preparation to determine the most acceptable development version, as well as to unify the means of strategies implementation monitoring, organically linking local, national and global tasks.

Conclusions

In this research the generalized technological schemes for computation the social infrastructure provision, the impact on the environment of greenery and industrial territories and transport based on the use of GRID-modeling and fuzzy logic are proposed, the proposed technological schemes are implemented as SQL-functions on the example of the territories of Popasnianskyi district with the use of open data.

The application of the proposed approach based on the use of GRID-modeling and fuzzy impact assessment in assessing the quality of the environment allows to integrate different indicators, compare them by bringing them into a single evaluation system.

The improvement of the mathematical apparatus used for modeling, the expansion of logical rules for fuzzy assessment of the environment, and also adaptation of the proposed model for use at different levels of spatial planning are the perspective directions of further research.

To clarify the model of fuzzy assessment it is necessary to further expand the list of criteria taking into account not only the direct impact of the considered factors, but also feedback, in the form of physical and mental health of residents of the study areas. The possibility of integration the model with SCORE indicators is perspective direction.

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ВИКОРИСТАННЯ НЕЧІТКОЇ ОЦІНКИ ВПЛИВУ ДЛЯ ОЦІНЮВАННЯ ЯКОСТІ СЕРЕДОВИЩА

Метою дослідження є розроблення моделей нечіткої оцінки впливу природних та антропогенних впливів, які дають можливість інтегрувати в собі різні за своєю фізичною природою фактори, що в свою чергу дає можливість приведення їх до єдиної системи оцінювання стану довкілля та порівняння стану різних оцінюваних територій. Методика. Основу запропонованого моделювання складає традиційний підхід до проектування таких моделей, що включає рівні концептуального, логічного та фізичного моделювання. Для концептуального моделювання використано уніфіковану мову моделювання UML (Unified Modeling Language), яка рекомендована як основний засіб моделювання в комплексі міжнародних стандартів з географічної інформації / геоматики та програмний засіб, що підтримує інтерактивний режим створення UML-діаграм Visio. Для розглянутих моделей реалізовано базу геопросторових даних та SQL-функції, використано розширення стандартної мови SQL99 новим типом даних geometry і вбудованими функціями, що забезпечують зберігання, опрацювання і аналіз геопросторових даних в системах керування базами даних. Запропоновані моделі в дослідженні реалізовано у середовищі об'єктно-реляційної СКБД PostgreSQl/Postgis та геоінформаційної системи QGIS. Результати. Виконано огляд досвіду застосування нечіткої логіки для оцінки стану довкілля. Запропоновано та реалізовано технологічні моделі для розрахунку показників забезпеченості досліджуваної адміністративної одиниці об'єктами соціальної інфраструктури, впливу зелених насаджень та промислових об'єктів і транспорту на навколишнє середовище. Наведено приклад апробації запропонованого підходу на основі відкритих даних OpenStreetMaps для території Попаснянського району Луганської області. Наукова новизна. В роботі виконано теоретичні узагальнення та одержано практичні результати вирішення прикладної задачі розроблення моделі нечіткої оцінки впливу різних факторів на навколишнє середовище з використанням ГІС. Така оцінка може застосовуватись на етапі розробки стратегій просторового розвитку громади, для визначення найбільш прийнятного варіанту розвитку, а також для уніфікації засобів моніторингу реалізації стратегій, органічно пов'язуючи між собою локальні, національні та глобальні завдання. Практична значущість. Застосування запропонованого підходу щодо використання ГРІД-моделювання та нечіткої оцінки впливу при оцінці якості навколишнього середовища дозволяє інтегрувати в собі різні показники, порівнювати їх шляхом приведення до єдиної системи оцінювання.

Ключові слова: геоінформаційні системи, стратегічна екологічна оцінка, ГРІД-моделювання, індикатори якості середовища, екологічний менеджмент, екологічний моніторинг.

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