Territorial assessment of the ecological and social comfort of the population living environment of large industrial cities (by the example of Kryvyi Rih)

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Abstract. Providing a favourable and comfortable living environment for the population is one of the main tasks of optimising urban development. The level of comfort is formed with the territorial interaction of natural and socio-economic conditions for the region’s development. This interaction is especially manifested in large industrial centres, characterised by a strong negative anthropogenic impact on the environment. The territorial assessment of the comfort of the living environment involves a comprehensive spatial analysis of the population comfort main factors. The purpose of this work is a spatial analysis of the population living comfort of one of the most industrialised regions not only Ukraine, but also Europe – the city of Kryvyi Rih. Functional zoning was carried out using GIS Map Info with the allocation of the following areas: residential zones, public and business zones, industry and warehouse zones, resort and recreation zones. The distribution of the residential area according to the level of comfort of the population living environment was carried out according to 3 groups of factors: transport accessibility, development of social infrastructure and ecological state. The first group characterises the habitat from the point of view of the city’s provision with transport routes for various types of public transport. The second group characterises the population’s social conditions, namely the number of educational, cultural and medical institutions. The third block includes the ecological state of the territory according to the criterion of atmospheric pollution. The method of scoring made it possible to compare individual parts of the area under study across the entire range of natural, ecological and social population comfort. The combination of indicators of the totality of all three groups factors was carried out using overlay operations. As a result of the research, a map characterising the spatial differentiation of indicators of the living comfort in the city of Kryvyi Rih has been created. The specialisation of the city as a large industrial centre has determined the leading role of the group of environmental indicators in the situational model of the living environment comfort in the region.

1. Introduction

Ensuring a favourable and comfortable environment is one of the main tasks of optimising urban development. The level of comfort is formed by the territorial interaction of natural and socio-economic conditions of the region’s development. This interaction is especially evident in large industrial centres, which are characterised by strong negative anthropogenic impact on the environment. An essential feature of such cities is the territorial differentiation not only
in terms of environmental indicators, but also in terms of development of social, transport and engineering infrastructures. As a result, in industrial cities there is a significant heterogeneity of the urban environment in terms of living conditions.

Therefore, spatial analysis of habitat comfort, which takes into account a set of conditions and their parameters meeting the basic needs of the population, becomes important for such regions. It provides an opportunity to develop measures optimising the interaction of the living environment with the functioning of the industrial sphere of a large industrial region.

The concept of “comfort of the living environment” is interpreted as a measure of subjective feelings and objective state of well-being, formed under the influence of a set of different conditions most favourable for human life and economic activity [1].

It is taken into account that the set of optimal natural and ecological conditions for life forms ecological comfort, and the one of favourable for population’s economic activity forms social comfort of living. Studying ecological comfort, a set of conditions and their parameters that meet the basic physiological needs of living in the investigated area (including natural and climatic, geological and geomorphological, the degree of pollution of the atmosphere, soil, etc.) is taken into consideration. Examining social comfort involves the analysis of various social factors that affect primarily the livelihood of the population (development of services, the degree of development of the territory, transport accessibility, etc.).

In general, ecological and social comfort of the population living is a complex, multifactorial system that is an element of a large anthropogenic urban ecosystem. The structural elements of this system are urbanised, industrially changed landscape, transport and social infrastructure, and environmental situation. Thus, the territorial assessment of living comfort involves a comprehensive spatial analysis of the main factors of living comfort. Such research is of particular importance for objects with high technogenic load.

The purpose of this work is a spatial analysis of population's living comfort in large industrial cities, and the object of the study is one of the most industrialized regions of Ukraine and Europe – the city of Kryvyi Rih.

2. Methods
The traditional practice of modern urban planning is the functional zoning of the territory. When planning urban areas for different functional purposes, experts take into account the type and purpose of the territory.

There are different approaches to the allocation of urban functional zones [2–10]. For example, there is a division of functional zones into: residential areas, public and business areas, industrial and warehouse areas and resort and recreational areas [8]. Often production zones are divided into transport infrastructure zones, engineering infrastructure zones, communal warehousing, production and special zones.

However, as practice shows, the more zones, the more complex the zoning structure is and it is more difficult to manage such a city. In addition, it is more difficult for the local population to adapt to more complex zoning structures, to understand the purpose of each of them and to develop a system of restrictive measures. Therefore, the desire to generalise the functional structure of large cities seems obvious.

In this paper, the basis of functional zoning of the city (by the example of Kryvyi Rih) is the classification defined by the current state building codes DBN B.2.2–12: 19 “Planning and development of territories”.

According to these norms, the territory of the city as for functional purpose and nature of use in general is divided into: residential, industrial, landscape recreational ones, within which individual land plots should be planned into functional zones: residential and public buildings, industrial buildings, communal and warehouse buildings, landscape and recreational, health and wellness, green areas, environmental protection, historical and cultural purposes,
transport communications (transport infrastructure), engineering communications (engineering infrastructure), special purpose [5].

*Residential zone* is the territory where there are zones of housing, public buildings, green areas of common use, adjacent areas of residential buildings, objects of daily and periodic service, public centres, green areas of general and limited use, special purpose, main and street-road network, sites for utilities, engineering support of residential areas, fire stations, garages and parking lots, bicycle parking lots, etc. [5].

*Industrial zone* is the territory of enterprises, facilities, utilities and facilities, transport infrastructure, warehouses, innovation development (technology parks, industrial parks) as the part of industrial zones, industrial areas, enterprises located separately or the groups of enterprises [5].

*Landscape-recreational zones* are the ones of green and other open spaces for various purposes, located in the settlements and suburban areas, and in inter-settlement areas, including landscape complexes, recreational areas, resorts and health areas, cultural heritage sites and tourist zones, territories of nature reserve and water funds, water and field protection zones, transport-distribution green strips and other objects of green economy [5].

The zoning is based on the general plan of the city of Kryvyi Rih on a scale of 1:25 000, executed by SE SDI Kryvbasproekt in 2011, generalised to a scale of 1:100 000. It should be noted that clear differentiation of urban areas by type of functional use is difficult in a large industrial city due to the close intertwining of different functions of one area, so to clarify the spatial data additional cartographic materials [11] and current satellite images have been used.

Methodology features for determining the level of the population living environment comfort of the city’s residential area should be vcharacterised separately. Comfort and quality of life have been evaluated by many researchers. There are a number of methods for determining various aspects of quality of life, based on various indices, indicators and opinion polls [6, 8, 12–17]. In general, these approaches reflect the socio-economic living conditions of the population and the degree of satisfaction with them, or the degree of environmental safety of the territory.

In this work the population’s living comfort is determined by three groups of factors: transport accessibility, development of social infrastructure and ecological condition of the territory. The first group characterises the territory of residence in terms of providing the city with transport routes of various types of public transport. The second group characterises the social living conditions of the population, in particular the number of educational, cultural, health care institutions, etc. The factors of the third group include the ecological condition of the territory by the criterion of air pollution.

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The choice of these factors as the main ones in assessing the living comfort of the city population is confirmed by the results of a survey of city residents conducted by the Institute of Urban Development (Kryvyi Rih). Thus, among the comfortable factors of living, the indicator of developed transport infrastructure (62.4% of respondents), developed trade infrastructure (44%), presence of playgrounds (37.1%), presence of park areas and squares (31.6%) and proximity of educational institutions (31.6%), services (28.7%), satisfactory environmental situation (25.2%), availability of cultural and entertainment facilities (21.1%) and sports grounds (16.3%) received the largest number of elections.

In order to quantify the population's living comfort, the method of scoring the territory of the city of Kryvyi Rih has been chosen. The scoring system is characterised by simplicity of calculations and allows: to correlate the existing level of comfort and identify its territorial imbalances; to include in the system of assessments any kinds of indicators of natural-ecological and social purpose; to derive an integrated indicator of comfort of a certain territory and carry out a comparative analysis of integrated indicators of comfort of different urban areas.

In order to perform the scoring, the territory of Kryvyi Rih on the city master plan is covered with a regular grid, the cell size of which is 500 × 500 m, which is determined by the mapping
scale (1:100 000). For each pixel of the grid, the scores of the factors of living comfort of the population are determined. In order to interpolate the conditional surface, the coordinates of the centroids of each cell are determined and a layer of points from the weighted averages is created. The Geo Info geographic information system has been used to process the weighted averages. The result is a series of maps illustrating the spatial differentiation of each of the comfort indicators.

Figure 1. Map of ecological and social comfort of the living environment of the population of Kryvyi Rih.

The determination of the integrated indicator of the population’s living comfort of the city of Kryvyi Rih has been carried out by averaging all estimates for each of the pixels.
The obtained total scores have been ranked according to the principle of natural gaps. This allows to distinguish within the statistical series of the integrated indicator of living comfort of the population of Kryvyi Rih three groups of conditions of comfort of the population living environment (ranging from the highest to the lowest ones): **good** (more than 3.8 points), **satisfactory** (from 2.3 to 3.7 points) and **uncomfortable** (less than 2.2 points).

Based on the principle of spatial combination of indicators of cells in polygons, a map of population living comfort in the city of Kryvyi Rih has been constructed (figure 1).

### 3. Results and discussion

Kryvyi Rih is the eighth most populous city in Ukraine (612.8 thousand people as of January 1, 2021), the largest of the cities which are not regional centers. It is a multifunctional centre with a dominance of industrial functions. More than 100 large industrial enterprises are located on its territory, which provide about 10% of the total industrial production of Ukraine. The negative result of the industrialization of Kryvyi Rih is serious environmental problems: the city is one of the most environmentally unfavourable regions for the population. Therefore, the study of quality of life in the current urban conditions is an important and urgent task.

The analysis of the zoning scheme of the territory of Kryvyi Rih performed in the framework of this study (figure 1) allows to determine the linear type of functional zoning of the urban area. It is natural for a city longer than 100 km.

A unique feature of such a structure is the lack of a clear urban "core" in Kryvyi Rih, which is typical of most large cities. As a result of the dispersed location of individual industrial facilities, the central part of the city has the shape of a central axis that crosses Kryvyi Rih from the south to the north. As a powerful centre of the mining and metallurgical industry in the historical perspective, Kryvyi Rih was formed along the ore body of the Kryvyi Rih iron ore basin, so industrial enterprises tend to iron ore deposits.

Residential areas have been formed around these facilities, gradually creating a single urban infrastructure. Today it significantly increases the time for moving from the suburbs to the central part, the cost of engineering and transport infrastructure of the city, etc. Inconveniences also occur due to the stretching of the entire system of public and cultural services, as well as the growing tendency to monotony of urban landscapes.

![Figure 2](image.png)

**Figure 2.** The ratio of functional areas in the structure of the city of Kryvyi Rih.

A characteristic feature of the functional zoning of large industrial centers is the dominance of industrial zones in the structure of their territories. In Kryvyi Rih, **industrial areas** occupy a significant part – about 45% of the city (figure 2).
The largest industrial area is located in the southern part of the city (figure 3) and is represented mainly by large enterprises of the metallurgical industry: PJSC “ArcelorMittal Kryvyi Rih”, JSC “Southern MPP”, PrJSC “Ingulets MPP”. In the general structure of the territory of this city’s part, the industrial zone covers more than 70%, among which quarries, dumps and tailings dominate.

In the central and northern parts of Kryvyi Rih, industrial areas cover less than 40% of the territory (figure 3). In addition to large industrial enterprises (PrJSC “Central MPP”, PrJSC “Northern MPP”), there are enterprises of trade, utilities, consumer services, food industry and others.

**Landscape-recreational areas** occupy only 18% of the city and are represented by parks (Fedir Mershavtsev, Bohdan Khmelnytsky, Jubilee and others), squares, beaches. The location of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine, which belongs to the zone of the Nature Reserve Fund is of great importance for the city. In the southern part of the city the share of landscape-recreational areas is the smallest one (12%). Due to the significant anthropogenic pressure on the environment, the city does not have enough recreational facilities.

**Residential areas** occupy 37% of the city’s territory, with a significant predominance in its central part (67%). They occupy the smallest area (12%) in the south of Kryvyi Rih (figure 4). The basis of the residential area of Kryvyi Rih is occupied by manor buildings, the other part of it is covered with the areas of medium and multi-storey buildings. The last also include public and business zones: city government agencies, organizations, educational and health care institutions, etc.

According to the analysis, in Kryvyi Rih the residential areas are as close as possible to the industrial ones, they often fall into the sanitary protection zones of enterprises, which violates the state building norms.

Characteristics of the population’s living environment comfort of the residential area of the city requires analysis of indicators of each of the three groups of factors: transport accessibility, development of social infrastructure and environmental condition of the territory.
Transport accessibility, or accessibility of transport services for the population, is an important socio-economic condition for the development of the city. Availability of transport services means the ability of different groups of population to use transport infrastructure to realise their movements, the ability of people to reach jobs, study, purchase goods and services, as well as the implementation of other life functions.

In the work, transport accessibility is assessed by the following criteria: the number of transport routes (according to the site Easy way), distance from the city centre, proximity to high-speed tram stations and land transport stops.

As in the other large industrial regions, the most favourable for the livelihood of the population are urban areas with the highest rates of transport accessibility. In Kryvyi Rih they are naturally located along the central axis of the city along its entire length.

Urban areas, characterised by a sufficient number of transport routes for the normal functioning of the population have a satisfactory rate. These large areas are usually located between the central part and the outskirts of the city.

The most separated from the main highways areas of Kryvyi Rih are unfavourable for the population's livelihood. This category includes areas with a small (1–3) number of urban transport routes, as well as areas with zero transport coverage. There are no high-speed tram lines in these areas either. These unfavourable areas are located in the outskirts of Kryvyi Rih.

In the work territorial development of social infrastructure is assessed by the number (within a certain area) of institutions of education (preschool, general secondary, extracurricular, higher, etc.), culture (cultural-artistic, entertainment, art education, museums, theatres, libraries, etc.), health service (primary, secondary, tertiary link, pharmaceutical, etc.).

The highest scores were given to about 10% of the residential areas of Kryvyi Rih. Mostly these are the territories of the old and new central parts of the city, as well as separate plots of its northern part.

The largest share (about 55% of the residential area) falls on the territory with a satisfactory indicator of social infrastructure development. These are the areas of large and the most populated Saksahan and Pokrovskyi administrative districts of the city. In the other districts the areas with the average value of the indicator are distributed locally. Social and healthcare facilities predominate among the social infrastructure facilities here.

About 35% of the territories have the worst assessed social characteristics. They are classified
as socially disadvantaged due to the small or zero number of social infrastructure facilities. Mostly they are the territories of the residential areas distant from the central axis of the city.

The assessment of the ecological condition of urban areas is based on the nature protection scheme of Kryvyi Rih, in which the areas are differentiated by the total indicator of air pollution.

There is a significant territorial differentiation of Kryvyi Rih in terms of air quality. The most polluted is the air basin of the east of the central and southern parts of the city. The most favourable one is removed from the contaminated areas of the extreme southern and northern parts of the city. Other urban areas have intermediate values for air pollution.

The introduction of an integrated indicator of comfort as a set of indicators that characterise individual factors of comfort with their territorial affiliation, has allowed to build a map of ecological and social comfort of Kryvyi Rih population (figure 1), which reflects the territorial differentiation of three levels of residential area of the city: favourable (good), satisfactory and uncomfortable.

![Figure 5. The ratio of areas of the residential zone with different levels of ecological and social comfort of the living environment of the city population in Kryvyi Rih.](image)

The spatial position of the comfort areas of the residential zone together with the localization of the industrial and landscape-recreational zones form the basis of the spatial-planning organisation of the city, its “framework”. The framework divides urban spaces according to the intensity of their development and the degree of population’s comfort of life and, in general, significantly complements the functional zoning of the city.

Presented on figure 5 the ratio of the areas of the residential zone with different levels of ecological and social comfort of the population’s living environment of Kryvyi Rih shows the dominance of uncomfortable areas (40%) in the city.

There are significantly fewer urban areas favourable for life in Kryvyi Rih. Their share does not exceed 25%. Almost twofold exceedance of the share of areas with extremely uncomfortable living conditions is a characteristic feature of large industrial cities. This is due to the link between the development of urban infrastructure and the industrial development of the region. Whereas social demand is of secondary importance here.

Analysis of the spatial differentiation of the habitat comfort indicator revealed that about 63% of the territories with favourable comfort are concentrated in the central part of Kryvyi Rih (figure 6), while in the north of the city there are only 7% of such territories. However, the vast majority (82%) of areas with uncomfortable living conditions are in the central part of the
city; they also significantly dominate in the east. The share of these territories in the north and in the southern part of Kryvyi Rih is insignificant (20%).

Figure 6. Spatial distribution of territories with different levels of ecological and social comfort of the living environment of the population of Kryvyi Rih.

Figure 7. Quantitative ratio of territories with different levels of ecological and social comfort of the living environment of the city population of Kryvyi Rih.

The analysis of the quantitative ratio of territories with different levels of the ecological and social comfort of the population living environment of the city of Kryvyi Rih shows somewhat different values compared to the spatial analysis (figure 7). In the context of quantitative
analysis, the northern part of the city is the most comfortable to live in, while the southern one and the east of the central part of Kryvyi Rih are the most unfavourable. The revealed destructiveness is caused by excessive (more than 2/3) concentration of territories of the residential zone in the central part of the city.

**Table 1.** Distribution (in %) of territories with different levels of ecological and social comfort of the population living environment by administrative districts of Kryvyi Rih.

| Comfort indicator group | Terny | Pokrovskskyi | Saksahan | Central City | Dovhintsevsky | Metalurhiyyny | Inhulets |
|-------------------------|-------|--------------|----------|--------------|---------------|---------------|--------|
| good                    | 24    | 33           | 18       | 7            | 7             | 4             | 7      |
| satisfactory            | 15    | 12           | 17       | 30           | 1             | 11            | 13     |
| uncomfortable           | 7     | 13           | 8        | 9            | 51            | 05            | 7      |

The regularities revealed during the research were reflected in the differentiation of the living comfort indicator by administrative districts of the city (table 1). Significantly more than half (57%) of the territories with favourable living conditions are in Terny and Pokrovskyi districts of Kryvyi Rih, located in the north and in the northern part of the city centre, respectively. More than half (51%) of the area considered as uncomfortable is located in Dovhintsevsky district, situated in the east of the central part of the city. In the other areas of the city this figure varies in the range of 5–13%.

**Figure 8.** Quantitative ratio of territories with different levels of ecological and social comfort of the population living environment by administrative districts of the city of Kryvyi Rih.

Thus, according to the set of criteria of ecological and social comfort of the population’s living environment (figure 8), the most favourable are Terny, Pokrovskyi and Central City districts,
the most uncomfortable is Dovhintsevsky district. Indirect confirmation of the obtained results is their correlation with the results of the survey of city residents conducted by the Institute of Urban Development (Kryvyi Rih). Thus, in the distribution of city districts by comfort through the eyes of respondents, Central City District was in the first place (28.8% of respondents), and Dovhintsevsky district was in the penultimate one (6.3%). Respondents defined rather low assessments of living comfort for Terny (7.8%) and Ingulets (4.6%) districts, because of the remoteness of the place of residence from the administrative centre.

4. Conclusions

1. An important result of the study has become the development of methods for spatial assessment of ecological and social comfort of the population living environment of large industrial cities by the example of Kryvyi Rih, which includes a set of criteria and evaluation indicators using mathematical and cartographic modelling based on geo-information technologies.

2. For the first time for the city of Kryvyi Rih a series of thematic maps of the main factors of formation of ecological and social comfort of the population living environment has been built, which made it possible to form an integrated map of the comfort of the urban environment.

3. The obtained results make it possible to identify territorial imbalances in the development of socio-economic policy of the city.

4. In order to ensure a balanced comfortable living of the population of all residential areas of the city it is necessary to systematically develop social infrastructure, improve public transport, increase the area of recreational areas, implement measures for enhancement of the ecological condition of the territory, etc.

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