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The Environmental Component of Sustainable Development Potential in the Odesa Industrial-Urban Agglomeration

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ABSTRACT

Given that 60% of Ukraine's population resides in urban areas, socio-economic and environmental modernization of the country's regions is indispensable for sustainable development. This study addresses the factors characterized by various challenges that impede the sustainable development of urbanized territories in Ukraine. The aim of this research is to analyze the conditions necessary for ensuring sustainable development, using the Odesa industrial-urban agglomeration as a case study. The methodological framework of this article relies on a critical analysis of existing assessments of the conditions for sustainable development in urbanized territories of Ukraine, alongside our own research findings on this issue. Preservation of a favorable natural environment and efficient resource utilization are fundamental principles underpinning the sustainable development of urbanized areas. To actualize these principles, a comprehensive set of measures is proposed to enhance the quality of the air basin, natural waters, soil cover, geological environment, and urban biocenosis. Additionally, an effective waste management system is advocated. Furthermore, strategies for conserving and expanding green spaces, which play a pivotal role in mitigating the adverse effects of urbanization on the environment, enhancing air quality, and improving the well-being of urban residents, are delineated. Horizontal and vertical landscaping initiatives further enhance the aesthetic appeal of the city.

Keywords: urbanized territories, sustainable development, Odesa industrial-urban agglomeration.

INTRODUCTION

Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. However, sustainable urban development implies a process by which sustainability can be attained, emphasising improvement, progress and positive change, incorporating both environmental and social dimensions. Cities should be healthy, providing housing and employment opportunities, meet environmental standards and be sustainable. Sustainability needs to be a addressed on a global scale, reforms need to concentrate on the interaction of the urban environment with the global economy and environment (Urban development, 2024). Europe's urban areas are home to over two-thirds of the EU's population. They account for about 80% of energy use and generate up to 85% of Europe's GDP. The various dimensions of urban life (environmental, economic, social and cultural) are interlinked and success in urban development can only be achieved through an integrated approach. Measures concerning physical urban renewal must be combined with those promoting education, economic development, social inclusion and environmental protection (EU regional and urban development, 2024). With about 60% of the world population living in cities and urban areas in 2030, these areas will play a very significant role in the attainment of sustainable development (Urban sustainable, 2021). Sustainable communities are promoted as a desirable policy goal and, in particular, local authorities are encouraged to contribute to climate change mitigation through urban planning. Furthermore, recent research takes a broad perspective on the environmental sustainability of urban areas and considers the environmental impact of all consumption. A focus group study was conducted in Finland for the purpose of examining how increased environmental awareness influences urban land use. The main finding was that urban planning is viewed as being unable to support environmental sustainability in the broader sense (Säynäjoki & Heinonen & Junnila, 2014).

The concept of sustainable development implies socially desirable, economically viable, and ecologically sustainable advancement of society. Sustainable development of urbanized territories involves ensuring a certain socio-economic development characterized by the harmonization of social, economic, and environmental goals, thereby ensuring the compatibility of interests in societal relations and an adequate level of socio-economic and environmental security for the well-being of present and future generations (Svirko et al., 2023).

With 60% of Ukraine's population residing in urban areas, the socio-economic and environmental modernization of the country's regions cannot proceed without activities aimed at ensuring sustainable development, which is one of the basic principles of the EU's regional policy stance. Achieving an appropriate standard of living in Ukraine's urbanized territories necessitates the creation of requisite conditions for habitation, recreation, safety, greening, etc. However, the realm of ensuring sustainable urban development faces numerous challenges associated with the accumulation of chronic social, economic, and environmental problems significantly impacting the quality and safety of life in Ukrainian cities (Ensuring, 2014).

Ukraine's urbanized territories are characterized by a range of problems hindering their sustainable development:
- concentration of population and production in major cities, posing environmental threats;
- unsatisfactory condition of housing stock and its energy supply;
- inefficient functioning of water supply and sanitation systems;
- low level of urban amenities and ineffective waste management systems;
- incoherence and low efficacy of national, regional, and local concepts, strategies, and plans aimed at sustainable development of urbanized territories;
- industrial enterprises within urbanized territories contributing to technogenic burden;
- unsatisfactory state of the road transport system;
- high technogenic load on components of the natural environment.

The economic and social security issues of Ukraine's urbanized territories have been addressed in works (Boreiko & Paranytsia, 2020; Romanovskaya, 2019; Zasadko, 2016), while aspects of environmental security have been analyzed in works (Kirin, 2022; Sergienko, 2021).

Preservation of a favorable natural environment and efficient resource utilization are fundamental principles of sustainable development in urbanized territories. To realize these principles, it is necessary to scientifically substantiate a set of measures for the protection of the air basin, natural waters, soil cover, geological environment, and biota. Additionally, establishing an effective waste management system for production and consumption is crucial. Conservation and expansion of green areas play a vital role in mitigating the impact of urbanization processes on the environment, promoting air purification, and improving conditions for urban inhabitants. Furthermore, horizontal and vertical greening enhances the aesthetic appeal of urbanized territories, contributes to biodiversity conservation, and improves bioclimatic conditions. Rational land use and mixed development are essential strategies in the toolkit for sustainable urban development, enabling cities to optimize their space while strengthening a sense of community, reducing environmental impact, and enhancing overall urban quality of life (Greenfield, 2023). Environmental protection, economic development, social justice and equality, administration and governance, are the cornerstone elements of sustainable urbanization (Dahiya, 2016; Liu & Xu & Luo, 2014).

The objective of this study is to evaluate the ecological dominant of sustainable development in urbanized territories (using the Odesa industrial-urban agglomeration as a case study). The article is the first to analyze the ecological aspects of sustainable development potential for urbanized areas in Ukraine.

MATERIALS AND METHODS

The work is based on a critical analysis of published materials on various aspects of sustainable development of urbanized areas in Ukraine. The results of own previously performed researches were also used, which include the assessment of the ecological state of the components of the natural environment of the Odesa industrial-city agglomeration (Chugai & Safranov & Lavrov, 2020; Chugai et al., 2021; Gusyeva & Safranov, 2018; Safranov et al., 2019). Parameters of metrics for measuring sustainable development processes (Zgurovsky, 2009) were employed to assess the ecological component of sustainable development.

RESULTS AND DISCUSSION

The Odesa industrial-urban agglomeration with population 1.3 million (Ukraine, 2024), encompassing Odesa and all its suburbs, stretches along the northwestern coast of the Black Sea (see Fig. 1). Within the agglomeration are enterprises in machinery manufacturing, chemical, oil refining, and food industries. Odesa serves as a significant transportation hub, cultural, and scientific center in the south of Ukraine. The primary factors driving the growth of the agglomeration include its maritime ports, international trade, cultural and educational center, recreational and tourist attractions, and concentration of skilled labor resources. Given the high recreational and tourist potential of the Odesa industrial-urban agglomeration, the ecological dominant serves as the foundation for its sustainable development as it underpins the socio-economic fabric of the region. It is worth noting that agglomerations are considered compact spatial groupings of settlements, predominantly urban, interconnected by various intensive links into a complex multi-component dynamic system. As a cohesive territorial socio-economic entity, an urban agglomeration emerges based on the functional and spatial development of the core city. In this case, the city of Odesa serves as the core, with 85% of the agglomeration's population residing there as of January 1, 2022.

Figure 1. Scheme of the Odesa industrial-urban agglomeration

For urbanized territories, strengths include various positive situations, opportunities, and territorial characteristics, while weaknesses encompass existing environmental issues. Environmental opportunities encompass the natural potential of surrounding territories, as well as environmentally positive socio-economic conditions at regional and national levels. Environmental threats consist of factors capable of causing harm to the urban environment and deteriorating its ecological situation. This is demonstrated by the results of a SWOT analysis conducted for Odesa, which serves as the core for the formation, existence, and development of the agglomeration (Safranov et al., 2019).

Previous assessments of sustainable development indicators have been conducted for some cities in Ukraine, including the Odesa agglomeration (Chugai et al., 2021). It was found that among the regions of the Northwestern Black Sea region (Odesa, Mykolaiv and Kherson oblasts), the Odesa region (including the Odesa agglomeration) exhibits the worst indicators in terms of the ecological component of sustainable development (Table 1).

According to observations of the air quality in Odesa in 2021, the following annual average and maximum single concentrations (in parentheses) of pollutants in the atmospheric air were recorded in units of maximum permissible concentration (MPC): dust – 1.3 (1.6); soot – 1.0 (1.5); CO – 1.0 (1.4); NO_2 – 1.5 (0.75); H_2S – 0.0 (0.9); C_6H_5OH – 1.3 (1.4); HF – 1.0 (0.75); CH_2O – 4.7 (1.1). The air pollution index (API) value was 12.5.

A network of 8 stationary observation posts covers mainly the central and northern parts of Odesa, while 23 route posts are distributed across the entire city area. Most stationary observation

Table 1. Indicators of ecological assessment for the sustainable development of the Odesa agglomeration (2014–2018)

Index	Odesa agglomeration
"Ecological systems" I_{SYS} policy category	
I_{NO2} (NO_2 concentration)	0.23
I_{SO2} (SO_2 concentration)	1
I_{TCP} (dust concentration)	1
I_{PZF} (NRF objects)	0.77
I_{EGP} (spread of exogenous geological processes)	1
I_{EXH} (worked and re-cultivated lands)	1
I_{NIT} (nitrate concentration)	1
I_{MIN} (mineralization)	0
I_{WAV} (water abstraction from natural sources per 1 person)	0.22
I_{GAV} (water intake from underground sources per 1 person)	0.16
I_{RHZ} (potential radiation hazard)	0
I_{IHZ} (environmentally hazardous enterprises)	1
"Environmental load" I_{STR} policy category	
I_{NOX} (N_{OX} emissions)	0.67
I_{SOT} (SO_2 emissions)	1
I_{CAR} (emissions from motor vehicles)	1
I_{EKM} (emissions per 1 km^2)	1
I_{EPC} (emissions per 1 person)	0.81
I_{EF1} (arable land)	1
I_{EF2} (hayfields and pastures)	0.775
I_{EF3} (forests and wooded areas)	1
I_{EF4} (built-up land)	0
I_{EF5} (use of freshwater per 1 person)	0
I_{ACC} (waste accumulation)	0.18
I_{WKM} (generation of wastes of I - III classes of danger on 1 km^2)	0
I_{WPC} (generation of wastes of I - III hazard classes per 1 person)	0
I_{REW} (discharge of return water into surface water entities)	1
"Regional Environmental Management" I_{REG} policy category	
I_{ORG} (public environmental organizations)	0

posts are located in areas influenced by stationary and mobile sources of air pollution, thus the average *API* values do not provide a real representation of the difference between technogenically tense and residential-recreational zones (accounting for 25% and 75% of the urban area, respectively). Therefore, the air quality assessment network in Odesa needs to be modernized and optimized. Additionally, the list of monitored pollutants in Odesa does not meet current needs; notably, observations for fine particulate matter with diameters of 10 µm and less (PM10) and 2.5 µm and less (PM2.5) are virtually absent. Unlike larger particles, these fine particles easily penetrate biological barriers and thus pose the greatest threat to human health. They consist of the finest particles of soot, asphalt, and automobile tires, mineral salts (sulfates, nitrates), heavy metal oxides, as well as certain allergens and microorganisms. The main anthropogenic sources of these particles include transportation, thermal power facilities, construction sites, cement, ceramic, and brick manufacturing plants, as well as abrasion of road surfaces, brake pads, and tires. Natural sources include soil erosion in arid regions and organic emissions. According to the World Health Organization standards, the annual average level of PM2.5 should not exceed 10 µg/m3, and the daily average level should not exceed 25 µg/m^3. Currently, observations of PM2.5 and PM10 levels are conducted only at the OSENU monitoring station using a Vaisala AQT420 instrument.

A number of harmful pollutants are also typically overlooked (As, Cd, Hg, Ni, polycyclic aromatic hydrocarbons, volatile organic compounds). In EU countries, the observation program is based on threshold levels, exceeding which necessitates the implementation of certain monitoring types. This allows for the omission of measuring a large number of pollutants, focusing instead on key pollutants.

Another indicator is the Air Quality Index (AQI), proposed by the US Environmental Protection Agency. To determine air quality, 5 parameters are assessed: O_3, NO_2, SO_2, PM2.5, PM10. AQI values in the range of 0–50 indicate good air quality and pose no threat to health; 51–100 – moderate quality, but some individuals may experience discomfort; 101–150 – air quality in this range is harmful to sensitive groups. In Ukraine, the public air pollution monitoring system is actively developing. An example of such a system is LUN Misto AIR, which includes over 80 stations in many cities of Ukraine, including Odesa, where AQI is determined. According to the *AQI* ranking system, Odesa is on 5th place among the cities of Ukraine. At the same time, the daily average concentrations of individual pollutants exceed the MPC values: dust – 1.7; NO_2 – 4.25; C_6H_5OH – 4.0; CH_2O – 14.0. However, according to observations in Odesa during the spring months of 2024, the *AQI* was in the range of 0–50, indicating good air quality and posing no threat to public health (Air quality, 2024). These data sharply contrast with the data from the Central Geophysical Observatory named after B. Sreznevsky (2021), which ranked Odesa among the top five most polluted cities in Ukraine by the Comprehensive *API* (Mariupol – 15.7, Kamenskoye – 14.7, Dnipro – 12.8, Odesa – 12.5, Kryvyi Rih – 12.1). According to this geophysical observatory, Odesa ranked third in Ukraine for air pollution in the first half of 2023. The high level of air pollution was mainly due to significant average concentrations of formaldehyde, nitrogen dioxide, phenol, hydrogen fluoride, carbon monoxide, and particulate matter.

This could be a seasonal phenomenon. Alternatively, different methodological approaches to determining AQI and the Comprehensive API, which is defined as the sum of all air pollution indices, could be the cause. Furthermore, public monitoring systems operating in Ukraine only determine AQI based on the concentration of particulate matter PM2.5 and PM10.

Most stationary air pollution monitoring sources are located on the windward side, which negatively impacts the air basin status in the historical and residential parts of the city. While the environmental safety level of stationary pollution sources can be enhanced through improvements in air protection measures, technological processes, and the organization of sanitary protection zones, the predominance of mobile pollution sources (constituting 70–80% of total emissions) complicates the situation, as these measures need to be applied to a large number of vehicles. Due to its proximity to the border with Romania and Moldova, significant highways pass through Odesa and its region, leading to the transit of a large volume of traffic. Additionally, it is important to consider that the average age of passenger cars in Ukraine is 14 years. Despite nearly 20% being premium-class vehicles, overall unsatisfactory technical conditions of automobiles remain one of the factors contributing to air basin pollution in the city and its agglomeration.

In Odesa, as in other major cities in Ukraine, there is a problem with optimizing traffic flows, especially in the central part of the city. The increasing number of vehicles leads to traffic jams and queues, resulting in increased emissions of harmful substances in exhaust gases, as vehicles operate at lower gears. To minimize the negative impact of transportation, efficient traffic management is necessary, relieving traffic management from parking functions, creating a system of conditional ring connections and continuous traffic highways (Getsovich & Kazakova, 2010). Additionally, strict requirements for the technical condition and ecological compatibility of vehicles are necessary (replacement of vehicles with internal combustion engines operating on liquid hydrocarbon fuel, hybrid engines, electric vehicles, and vehicles operating on methane, hydrogen, or biofuels).

Some authors (Khrutba et al., 2017) propose the following approaches to sustainable development of the transportation system: (1) high-density urban planning;(2) focus on urban transportation; (3) optimization of road networks and their use; (4) control of vehicle usage; (5) creation of conditions for pedestrian and bicycle traffic; (6) communication strategy; (7) use of a comprehensive approach; (8) promotion of environmentally friendly transportation; 9) improvement of urban transportation. All these approaches can be implemented in the Odesa industrial-urban agglomeration.

Green plantings are an important factor in cleaning the air basin and improving the functioning conditions of urban populations. The area of green plantings in Odesa is 742 hectares, which, in terms of per capita, amounts to 7.4 m^2/person (Shevchenko & Vlasiuk, 2015). According to the Department of Ecology and Development of Recreational Areas of the Odesa City Council, areas with a large proportion of private sectors are the most green. In other areas, the area of green zones is significantly smaller (Fig. 2).

However, while in the city center there are approximately 4 m^2 of greenery per inhabitant on average (with a norm of 12 m^2), in large residential areas, there is no more than 1 m^2 of greenery per capita. In some areas along the northern border of the city, the specific amount of greenery is even lower (only 17% of the national norm per inhabitant). It should be noted that the World Health Organization suggests an even higher Figure of 50 m^2 per urban resident as a necessary norm for ensuring population health.

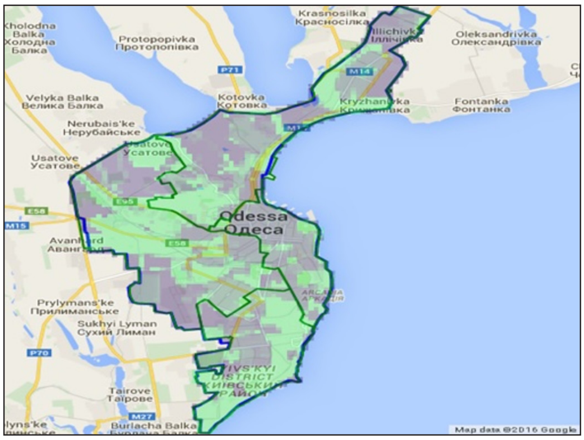

Figure 2. Map illustrating the greenery coverage of Odesa (green color indicates parks and squares; grey color indicates buildings)

Satellite imagery indicates a reduction in the area of greenery. The recent urban development is characterized by a lack of greenery and social infrastructure; there is a trend of increasing residential construction and decreasing recreational areas. The total area of Odesa is 237 km^2, with greenery covering 10.4 km^2. Only 5% of the city's territory is occupied by parks and squares. In this regard, the creation of the "Odesa Green Belt" project (Odesa Green Belt, 2020) appears promising, proposing the establishment of a continuous ring of parks, squares, and green corridors around the historic center of the city (Fig. 3). Promising is the use of organ-containing waste and sewage treatment sludge to create fertile soil for landscaping purposes (Tymchuk et al., 2020, Tymchuk et al., 2021), the use of capsulated fertilizers of prolonged action (Vakal et al., 2020).

Furthermore, it is proposed to create conditions for barrier-free movement of pedestrians and cyclists. For the convenience of movement within the green belt, it is recommended to place several intermodal transport stop complexes for electric transport, which will attract investors' interest in building residential complexes on the border of the "Odesa Green Belt". The implementation of this project will contribute not only to creating a comfortable environment but also to adapting to new climatic conditions. Additionally, creating a recreational belt around the historical city center will increase the value of areas beyond its boundaries and attract investors to

Figure 3. Scheme of the Odesa Green Belt

depressed areas, promoting sustainable development of this urbanized territory. Vertical greening is also a promising practice for increasing the area of green spaces worldwide. Green fences and building facades conceal flaws and beautify the city, absorbing dust and reducing the impact of harmful substances by 40%, as well as producing oxygen, absorbing rainwater and noise, and providing a cooling effect.

The condition of the air basin and the environmental situation within the Odesa industrial-urban agglomeration are influenced by environmentally hazardous industrial enterprises (for example, the Odesa Port Plant is located in the city of Yuzhny). According to the "State Register of Hazardous Facilities" (State Register, 2024), there are several environmentally hazardous industrial facilities in the Odesa region. To ensure the sustainable development of the city, it is necessary to develop a set of measures to minimize their environmental hazard or relocate them beyond the urbanized territory.

An important factor in the sustainable development of urbanized territories is the state of the water supply and sanitation system. The main source of centralized water supply for cities in the Odesa industrial-urban agglomeration is the Dniester River. Water treatment is carried out at the Dniester water treatment plant, where basic water treatment technologies such as settling, coagulation, filtration, and chlorination are applied.

Water supply to Odesa is provided by 7 zonal stations, where secondary chlorination of water is carried out, and to the lower part of the city – in a pressure-gravity mode. Despite the total length of all water supply networks being 1917 km, more than 386 km of them are in a state of emergency and require relocation. Water transportation to consumers is carried out by a system of main water supply lines with a diameter of 700–1400 mm, with a total length of about 600 km. Disinfection, storage, and distribution of water in settlements are carried out by local water supply systems, which include clean water reservoirs, pumping stations, chlorination, and distribution networks. Overall, the quality of tap water is satisfactory, although there is non-compliance with regulatory requirements for residual chlorine, odor, and color. According to the official website of the Infoks-Vodokanal branch, tap water meets the requirements of state sanitary rules and norms for drinking water. The majority of indicators of the physiological adequacy of the mineral composition of river and tap water also fall within the range of normative values (Table 2). The prolonged transportation of water through trunk pipelines and the unsatisfactory technical condition of the distribution network create favorable conditions for the development and accumulation of microflora, the formation of biological growths, and deposits. This is also facilitated by the presence of organic substances and biogenic elements in the water, which serve as a nutrient substrate for microflora. Although the development of microflora in the network is suppressed by maintaining certain residual chlorine levels in the water, this does not solve the problem of the presence of organochlorine compounds in the water, the problem of viral contamination of drinking water, and the emergence of chlorine-resistant microflora.

An alternative source of drinking water supply is groundwater from the aquifer associated with the deposits of the Upper Miocene, which is exploited by 15 artesian well complexes.

Groundwater (interlayer) located at depths of 120–130 meters and less are contaminated with

Table 2. Indicators of the physiological completeness of the mineral composition of water from the Dniester River and tap water

№	Indexes	Range of actual values		Range of normative values
		Water from the Dniester River	Tap water	
1	Total hardness, mmol/dm^3	3.70–5.40	3.5–5.4	1.5–7.0
2	Total alkalinity, mmol/dm^3	2.75–3.90	2.9–4.1	0.5–6.5
3	Potassium, mg/dm^3	**1.60↓**–8.45	3.9–8.2	2–20
4	Calcium, mg/dm^3	30.06–74.15	46.1–74.15	25–75
5	Magnesium, mg/dm^3	12.16–40.74	11.55–20.67	10–50
6	Sodium, mg/dm^3	6.40**–33.80↑**	15.8**–33.00↑**	2–20
7	Total dissolved solids, mg/dm^3	300.0–440.0	301.0–441.5	200–500
8	Fluorides, mg/dm^3	**0.19↓–0.42↓**	**0.132↓–0.32↓**	0.7–1.2

anthropogenic substances, but they do not always meet the requirements for the physiological completeness of the mineral composition. Deviations from the normative values are characteristic for almost all indicators of the balanced mineral composition of groundwater; however, after purification, there is a significant decrease in the concentrations of Ca^{2+}, Mg^{2+}, and Na^{+} in them (see Table 2), which initiates the development of diseases caused by a deficiency of these essential elements (Safranov & Husieva, 2016). Moreover, both surface and groundwater are characterized by a deficiency of fluoride (< 0.7 mg/dm^3), which can lead to bone fragility and the development of caries. The insignificant operational reserves of groundwater do not allow their use for centralized water supply. Thus, the presence of environmentally safe sources of water supply in the Odesa industrial-urban agglomeration is one of the factors of sustainable development.

The situation with the sewage system is more complex. In Odesa, a combined sewage system operates according to a decentralized scheme. The city is divided into 3 drainage basins. In the northern part of the city, the disposal of communal, industrial, and surface wastewater is carried out by a combined and incomplete separate method, while in the southern part, it is carried out by a complete separate method. Discharges of surface wastewater (rainwater, meltwater, irrigation and wash water, municipal waste), which become surface in case of emergency situations, are located in the coastal recreational zone of the Black Sea. Therefore, the quality of the marine environment in this area is shaped by coastal anthropogenic sources of pollution, among which one of the main factors is surface wastewater coming from the built-up areas of the city. The Black Sea waters, where drainage waters are discharged, are also used by the population for therapeutic and recreational purposes. The main sources of pollution of the coastal zone are the discharge of wastewater by biological treatment plants, as well as the discharge of untreated stormwater. There are several points of discharge of industrial wastewater located 20–30 m from the waterline, which are concentrated in the northern part of the Odesa Bay. Due to the insufficient capacity of collectors in this part of the city, up to 20,000 m^3 of wastewater is discharged into the water area daily. When examining stormwater as a source of pollution of the coastal zone, it was found that they contain a wide range of pollutants (oil and oil products, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, synthetic surfactants, heavy metals, pesticides), biogenic compounds, etc. The dominant pollutants in port waters are oil products and phenols. Stormwater runoff is a powerful source of pollution. In the coastal waters of the Black Sea near Odesa, through just one stormwater discharge during the year, 1 ton of oil products, 3 tons of surfactants, 3.8 tons of ammonium ions, 2.5 tons of phosphate ions, as well as a large amount of heavy metal ions and suspended solids are discharged. When untreated stormwater is discharged into the sea, pathogenic microflora enters the seawater. Bacterial contamination is closely related to the enrichment of water with organic matter, which microorganisms use for growth and reproduction. From a sanitary point of view, stormwater, in terms of the coliform index, the content of salmonella and streptococci, are extremely unfavorable and are equated with sewage from urban sewage systems - sources of fecal contamination. In Odesa's stormwater discharges, a high content of pathogenic microorganisms has been noted (coliform index 1,285 million cells/dm^3) (State and quality, 2017). Therefore, for the sustainable development of the considered urbanized area, it is necessary to improve the sewage system, i.e., increase the efficiency of wastewater treatment and create a system for treating stormwater.

Industrial enterprises in the city of Odesa annually emit up to 40,000 tons of pollutants (including heavy metals such as Pb, Sn, Zn, Mo, Cr), making the soil cover of the industrial zone the most polluted, while the soil cover of the recreational zone along the Black Sea coast is the least polluted. For almost 70% of the territory, the values of the total soil pollution index (Zc) are within the range of 16–32, corresponding to an acceptable level of pollution (moderately hazardous level). However, in the industrial zone, the values of this index range from 32-128, indicating an ecologically hazardous level of pollution. Consequently, the average content of detected heavy metals (especially Pb) exceeds the MPC. Exceedances of the MPC for Pb are noted not only in the soils of the industrial zone but also in the recreational zone, which is associated with emissions from automobiles using gasoline with leaded antiknock additives $Pb(CH_3CH_2)_4$. Therefore, remediation and purification of groundwater is necessary to clean up the soil cover. Adsorption treatment of groundwater using magnetically sensitive sorbents (Ptashnyk et al., 2020, Soloviy et al., 2020) or natural dispersed sorbents (Malovanyy et al., 2020, Kochubei et al., 2020) is promising.

In the Odesa agglomeration, the water supply network is worn out, which not only causes secondary contamination of drinking water but also leads to water losses ranging from 30% to 50% of the total volume supplied to the network. The water loss indicator in urban networks is unacceptably high, ranging from 0.4 to 3.0 m^3/km/h compared to figures in Western Europe, which range from 0.1 to 0.4 m^3/km/h (Giroly et al., 2013). Out of the total length of all water supply communications in Odesa, which is 1917 km, more than 386 km are in a state of disrepair and need to be replaced. The high deterioration of trunk and distribution networks are the main problems in the city's water supply system. Corrosion processes, overgrowth, material erosion, biofilm formation, and sedimentation predominate in water supply networks, which were once laid with metal pipes. Deterioration in the quality of drinking water primarily occurs in water supply and indoor networks, the technical condition of which on many sections does not meet sanitary and hygienic safety requirements. The drainage is provided by the city's sewerage system, which directs wastewater from city consumers to treatment facilities. Sewerage outlets of residential buildings are mainly made of ceramic and cast iron pipes. The materials used for pressure pipelines (steel and reinforced concrete) have diameters ranging from 600 to 1400 mm. Sewerage networks are usually laid at depths of 2–13 m. Collectors are made of concrete, reinforced concrete, or natural stone. The service life of the sewerage system ranges from 30 to 140 years. The length of Odesa's sewerage network is about 690 km. Due to unsatisfactory technical condition, leaks occur.

One of the peculiarities of the Odesa agglomeration is the active development of engineering-geological processes associated with anthropogenic impact on the geological environment: flooding of urbanized areas, activation of landslides on coastal slopes, subsidence of loess masses, and subsidence of the earth's surface due to mining activities, among others. This leads to deformation and destruction of engineering structures and utilities. The filtration losses from the water supply and sewage systems, as well as static loads from buildings and structures, cause negative changes in hydrogeological and engineering-geological conditions. Technogenic activity mostly affects the Quaternary loess deposits, where groundwater has formed, reaching critical levels. Consequences of area flooding include: uneven subsidence of loess soils with deformation of building structures and utilities; decreased operational suitability of flooded parts of buildings and structures; development of suffusion and ground collapses above underground structures; decreased soil strength and landslide development on coastal slopes, etc. The intensity of the flooding process depends on the technical condition of the water supply, sewage, and drainage systems. In Odesa, areas where groundwater levels are deeper than 10 m cover 3% of the city's territory, 26% at depths of 5–10 m, 40% at depths of 3–5 m, and less than 3 m at 31%. Most of Odesa's territory is underlain by Pontic horizon limestone deposits of the Miocene, which have good aquifer properties and are located at shallow depths. This geological structure has led to widespread use of vertical drainage wells. Currently, over 300 sites have 2500 such wells in operation. Figure 4 shows the dynamics of groundwater levels at one of the Odesa sites; dashed lines indicate linear trends in groundwater level changes before (1947–1963) and after the construction of vertical drainage wells (1964–2015).

Due to the discharge of polluted drainage and domestic waters into the Pontic aquifer, the quality of its water has significantly deteriorated, leading to the activation of suffosion, karst formation, and the collapse of underground excavations in limestone, resulting in pollution of the beach zone. The rise in groundwater levels also contributes to the deterioration of the physico-mechanical properties of loess soils due to their saturation with water. As a result of overmoistening and flooding of forested areas, subsidence occurs, namely, changes in their structure and volume reduction. This leads to deformation and destruction of structures, the formation of new landslides, and the emergence of other engineering-geological processes. It is known that changes in groundwater levels trigger subsidence processes in loess soils and also affect the seismic activity of specific areas. It has been established that the average increase in seismic intensity in the Odesa area due to changes in local engineering-geological conditions can reach 1 point (State and quality, 2017).

Along the coast of the Odesa agglomeration, landslides are widespread. More than 75% of these landslides formed as a result of changes in

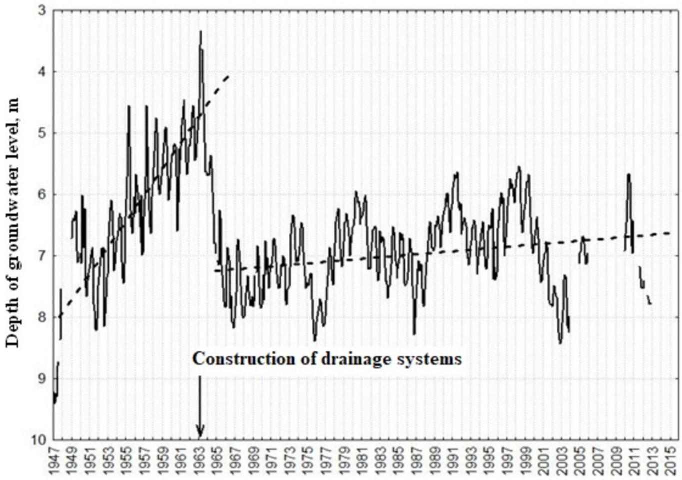

Figure 4. Dynamics of groundwater levels at one of the Odesa sites before and after the construction of vertical drainage wells

the physico-mechanical properties of rocks when they become moistened. The intensity of landslide processes is approximately 1 meter per year. To prevent them, it is recommended to create beaches with a length of 40-50 m in front of them, grass cover at the foot of the slopes, and special coastal protection structures, as well as planting trees at the top of the slopes, which actively absorb moisture. Coastal engineering protection in the Odesa agglomeration may also include: 1) creating gentle slopes and terraces; 2) planting trees and shrubs; 3) construction of external water intake troughs, underground drainage adits, and galleries for discharging groundwater into the sea; 4) hydraulic engineering works aimed at preventing coastal erosion.

It should be noted that the agglomeration area is characterized by very complex engineering-geological conditions. Collapses, landslides, gullies, and karst are widespread along the coast. Engineering-geological conditions are further complicated by the presence of catacombs stretching over 3000 km, which formed in the 19th and 20th centuries during the extraction of limestone-shells of Pontic deposits for the construction of Odesa. This complicates the development of urban infrastructure, particularly the possibility of constructing a subway.

Due to the intensification of anthropogenic activities, the man-made factor becomes dominant in certain areas. An example of such influence is the coastal area of the Odesa coast. According to the initial General scheme of anti-landslide measures for the coast of Odesa, dated 1940, the width of the beaches in the northern flank of the Northern Black Sea section was 20–25 m with the thickness of bottom deposits up to 1.0 m. In scientific publications from the early 1960s, the beaches in this area are described as wide, extensive, and well-preserved. From 1963 to 1977, the width of the beaches in this area also remained 20–25 m, but the average erosion rates of the bottom layer increased to 0.05-0.1 m per year. Overall, during this period, erosion rates by abrasion of soil masses along the coast near the Chernomorka village ranged from 6 to 50 m^3 per year. In recent years, the width of the beach has decreased to 1–7 m. Due to the development of the plateau area, groundwater levels are rising, saturating loess soils, triggering landslide deformations, and causing the destruction of drainage troughs, residential buildings, and other structures (State and quality, 2017).

To prevent coastal and slope erosion, concrete breakwaters have been constructed. However, stagnant hydrodynamic zones have formed between them and the coastline, where polluted drainage waters enriched with biogenic substances are discharged in some areas, leading to eutrophication processes. The existing breakwaters are insufficient, and those that exist are in poor condition, so there are projects to expand the beaches up to the breakwaters, allowing bathers to swim in the open sea. There are proposals to create something like troughs instead of concrete structures, where waves will change their trajectory and thus dampen the following waves. It is also proposed to create artificial reefs. Despite the attractiveness of all these proposals, it is unlikely that in the near future these hydraulic engineering structures will be dismantled, as this could lead to the activation of processes of coastal and slope erosion.

The establishment of an effective waste management and disposal system for production and consumption in the agglomeration area and its core (Odesa) is a crucial factor for sustainable development. Annually, industrial enterprises in the Odesa region generate about 35,000 tons of hazardous waste of classes I-III, with the majority being generated in the Odesa agglomeration. Class I hazardous waste includes mercury and mercury-containing waste. A system for collecting, storing, and transporting these extremely hazardous wastes for recycling has been established, although the issue of centralized disposal of mercury-containing waste is only partially resolved. Within Odesa, facilities for processing, treating, and disposing of hazardous waste have been established (6 complexes for thermal treatment of waste are in operation), but these facilities are insufficient.

Within the Odesa agglomeration, which is home to about half of the population of the Odesa region, over 1 million tons of solid municipal waste (SMW) accumulate annually, approximately 3 m^3 per capita per year. The increasing volumes of SMW are one component of the escalating anthropogenic pressure on the environment and its degradation. At the same time, Odesa practically lacks a system for separate collection and recycling of SMW, so almost all of it is disposed of at the "Dalnitskie Quarries" landfill. The landfill, covering an area of 96.2 hectares, has been in operation since 1974. Solid municipal and industrial waste of hazard classes III and IV is transported to this landfill from the entire agglomeration area, thus complicating the issue of further waste disposal due to excessive landfill load. The possibilities for creating new landfills are limited due to unfavorable geological and hydrogeological conditions and a shortage of land resources in adjacent areas. The level of utilization of individual components of SMW is insignificant, although there are facilities for processing paper, plastic, glass, textiles, and worn-out tires. There are several organizations in the city engaged in the utilization of specific types of recyclables. Projects have been developed for the collection of specific types of recyclables and hazardous waste (collection of batteries, reception of polyethylene bags, etc.). There is also a network for receiving traditional recyclables such as glass, paper, and plastic. Therefore, conditions for increasing the efficiency of selecting valuable and hazardous components from the SMW stream exist, but to date, due to these efforts, only a very small portion is recycled.

The basis for creating an effective SMW management system is an analysis of the initial conditions: waste classification and quantitative assessment of individual resource-valuable fractions. Taking into account the possibilities for using the resource potential of SMW, differentiation into easily decomposable organic waste, potential secondary material resources, and hazardous waste with detailed analysis in these streams was proposed. For further processing and use of these streams, their separation at the beginning of the life cycle is necessary. Such an approach to differentiating the SMW stream will allow for the production of high-quality secondary raw materials, which aligns with the principles of the circular economy (closed-loop economy). The first step in this direction is the construction of a degassing station at the "Dalnitskie Quarries" landfill, which will allow for the utilization of up to 12 million m^3 of biogas and the production of over 24 million kWh of electricity per year.

Odesa is an important transportation hub in southern Ukraine, so the main sources of noise are the arterial street network, railway, and "Odesa" airport. Specialists from the city's sanitary-epidemiological station conducted 627 measurements of noise levels at 26 points in the city, of which 41.3% exceeded the regulatory values, accompanied by household complaints from the population. An analysis of the acoustic situation of the street network is based on data on the traffic intensity of freight and public transport in the flow, taking into account their average speed. It was found that the level of acoustic pollution is felt within a distance of 22–82 m and 100 m on the bypass road from the traffic line. Specialists from the city's sanitary-epidemiological station, monitoring the level of the acoustic regime of the street-road network, continuously record the exceeding of permissible noise levels.

The noise impact of railway transport is recorded at a distance of 80–170 m from the track. Through reconstructive measures, the noise level can only be reduced by 10%. Calculations conducted by specialists at intervals showed that the levels of acoustic pollution are within the range of 80–170 m from the track. These parameters, provided by the sanitary-epidemiological service, are constant and will remain so in the foreseeable future, with the possibility of reducing them by 10%, perhaps through reconstructive measures.

The calculations of the acoustic impact of the "Odesa" airport are determined by the sanitary passport and correlate with the restricted construction zones. Taking into account the certification of aircraft and compliance with the requirements of the International Civil Aviation Organization (ICAO) and the Air Code of Ukraine, the acoustic impact zone is limited to 1.0 km from the runway and 0.4 km from the end of the "takeoff-landing" line.

Since transportation vehicles (primarily automobiles) create zones of acoustic discomfort, the construction of noise barriers and the implementation of other measures to reduce noise pollution are necessary in certain areas. Solving this complex problem requires a comprehensive understanding of its causes, consequences, and strategies for mitigating its effects. Reducing the level of environmental noise requires a multifaceted approach, including various solutions and strategies adapted to specific sources of noise pollution.

In addition to sources of acoustic pollution, the city has objects that are sources of electromagnetic pollution of the environment. This category includes, first of all, the system of high-voltage power lines. Secondly, the city has a network of 26 main transformer substations with capacities ranging from 35 to 330 kW. These transformer substations are mainly located near production areas and industrial zones. According to the city's sanitary-epidemiological service, there are a total of 664 objects in Odesa that are sources of electromagnetic radiation. Additionally, the city has objects of radio-television broadcasting, the operation of which must comply with sanitary passports with specified sanitary protection zones. These zones, based on the mentioned objects, are within the technical reserve area. The city also has a branched system of radio-technical objects of cellular satellite communication. The main criterion for their placement is their power and the height of antenna installation, taking into account the height of adjacent buildings. Control over their installation and operation is ensured through regular sanitary-technical inspections. No exceedances of permissible levels for this indicator have been detected. Unfortunately, the parameters of the acoustic and electromagnetic background are determined episodically for Odesa, not for all necessary parameters and not for the entire territory.

CONCLUSIONS

Based on the conducted research, the following conclusions can be drawn. To improve the air quality, it is necessary to optimize and modernize the air monitoring system, implement a set of measures to reduce emissions of pollutants into the atmosphere by industrial enterprises, relocate beyond the urbanized area those facilities that cannot be re-profiled, gradually transition to alternative (low-carbon) energy sources, optimize transportation flows, create conditions for the priority development of high-speed urban transport, pedestrian and bicycle traffic, ensure the transition to vehicles with low emissions of exhaust gases, tighten requirements for the technical condition of vehicles and fuel quality, restrict the movement of heavy-duty and transit vehicles, and prohibit the burning of solid waste, fallen leaves, etc. It is necessary to increase the area of green plantings resistant to urban pollution to national norms and, where possible, to the norms recommended by the World Health Organization, which will contribute to air purification and reduction of acoustic pollution. The water treatment system needs to be modernized, and the water supply network needs to be reconstructed. It is necessary to improve the efficiency of wastewater treatment at urban treatment facilities, carry out reconstruction of the sewerage network, and create a system for treating stormwater runoff. The municipal solid waste management system needs to be improved. Chemical and biological technologies should be used for cleaning the most polluted soil areas. Comprehensive measures need to be developed to prevent further flooding and the development of hazardous geological processes.

The analyzed data reflect only part of the diverse natural and anthropogenic features of the Odesa industrial-urban agglomeration. To ensure sustainable development, the main efforts to improve the environmental situation in the urbanized area should be directed towards protecting the air basin, greening, modernizing water supply and sewage systems, improving waste management systems, preventing the development of hazardous geological processes in Odesa, and developing comprehensive measures to reduce the level of acoustic pollution.

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