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GEOGRAPHIC INFORMATION SYSTEMS FOR WATER QUALITY MODELING IN THE ZHYTOMYR DISTRICT COMMUNITIES

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Abstract

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To ensure safe and quality drinking water for residents of rural settlements who use their own wells, boreholes, and natural sources for domestic water supply, a comprehensive approach to evaluating the quality of underground drinking water using geographic information system (GIS) technologies is necessary. The purpose of the study was to assess the quality of drinking water sources of noncentralized water supply in rural settlements of the united territorial communities (UTCs) of Zhytomyr district and to create geoinformation models based on the research results. The following research methods were used during the research: analytical, field, laboratory, statistical, calculation, and cartographic. The research was conducted in 129 settlements of 12 UTCs of Zhytomyr district, where drinking water samples were collected from noncentralized water supply sources for further analysis in the Measurement Laboratory of Polissia National University, and the creation of geoinformation models using the ArcGIS Pro software package. It has been proven that the average pH level in none of the studied settlements exceeded the norm. The average nitrate concentration in the drinking water from noncentralized water sources exceeded the norm by 1.4–3.5 times, specifically in the water of the Pulyny, Cherniakhiv, Vilshanka, Volytsia, and Oliivka communities, exceeding the maximum acceptable concentration (MAC) limit by more than two times. Only in rural settlements in the Liubar community was the average iron content found to be above the norm by more than 1.9 times. Overall, it was established that the calculated value of the overall water quality class in the Zhytomyr district was 2.03, which is determined as "good," clean water of acceptable quality. The best water quality was found in the Vilshanka, Cherniakhiv, and Stanyshivka communities, with a quality class range of 1.85–1.93, while the worst water quality was recorded in the Oliivka, Teterivka, and Liubar communities, with a quality class range of 2.13–2.31. It was determined that the highest contribution to the overall water quality was made by nitrate and iron content. The obtained research results and models based on them can be used by local governments of the studied communities to inform the population about the quality of drinking water and to develop a plan for improving the state of drinking water supply with the aim of increasing the level of environmental safety of drinking water.

Key words: drinking water, water quality class, pH, nitrates, iron, GIS.

Introduction

Safe and adequate water supply is an important factor in maintaining human health, and therefore access to clean drinking water is now a basic human right. Universal access to quality drinking water and sanitation is a global development policy priority (UNDP). Currently, more than 700 million people, mostly in developing countries, do not have access to improved water supply and sanitation facilities (WHO). The problem is particularly acute among rural settlements worldwide.

In particular, in Ukraine, as of the beginning of 2020, only 26.9 and 1.8% of rural settlements were provided with centralized water supply and sewerage, respectively (Ministry for Communities and Territories Development of Ukraine, 2020). Given this situation, the main sources of domestic water supply are private wells, boreholes, natural sources, and so on, the water quality of which may be questionable and hazardous to the health of rural residents (Valerko, Herasymchuk, 2021).

Munene et al. (2019) note that wells play an important role in providing water to rural populations, and agricultural activities have been identified as a significant risk factor for well water contamination. The responsibility for maintaining water sources lies with their owners. Mena-Rivera and Quiros-Vega (2018) consider it important to pay attention to research on drinking water in rural areas, as there is insufficient data on its quality. And given the low ecological culture of rural residents, which results in uncontrolled use of fertilizers, plant protection products, and large amounts of wastewater, which causes microbiological and chemical contamination of water sources, a large-scale study of the quality of drinking water from noncentralized water sources is needed. Gibson and Kelsey (2017) noted that the lack of comprehensive research on the quality of drinking water in rural areas is recognized as one of the main barriers to providing safe water to residents who consume it from noncentralized water sources.

The main water pollutants in noncentralized water supply sources are microorganisms, organic matter, and heavy metals.

Table 1. Characteristics of UTC and the number of surveyed settlements.

Territorial community name	Number of settlements	Territorial community area, km^2	Population, persons	Number of surveyed settlements
Zhytomyr	2	91.5	265126	2
Liubar	48	757	2628100	14
Novohuivynske	24	435.5	23741	13
Pulyny	40	528.38	13640	9
Cherniakhiv	37	538.4	20156	10
Berezivka	16	229	2559	14
Vilshanka	12	163.2	5466	5
Volytsia	8	162.2	6224	4
Hlybochytsia	13	180.5	10821	5
Oliivka	21	302.5	10641	18
Stanyshivka	21	286.1	15128	20
Teterivka	15	295.8	10264	15

The contamination of water with nitrates is of particular concern (Romanchuk et al., 2021; Valerko et al., 2018). Owing to the presence of toxic elements, water has poor quality, becomes unfit for drinking, and threatens human health, which in turn causes a significant environmental problem that is currently characteristic not only of Ukraine but is also being studied by scientists around the world, including India (Karunanidhi et al., 2021), Bangladesh (Ghosh et al., 2020), Iran (Qasemi et al., 2018), China (Yu et al., 2020), Indonesia (Moldovan et al., 2020), New Zealand (Richards et al., 2022), the United States (Wheeler et al., 2015), Kenya (Nyambura et al., 2020), and so on.

At the current stage of civilization development, geoinformation systems are of great interest, which allow for effective management decisions in many areas of human activity, including the field of drinking water supply in rural areas. The use of specialized application programs, which are developed based on geoinformation technologies, allows creating databases and geoinformation models of the qualitative composition of groundwater, which significantly increases the relevance of the conducted research.

Geographic information system (GIS) is widely used to determine water quality, including from noncentralized water sources. Aghapour et al. (2021) studied the distribution of nitrate levels in drinking well water and their impact on the health of the rural population using a GIS to identify risk areas. The results of such a study can be used to prevent long-term potential health risks to the population, as well as for the purpose of effective management of water supply in a specific area. Wang and Yang (2008) conducted a health risk assessment for humans from nitrate content in groundwater in Northern Ireland using GIS. It was found that areas of high and very high nitrate risk occupy 11% and 5% of the studied area, respectively. Bian et al. (2016) demonstrated in China that the high-risk zone for human health due to the presence of nitrates in drinking water accounts for 88.78% of the total study area. Chica-Olmo et al. (2017) used modeling and geostatistics to map health risk in Spain, and showed that the health risk coefficient for water contaminated with nitrates was greater than 1 for 10% of the studied area, where municipalities with the highest pollution thresholds were located in areas of agricultural activity. Armanuos and Negm (2016) used ArcGIS for visualizing the spatial classification of drinking water quality parameters. The calculation of water quality showed that only 45.37% of wells fall into the category of good drinking water. Mapping of groundwater contamination in the Tripura region of India conducted by Paul et al. (2019) showed that out of the entire study area, resources suitable for drinking water occupy less than 1 km^2 due to the presence of excessive concentrations of heavy metals.

Assessment of the quantity and quality of surface and groundwater using GIS technology was carried out in Spain (Ferrer et al., 2012), China (Bao-wen, Yang, 2011), and South India (Rawat, Singh, 2018). Abbasnia et al. (2018) conducted an assessment of the quality of groundwater and its suitability for irrigation based on GIS within rural settlements in Iran. Evaluation of groundwater resources in the United Arab Emirates (Batarseh et al., 2021) as well as their vulnerability in India (Bera et al., 2021) was conducted using GIS tools. However, studies on the quality of drinking water in rural settlements and the creation of geoinformation models based on their results in Ukraine and, in particular, in the Zhytomyr region (Valerko et al., 2022), have not been conducted sufficiently.

Thus, to ensure guaranteed supply of safe and high-quality drinking water for rural population, a comprehensive approach to assessing the quality of groundwater using GIS technologies is necessary. Taking this into account, research on the assessment of water quality in noncentralized water supply sources located in rural areas and the use of geoinformation technologies are relevant and require detailed study.

The purpose of this study is to evaluate the quality of drinking water in rural settlements of territorial communities in the Zhytomyr district and to present its results thematically in the form of geoinformation models for effective management of environmental safety of water supply in the community.

Material and methods

The research was conducted on the territory of the UTCs of the newly enlarged Zhytomyr district of Zhytomyr region. As part of the research, drinking water samples were collected from noncentralized water supply sources in rural and urban settlements within the following UTCs:

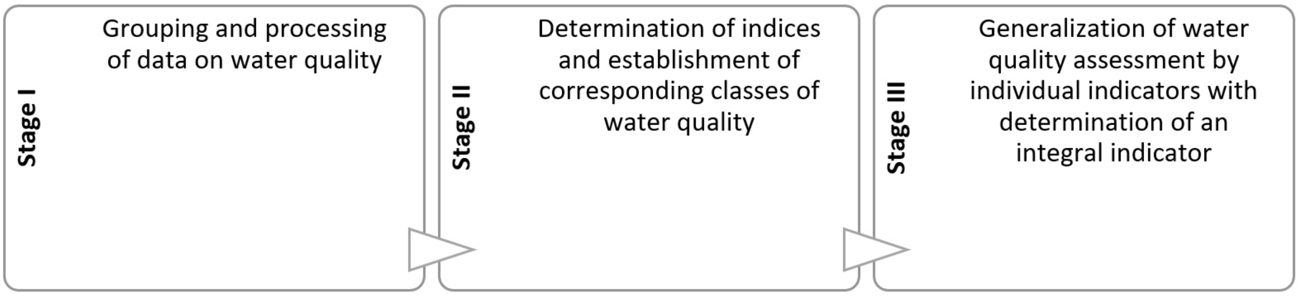

Fig. 1. Stages of water quality assessment according to DSTU 4808:2007.
Note: Based on data (DSTU, 2007).

Table 2. Classes and subclasses of water quality according to DSTU 4808:2007.

Quality class	Average values of block water quality indices	Designation of corresponding water quality subclass	Characterization of water quality classes and subclasses
1	1.00 – 1.25	1	„Excellent," very clean water
	1.26 – 1.50	1(2)	„Excellent," very clean water with a bias toward "good," clean water of the desirable quality
2	1.51 – 1.75	1-2	Water that ranges in quality from "excellent," very clean to "good," clean
	1.76 – 1.99	2(1)	„Good," clean water with a bias toward "excellent," very clean water
	2.00 – 2.25	2	„Good," clean water of acceptable quality
	2.26 – 2.50	2(3)	„Good," clean water with a bias toward the "satisfactory" class, slightly polluted water of acceptable quality
3	2.51 – 2.75	2-3	Water with a quality transition from "good," clean to "satisfactory," slightly polluted
	2.76 – 2.99	3(2)	„Satisfactory," slightly polluted water with a bias toward "good," clean water
	3.00 – 3.25	3	„Satisfactory," slightly polluted water of acceptable quality
	3.26 – 3.50	3(4)	„Satisfactory," slightly contaminated water with a bias toward the "limited suitability," undesirable quality
4	3.51 – 3.75	3-4	Water that transitions in quality from "satisfactory," slightly contaminated acceptable quality to "limited suitability," undesirable quality
	3.76 – 3.99	4(3)	„Limited suitability" of undesirable quality with a bias toward the class of "satisfactory," slightly polluted water, acceptable quality
	4.00	4	„Mediocre," "limited suitability," undesirable quality

Note: Based on data (DSTU, 2007).

- City: Zhytomyr city territorial community;
- Town: Liubar, Novohuivynske, Pulyny, and Cherniakhiv territorial communities;
- Village: Berezivka, Vilshanka, Volytsia, Hlybochytsia, Olivka, Stanyshivka, and Teterivka UTCs.

The characteristics of the studied communities and the number of surveyed settlements are presented in Table 1. A total of 129 settlements from 12 UTCs were surveyed.

Analytical research on the quality of drinking water was carried out at the Measurement Laboratory of the Polissya National University based on the following indicators: pH, content of nitrates and total iron, which were determined by generally accepted methods. In particular, the pH indicator was determined by potentiometric method, the content of nitrates—by ionometric method, total iron—by photocolometric methods. The obtained results were compared with the standards that apply in Ukraine, namely: DSanPiN 2.2.4-171-10 «Hygienic Requirements to Drinking Water Intended for Human Consumption» (Verkhovna Rada of Ukraine, 2010).

The water quality assessment was conducted in accordance with DSTU 4808:2007, the main stages of which are provided in Fig. 1.

The correspondence of calculated quality indices to water quality classes and subclasses is presented in Table 2.

The water quality class was determined separately for each indicator (pH, nitrate, and total iron) and as an integral indicator of water quality within the amalgamated community. The calculations were based on the average and worst values of the indicators.

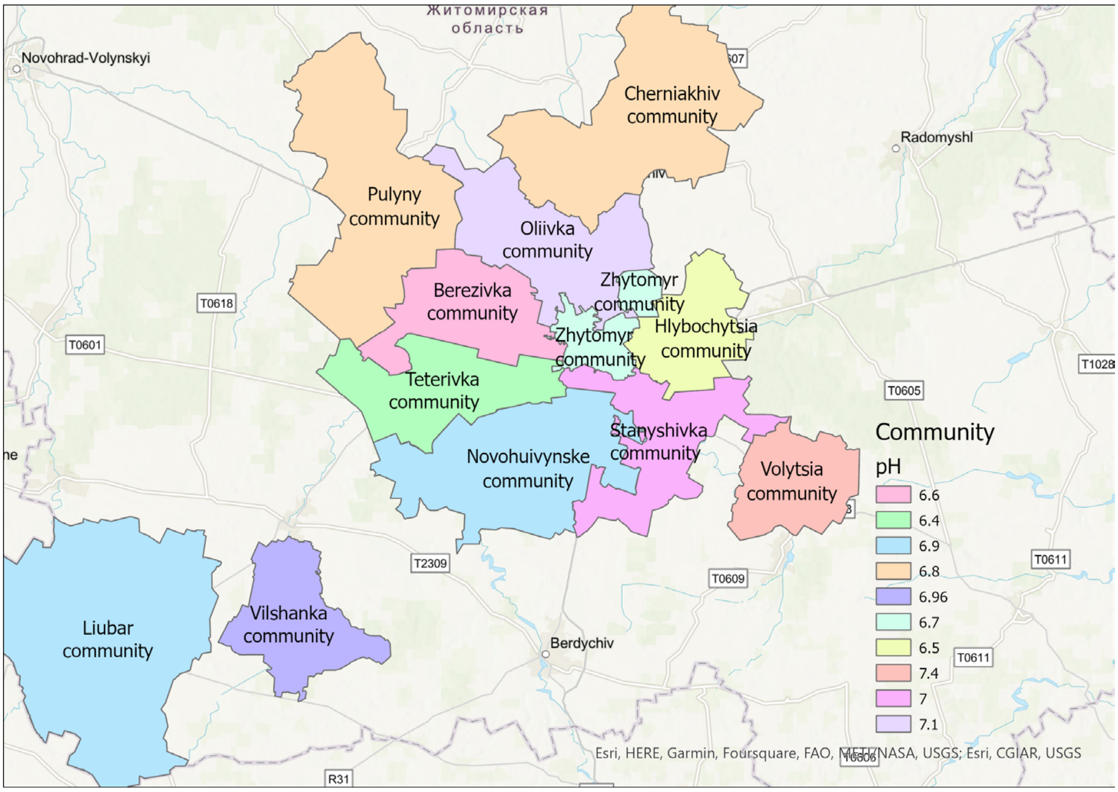

Fig. 2. Level of pH indicator in drinking water from noncentralized water supply sources in the studied communities, pH units.
Note: Own research.

The results of analytical studies on the quality of drinking water from noncentralized water supply sources, which were conducted within the rural settlements of the UTCs of the Zhytomyr consolidated district, were grouped into the relevant observation and testing databases and became the basis for creating geoinformation models of the studied objects. The construction of a geodatabase and output maps based on the research results was carried out using the ArcGIS Pro software package (developed by ESRI, USA), which provides access and management of geospatial data on a local network or via the Internet, contains a large number of tools for their processing and provides geocoding of large volumes of cartographic data suitable for processing in batch mode.

Results and discussion

Ensuring that the population has access to quality and safe drinking water is regulated by legislative acts of Ukraine, the main of which is the Law of Ukraine "On Drinking Water and Drinking Water Supply," "On Ensuring Sanitary and Epidemiological Welfare of the Population," and the national targeted program "Drinking Water in Ukraine" for 2022–2026. Access to quality drinking water is necessary for preserving public health. According to the World Health Organization, nearly 1 billion people lack access to improved water sources. In accordance with Ukraine's sixth Sustainable Development Goal, universal and equal access to safe and affordable drinking water for all should be achieved by 2030 (UNDP).

Quality water supply is one of the priorities, especially for rural population. This is evidenced by the National Report on Drinking Water Quality and Drinking Water Supply in Ukraine for 2019, according to which only 39.9% of the residential area is provided with centralized water supply and 39.5% with centralized wastewater disposal. In particular, out of 1613 rural settlements in the Zhytomyr region, only 229 or 13.7% are covered by centralized water supply (Ministry for Communities and Territories Development of Ukraine, 2020).

As an alternative to centralized water supply, rural residents use private wells, wells, and natural sources, the quality of water in which is currently very poor in many indicators, especially in terms of nitrate levels, throughout Ukraine, including in the Zhytomyr region. Private farms operating in and around rural areas often do not comply with fertilizer and crop protection requirements, leading to contamination of soil, vegetable gardens, and groundwater with toxic substances, especially nitrates (Valerko et al., 2018). The problems of water quality at noncentralized water sources are exacerbated by the fact that no comprehensive studies of water quality are currently being conducted.

Khatri and Tyagi (2015) noted that anthropogenic factors that affect water quality in rural areas include the use of fertilizers and chemical plant protection agents, river siltation, excess nutrients in water, runoff from degraded forest areas, and livestock breeding, which differ in quality from those in urban ecosystems. Daud et al. (2017) emphasized that human activity causes water-related illnesses, which account for about 80% of all illnesses and result in 33% of deaths. Schaider et al. (2019) noted

Table 3. Water quality classes of noncentralized water supply sources in Zhytomyr district by pH.

UTC	**Water quality class**	
	$\bar{x}$	$\bar{x}_{нг}$ $\mathbf{x}_{lt.}$
City UTC		
Zhytomyr	1.52 [1–2]	2.0 [2]
Village UTC		
Teterivka	2.47 [2(3)]	4.0 [4]
Vilshanka	1.4 [1(2)]	2.0 [2]
Volytsia	2.0 [2]	2.0 [2]
Hlybochytsia	2.04 [2]	3.0 [3]
Oliivka	1.86 [2(1)]	4.0 [4]
Stanyshivka	1.61 [1–2]	3.0 [3]
Berezivka	1.84 [2(1)]	3.0 [3]
Town UTC		
Liubar	1.38 [1(2)]	2.0 [2]
Novohuivynske	1.88 [2(1)]	3.0 [3]
Pulyny	1.39 [1(2)]	3.0 [3]
Cherniakhiv	1.5 [1(2)]	3.0 [3]
$\mathbf{I}_{avg.**}$	1.74 [1-2]***	
$\mathbf{I}_{lt.}$	2.92 [3(2)]	

Notes: * $\bar{x}$ та $\boldsymbol{x}_{lt}$—calculated water quality indices and classes based on the average and worst values of the analyzed indicator;
** calculation of the integral water quality indicator is based on the average and worst values of the indices of the analyzed indicator;
**2.5 [(2–3)] are the values of the calculated water quality index and the corresponding quality subclass is indicated in parentheses.

that low-income communities (in our case, rural residents) face disproportionately high levels of pollutants.

The pH value is an indicator of the water's properties caused by the presence of free hydrogen ions. According to pH, water is classified from strongly acidic to strongly alkaline (DSTU, 2007).

Noncompliance of the pH parameter with the norm, especially toward decrease, can have a negative impact on human health, as acidification of the aquatic environment increases the toxicity of pollutants in the water.

The study results showed that, on average, none of the studied communities were found to be noncompliant with the pH indicator criteria. However, in almost all communities, except for Liubar, Vilshanka, and Volytsia, a decrease in pH to the level of 5.45 was observed, indicating water acidification. An increase in pH up to 12.5 units was recorded in the water of the well at Nekrashivska gymnasium, located in the village of Nekrashiv of Oliivka community (Fig. 2).

Saalidong et al. (2022) present results on the correlation of pH with other physicochemical properties of water. It was found that noncompliance with hydrogen ion standards in groundwater was associated with the presence of E. coli, indicating fecal contamination of the water. Dirisu et al. (2016) have shown that pH level is an indicator of potential health risks and loss of biodiversity due to acidification of soil and aquatic environments. In addition, it was found that the pH level was lower for water from wells and boreholes than for rainwater.

Author's research has shown that, on average, the pH level of water from noncentralized water supply sources in the Zhytomyr region corresponds to quality class 2 of subclass 1–2, which is transitional in quality from "excellent" to "good," with the worst values of this indicator belonging to class 3 of subclass 3(2) ("satisfactory" water with a tendency toward "good" class). Data on calculated indices and corresponding water quality classes based on pH level in urban, rural, and settlement UTCs of the Zhytomyr region are presented in Table 3.

The worst water quality class was established for Teterivka UTC, while the water from noncentralized water supply sources in Liubar UTC corresponded to the first-class quality. The studied UTCs are placed in the following ranked row by water quality class (Fig. 3): Liubar (1.38) → Pulyny (1.39) → Vilshanka (1.4) → Cherniakhiv (1.5) → Zhytomyr (1.52) → Stanyshivka (1.61) → Berezivka (1.84) → Oliivka (1.86) → Novohuivynske (1.88) → Volytsia (2,0) → Hlybochytsia (2.04) → Teterivka (2.47).

The content of nitrates is one of the limiting indicators of the quality of water in noncentralized water supply sources, which leads to elevated levels of noncarcinogenic health risks. High levels of nitrates/nitrites in drinking water can cause methemoglobinemia or "blue baby syndrome." These substances reduce the blood's ability to carry oxygen. Infants up to six months old who drink water with high levels of nitrates may become seriously ill or die (US EPA). Aghapour et al. (2021) presented the results of assessing nitrate pollution of groundwater and non-cancer health risk to the population in the form of geoinformation models and found that infants are the most vulnerable category to the effects of nitrates. Sasakova et al. (2018) note that levels in the range of 100–200 mg/L nitrate-N (443–885 NO^{-3}) begin to affect the health of the population as a whole, but the impact on any individual depends on many factors. Njeze et al. (2014) and

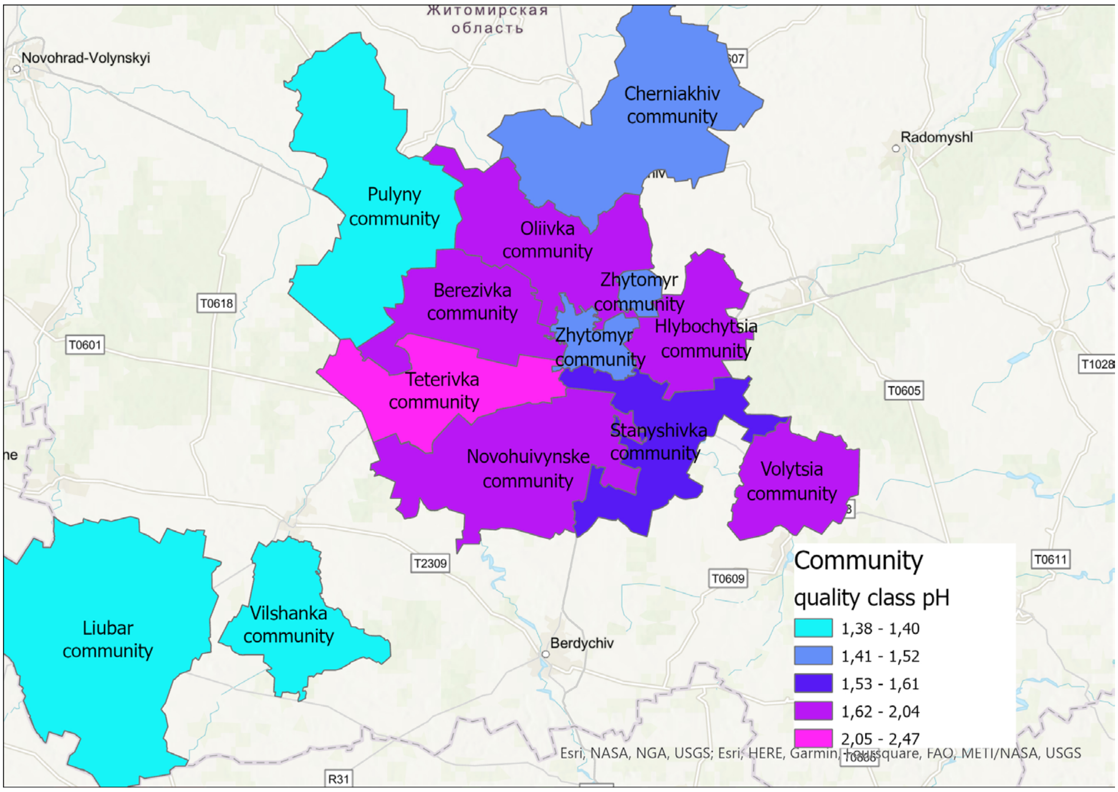

Fig. 3. Ranking of communities by quality classes by pH indicator.
Note: Own research.

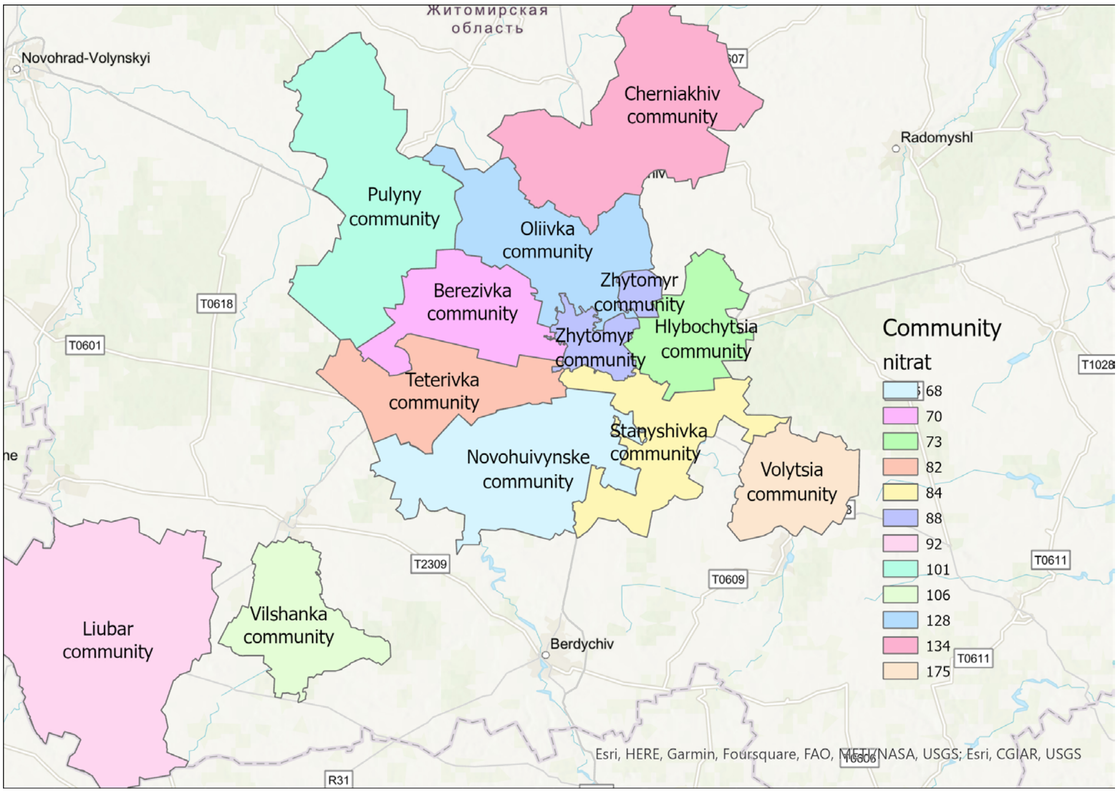

Fig. 4. Nitrate content in drinking water from non-centralized water supply sources in the studied communities, mg/dm^3.
Note: Own research.

Schullehner et al. (2018) suggest that this may also increase the risk of cancer in adults, as nitrates are converted to nitrites and form N-nitroso compounds (NOCs), which are highly carcinogenic and can act systemically.

Gan et al. (2021) reported that the nitrate content in groundwater in suburban areas of the North China Plain was 1.3 times higher than in other areas. The reasons for this phenomenon, according to the researchers, are domestic wastewater, livestock waste, fertilizer use, and heavy groundwater exploitation, which contributes to nitrification.

The permissible content of nitrates in Ukraine is regulated by the DSanPiN and is set at 50 mg/dm^3. This standard is also set by the World Health Organization, but does not take into account the requirements of Council Directive 98/83/EC on the quality of water intended for human consumption, which sets the nitrate content at 5 mg/dm^3, which is reflected in DSTU 7525:2014 «Drinking Water. Requirements and methods of quality control."

The average nitrate content in the drinking water of all the communities studied exceeds the standard (50 mg/dm^3) from 1.4 times in Novohuivynske community to 3.5 times in Volytsia (Fig. 4). The maximum nitrate content of 660 mg/dm^3 was recorded in the well water of Veresy, a village that is part of the Zhytomyr community. In general, the concentration of nitrates varied within a fairly wide range from 0.508 to 660 mg/dm^3.

The communities were grouped according to the average nitrate content in drinking water. Thus, it has been established that an excess of nitrate content by 1.1 to 2 times was recorded in seven communities, and an excess of the MAC by more than two times was detected in five communities (Table 4).

In terms of nitrate content, the water in UTCs of the Zhytomyr district do not exceed the third-quality class (Table 5). Based on the average nitrate content values in water sources of noncentralized water supply, the calculated index values correspond to the class of "satisfactory," slightly contaminated water with a bias toward the "limited suitability," undesirable quality, and the worst values correspond to the fourth-quality class—"mediocre," "limited suitability," and undesirable quality.

Thus, the worst class 4 water quality was recorded for noncentralized water supply sources in five UTCs, namely: Stanyshivska, Volytsia, Oliivka, Zhytomyr, and Vilshanka.

The studied UTCs are placed in the following ranked row by water quality class based on the nitrate content (Fig. 5): Liubar (2.81) → Novohuivynske (2.96) → Berezivka (3.17) → Teterivka (3.21) → Novohuivynske (3.43) → Pulyny (3.44) → Cherniakhiv (3.5) → Stanyshivka (3.68) → Volytsia (3.75) → Oliivka (3.78) → Zhytomyr (3.89) → Vilshanka (4.0).

Schaider L. et al. (2019) note that even well below the standard, nitrate levels of 1 mg/L and above are associated with anthropogenic impacts, and therefore nitrates can be an indicator for identifying drinking water sources that may also contain a number of other hazardous substances.

Table 4. Grouping of UTCs by the indicator of exceeding the average nitrate content in drinking water.

Exceedance of standard	UTCs
1.1–2.0 MAC	Zhytomyr, Liubar, Novohuivynske, Berezivka, Hlybochytsia, Stanyshivka, Teterivka
2.1–5.0 MAC	Pulyny, Cherniakhiv, Vilshanka, Volytsia, Oliivka

Note: Own research.

Table 5. Water quality indices of noncentralized water supply sources in Zhytomyr district by nitrate content.

UTC	Calculated index value with indication of water quality subclass	
	$\overline{x}$	$\overline{x}_{нг}$ $\mathbf{x}_{\mathbf{lt.}}$
City UTC		
Zhytomyr	3.89 [4(3)]	4.0 [4]
Village UTC		
Teterivka	3.21 [3]	4.0 [4]
Vilshanka	4.0 [4]	4.0 [4]
Volytsia	3.75 [3–4]	4.0 [4]
Hlybochytsia	2.96 [3(2)]	4.0 [4]
Oliivka	3.78 [4(3)]	4.0 [4]
Stanyshivka	3.68 [3–4]	4.0 [4]
Berezivka	3.17 [3]	4.0 [4]
Town UTC		
Liubar	2.81 [3(2)]	4.0 [4]
Novohuivynske	3.43 [3(4)]	4.0 [4]
Pulyny	3.44 [3(4)]	4.0 [4]
Cherniakhiv	3.50 [3(4)]	4.0 [4]
$\mathbf{I}_{\text{avg.**}}$	3.47 [3(4)]***	
$\mathbf{I}_{\text{lt.}}$	4.0 [4]	

Note: Notation is similar to Table 3.

One of the main sources of iron in the human body is its content in groundwater. Iron is a necessary element for the normal functioning of the human body, as it is a part of some enzymes and maintains optimal hemoglobin levels. In particular, the study by Choudhury et al. (2022) shows that groundwater with a high iron content is significantly associated with a reduced risk of childhood anemia. However, a significant excess of iron in drinking water can be associated with such dangerous phenomena as Parkinson's, Huntington's, Alzheimer's, cardiovascular diseases, hyperkeratosis, diabetes mellitus, pigmentation changes, kidney and liver diseases, and respiratory and neurological disorders (Kell, 2010).

In Ukraine, the normative iron content for noncentralized water supply sources is set at 1 mg/dm^3, but in European legislation, its level is 0.2 mg/dm^3.

The average content of total iron in drinking water from noncentralized water supply sources in territorial communities ranged from 0.17 to 1.89 mg/dm^3. Exceedance of the standard, on average, was recorded only in rural settlements of the Liubar community, which amounted to 1.9 times (Fig. 6).

According to the average values of total iron content, the calculated values of the indices correspond to the first-quality class of subclass 1(2)—"excellent," very clean water with a bias toward "good," clean water of the desirable quality, and according to the worst values—to the third-quality class of subclass 3(4)—"satisfactory," slightly contaminated water with a bias toward the "limited suitability," undesirable quality (Table 6).

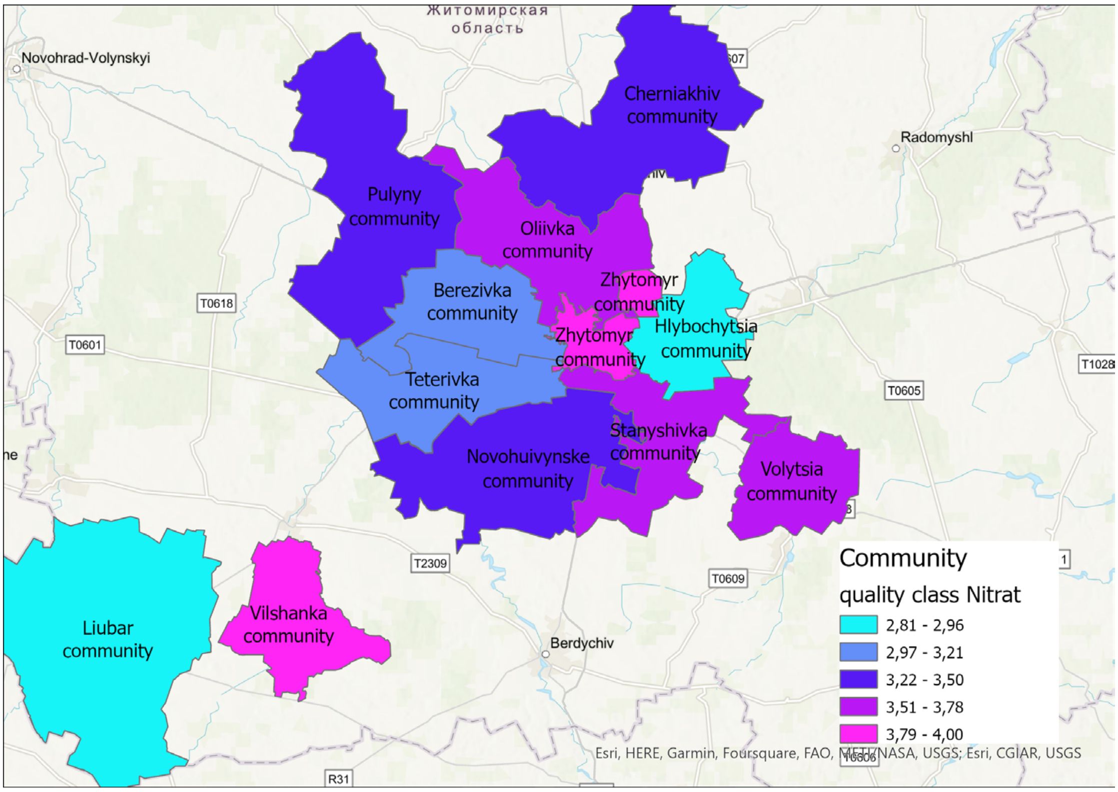

Fig. 5. Ranking of UTCs in Zhytomyr district by nitrate content.
Note: Own research.

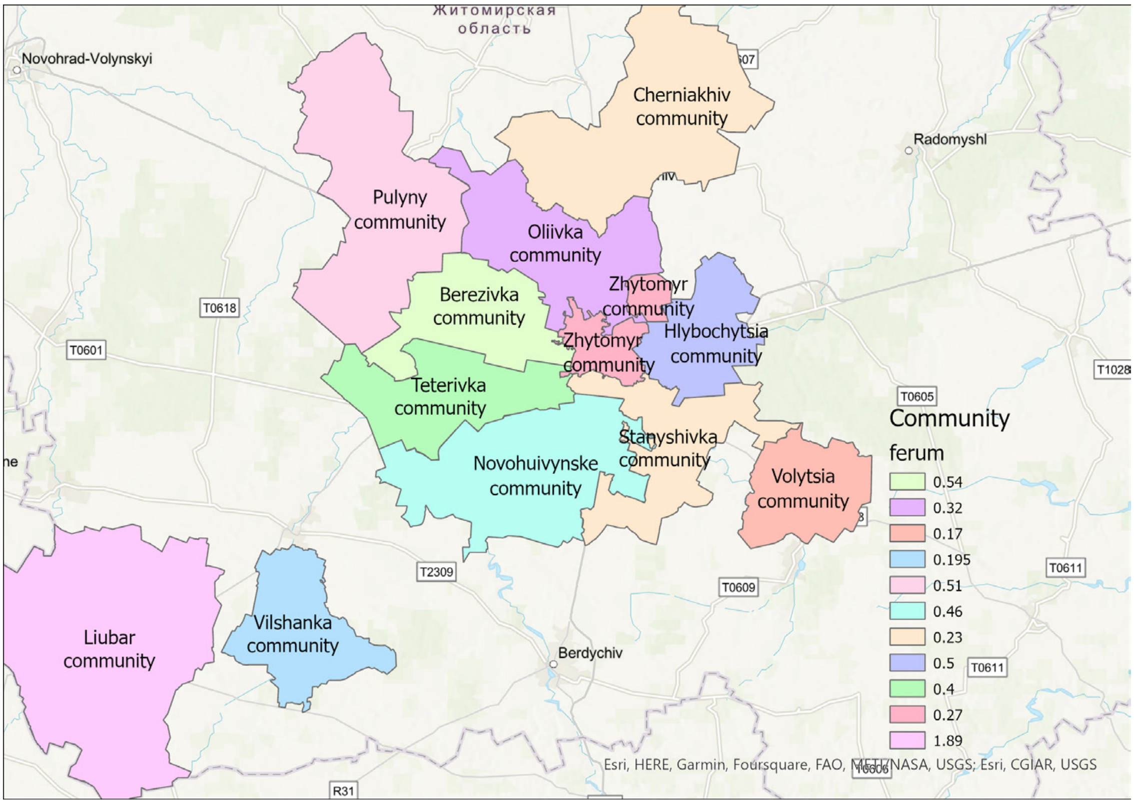

Fig. 6. Total iron content in drinking water of the studied communities, mg/m^3.
Note: Own research.

The studied UTCs are placed in the following ranked row by water quality class based on the total iron content (Fig. 7):

Vilshanka (1.0) → Volytsia (1.12) → Stanyshivka (1.21) → Cherniakhiv (1.25) → Zhytomyr (1.31) → Teterivka (1.42) → Oliivka (1.43) → Novohuivynske (1.47) → Hlybochytsia (1.50) → Pulyny (1.61) → Berezivka (1.63) → Liubar (2.52).

Based on the data obtained, the integral indicator of water quality of noncentralized water supply sources in the UTCs of Zhytomyr district was calculated (Table 7).

It was determined that in general, in the Zhytomyr region, the value of the integral class of water quality of noncentralized water supply sources at the level of 2.03 corresponded to class 2, which, according to DSTU 4808:2007 (DSTU, 2007), is defined as "good," clean water of acceptable quality. Among the 12 UTCs studied, only one territorial community (8.3%) had subclass 2(3) water quality of noncentralized water supply sources, eight territorial communities (66.7%) had subclass 2, and three territorial communities (25%) had subclass 2(1).

In the context of individual amalgamated territorial communities, the worst index values—2.31 and 2.13—were established for the Liubar, Teterivka and Oliivka UTCs, respectively. The index value of 2.31 corresponds to subclass 2(3) and defines "good," clean water with a bias toward the "satisfactory" class, slightly polluted water of acceptable quality. The index values of 2.0 to 2.13 calculated for Zhytomyr, Novohuivynske, Pulyny, Berezivka, Teterivka, Volytsia, Hlybochytsia, and Oliivka UTCs indicate "good," clean water of acceptable quality and correspond to subclass 2. For the noncentralized water supply sources of Stanyshivka, Cherniakhiv, and Vilshanka UTCs, the calculated index values ranged from 1.85 to 1.93, which corresponded to water quality subclass 2(1)—"good," clean water with a bias toward "excellent," very clean water.

Thus, the studied UTCs are placed in the following ranked row according to the integral water quality class (Fig. 8): Vilshanka (1.85) → Cherniakhiv (1.88) → Stanyshivka (1.93) → Volytsia (2.0) → Hlybochytsia (2.0) → Zhytomyr (2.01) → Pulyny (2.01) → Novohuivynske (2.06) → Berezivka (2.07) → Oliivka (2.13) → Teterivka (2.13) → Liubar (2.31).

Similar studies were conducted in some rural settlements of Zhytomyr district. Herasymchuk et al. (2022) note that despite the fact that the surveyed springs did not have water of poor quality, they are unsuitable for drinking due to the high content of nitrates, which is the limiting indicator of its quality.

Through water intake and surveys in the area of wells, interviews with local residents, and inspections of rural settlements, it was found that the water quality of noncentralized water supply sources is not ideal, which is associated with specific sources of pollution. The environmental and cultural level of local residents is low. The chaotic development of household plots, disregard for the requirements of sanitary legislation, the application of nitrogen fertilizers in violation of sanitation standards, combined with inadequate maintenance, are the reasons for the deterioration of water quality in modern noncentralized water supply systems (Herasymchuk et al., 2022).

In order to improve the environmental safety of drinking water supply from private wells and boreholes, it is necessary to observe the permissible distances between water supply structures and household buildings and structures within private plots of land in accordance with the State building regulations of Ukraine «Planning and Development of Territories» (DBN, 2019) (Fig. 9).

Table 6. Water quality indices of noncentralized water supply sources in Zhytomyr district by total iron content.

UTC	**Calculated index value with indication of water quality subclass**	
	$\bar{x}$	$\bar{x}_{нг}$ $\mathbf{x}_{\mathrm{lt}}$
City UTC		
Zhytomyr	1.31 [1(2)]	4.0 [4]
Village UTC		
Teterivka	1.42 [1(2)]	4.0 [4]
Vilshanka	1.0 [1]	2.0 [2]
Volytsia	1.12 [1]	2.0 [2]
Hlybochytsia	1.50 [1(2)]	4.0 [4]
Oliivka	1.43 [1(2)]	4.0 [4]
Stanyshivka	1.21 [1]	4.0 [4]
Berezivka	1.63 [1–2]	4.0 [4]
Town UTC		
Liubar	2.52 [2-3]	4.0 [4]
Novohuivynske	1.47 [1(2)]	4.0 [4]
Pulyny	1.61 [1–2]	4.0 [4]
Cherniakhiv	1.25 [1]	2.0 [2]
$\mathbf{I}_{\text{avg.**}}$	1.47 [1(2)]***	
$\mathbf{I}_{\text{lt.}}$	3.5 [3(4)]	

Note: Notation is similar to Table 3.

Table 7. Integral indicator of water quality of noncentralized water supply sources in the UTCs of Zhytomyr district.

UTC	**Calculated index value with indication of water quality subclass**	
	$\bar{x}$	$\bar{x}_{нг}$ $\mathbf{x}_{\mathrm{lt}}$
City UTC		
Zhytomyr	2.01 [2]	3.5 [3(4)]
Village UTC		
Teterivka	2.13 [2]	4.0 [4]
Vilshanka	1.85 [2(1)]	2.5 [2(3)]
Volytsia	2.0 [2]	2.5 [2(3)]
Hlybochytsia	2.0 [2]	3.75 [3–4]
Oliivka	2.13 [2]	4.0 [4]
Stanyshivka	1.93 [2(1)]	3.75 [3–4]
Berezivka	2.07 [2]	3.75 [3–4]
Town UTC		
Liubar	2.31 [2(3)]	3,75 [3–4]
Novohuivynske	2.06 [2]	3,75 [3–4]
Pulyny	2.01 [2]	3,75 [3–4]
Cherniakhiv	1.88 [2(1)]	2,75 [2–3]
$\mathrm{I}_{\text{integr.avg.**}}$	2.03 [2]***	
$\mathrm{I}_{\text{integr.lt.}}$	3.48 [3(4)]	

Note: Notations are similar to Table 3.

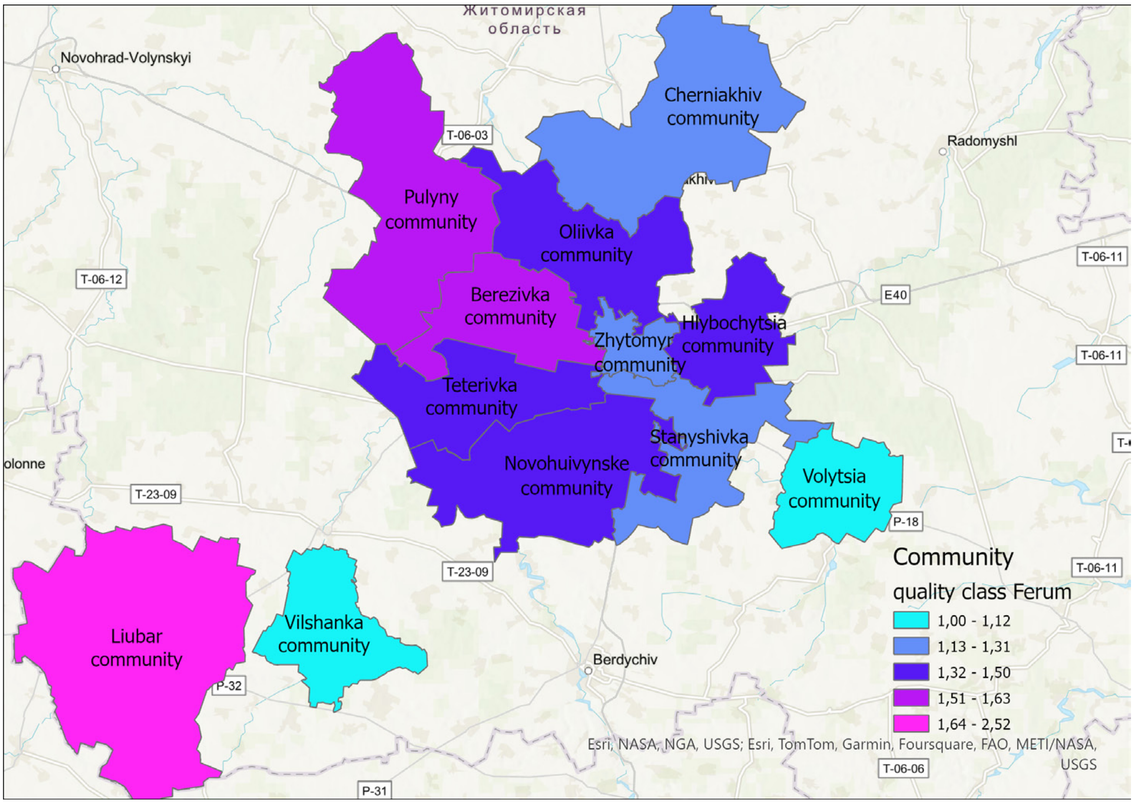

Fig. 7. Ranking of UTCs in Zhytomyr district by total iron content.
Note: Own research.

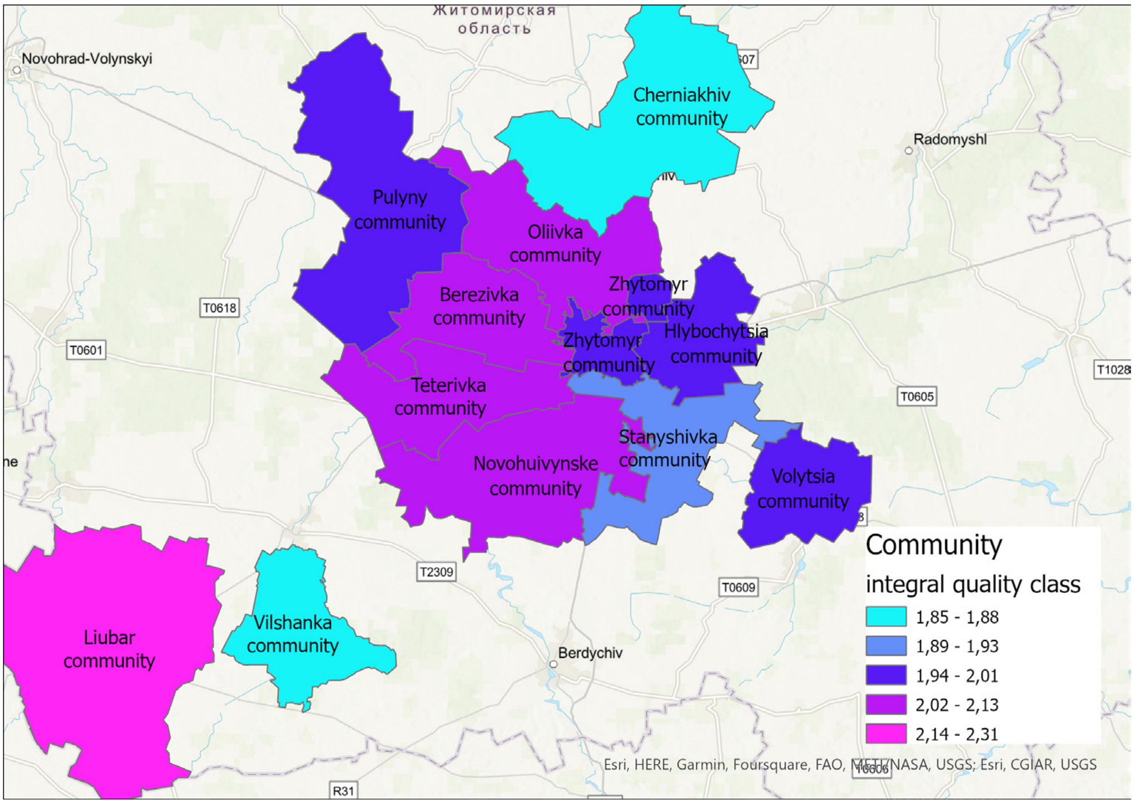

Fig. 8. Ranking of communities by integral water quality class.
Note: Own research.

In addition, the State Sanitary Rules and Regulations “Hygienic Requirements to Drinking Water Intended for Human Consumption” set out a number of requirements for the construction of shaft and tube wells (boreholes), as well as for the construction of spring caps.

The responsibility for managing the water resources of noncentralized water supply sources lies with their owners, who often have illusions about their control and water quality, and as a result underestimate the risks of pollution. The perception of water quality in noncentralized water supply sources is important for making decisions and taking measures to improve it and prevent pollution. However, such decisions and measures should be implemented not only at the individual level but also at the level of village and town councils and UTCs.

Having assessed the state of noncentralized drinking water supply in the studied communities of Zhytomyr district, it was proved that the quality of drinking water in many cases does not meet the standard, and its constant consumption can negatively affect the health of local residents, especially children. Therefore, there is a need to develop practical recommendations for local governments to improve the environmental safety of drinking water supply.

In view of this, it became necessary to develop a plan to improve the state of drinking water supply within the community. The strategic objective of this document is to achieve a safe level of water supply and drinking water quality in the community through the interaction of the governing body and village residents. The development of the plan must take into account public opinion, comments, and suggestions. Before starting the development of the plan for improving the state of community drinking water supply, it is necessary to conduct a survey of the local population to determine the level of their interest and awareness in the field of safe water supply.

The development of the plan should be based on the sequential implementation of 5 mandatory stages (Fig. 10), the number of which may be increased depending on certain conditions. The development team should include representatives of all settlements in the community, representatives of the governing body, heads of utility companies, village elders, members of the public, and engaged experts and scientists from certain institutions. In order to inform the population, the progress of the plan development process should be covered on the community website and in social media.

The first step in developing the plan should be to collect information on the state of drinking water supply in the community, namely: information on the size of the population, the presence or absence of centralized water supply in the settlement, the number of noncentralized water supply sources, the number of preschool and school educational institutions and the specifics of their water supply, the number of medical and public catering facilities and their water supply systems, as well as the presence of an agricultural or industrial enterprise, storage of fertilizers and pesticides, a landfill, and so on in the village. The resulting data is processed using geoinformation technologies.

The next step in developing the plan is to develop and list the problems and systematize them in the field of safe water supply by conducting analytical studies related to the quality of drinking water from noncentralized and centralized (if any) water supply sources. As a result of research on drinking water quality indicators, the parameters that most often exceed the standard content should be identified. The identification of the dominant drinking water pollutants will form the basis for management decisions to eliminate the negative impact on public health. A prerequisite for this stage is the territorial mapping using GIS technologies, which will allow to establish the most likely causes of the negative state of drinking water. In addition, if water samples are taken on the territory of private estates, it is necessary to establish how far away from the source of noncentralized water supply are household buildings, whether livestock is kept in the yard, whether the owners apply mineral and organic fertilizers when growing crops, and so on.

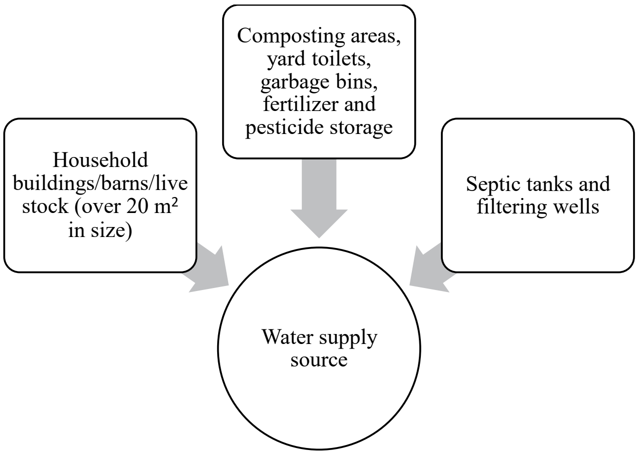

Fig. 9. Standard distances between the water supply source and other structures.
Note: Based on data (DBN, 2019).

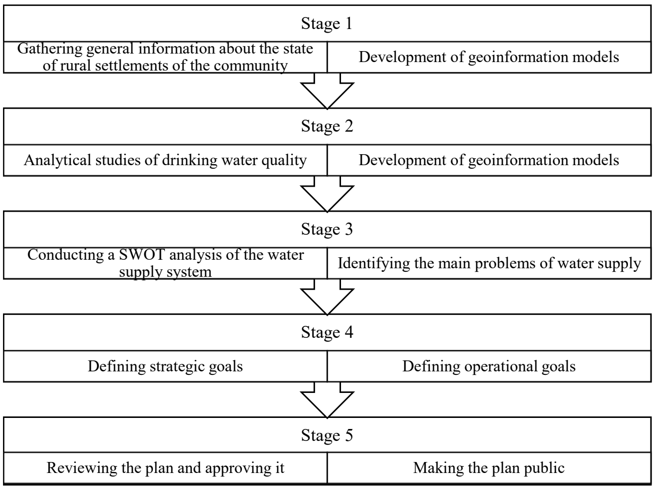

Fig. 10. Key stages of developing a plan for improving the state of community drinking water supply.
Note: Own research.

Based on the analysis of the main problems in the water supply sector, it is necessary to conduct a SWOT analysis of this system, which should be the next sequential stage in the development of a plan for improving the state of community drinking water supply. Subsequently, the systematized problems should be transformed into strategic goals, which should be achieved by identifying and developing operational objectives. The final stage of the plan development is its presentation at a working group meeting with public participation, approval, and publication on the official website of the communities.

Conclusion

On average, no inconsistencies in the pH of drinking water with the standards were found in any of the communities studied, and the average pH of the water is of transitional quality from «excellent," very clean to "good," clean; however, almost all communities, except for Liubar, Vilshanka, and Volytsia, have cases of acidification of water, and strongly alkaline water was found in the well water of Nekrashiv village of Oliivka community; The worst water quality class was established for the Teterivka community, and the water of the Liubar community corresponded to the first-quality class.

The average content of nitrates in drinking water from noncentralized water supply sources exceeds the DSanPiN 2.2.4-171-10 requirements by 1.4–3.5 times, in particular, in the water of Pulyny, Chernyakhiv, Vilshanka, Volytsia, and Oliivka communities, more than two MACs of nitrates were recorded; in terms of average nitrate content, the water corresponds to the class of "satisfactory," slightly contaminated water with a bias toward the "limited suitability," undesirable quality; while the worst values, for the water of Stanyshivka, Volytsia, Oliivka, Zhytomyr, and Vilshanka communities, correspond to a water class of "mediocre," "limited suitability," undesirable quality.

The excess of the average total iron content in the drinking water of noncentralized water supply sources of territorial communities was recorded only in rural settlements of the Lyubar community by 1.9 times, whose water corresponds to the third-quality class of subclass 3(4)—"satisfactory," slightly contaminated water with a bias toward the "limited suitability,", undesirable quality; and in terms of average iron content in other UTCs, the water is "excellent," very clean water with a bias toward "good," clean water of the desirable quality.

On average, the value of the integral water quality class in Zhytomyr district was found to be 2.03, which is defined as "good," clean water of acceptable quality, in particular, the worst quality class was in the water of Teterivka and Liubar communities, and "good," clean water with a bias toward the "excellent," very clean water class was recorded for Vilshanka, Cherniakhivs, and Stanyshivka communities; in addition, it was proved that nitrates make the greatest contribution to the quality of drinking water.

In order to improve the environmental safety of drinking water supply, it is necessary to develop a plan for improving the condition of drinking water supply within a particular community, which should be based on the joint efforts of the management staff and residents of rural settlements; also, when developing the plan, it is mandatory to use GIS technologies with a territorial reference to map and identify the causes of the negative state of drinking water.

The prospect of further research should be to assess the quality of drinking water from noncentralized water supply in rural areas in the context of communities in Berdychiv, Korosten, and Novohrad-Volynskyi districts of Zhytomyr region using a geoinformation system and to develop water supply improvement plans for specific communities.

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