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Emergency Household Water Treatment for Conflict-Induced Supply Disruption: A Case Study of Multi-Contaminant Raw Water in Mykolaiv, Ukraine

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Abstract

Damage to urban water supply infrastructure can rapidly compromise access to safe water and force households to rely on alternative sources of uncertain quality. This study presents a case-based assessment of water quality and emergency household-level treatment options in Mykolaiv, Ukraine, following conflict-induced disruption of the centralized water supply system. Water samples collected from selected groundwater and distribution-network points were analyzed for physicochemical, organoleptic, and microbiological indicators, including total dissolved solids, hardness, sulfates, chlorides, iron, permanganate oxidizability, total microbial count, and *E. coli*. The results showed elevated mineralization, increased sulfate and chloride concentrations, high hardness, organic load indicators, and episodic microbiological contamination in several samples. A low-cost four-stage household treatment procedure combining chemical oxidation, thermal treatment, sorption, and short-term preservation was evaluated as a preliminary emergency approach. The procedure improved odor, taste, hardness, iron content, permanganate oxidizability, and microbiological safety; however, it did not fully reduce total dissolved solids, sulfates, or chlorides to drinking-water standards. Therefore, the treated water should be considered non-potable and suitable mainly for limited domestic and hygienic uses unless additional desalination or blending is applied. The study highlights both the potential and the limitations of simple household-level interventions under emergency water supply disruption and emphasizes the need for decentralized treatment support, monitoring, and long-term infrastructure recovery.

Keywords: household water treatment; water quality; mineralization; shungite; urban water security

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1. Introduction

Access to safe and reliable water is widely acknowledged as a fundamental determinant of public health, human well-being, and socio-economic development. International frameworks, including those advanced by the United Nations, emphasize that water security supports not only hygiene and disease prevention but also long-term community resilience and economic stability [1]. Despite this recognition, substantial disparities persist in the availability and quality of drinking water worldwide. These disparities arise from a combination of factors such as aging or insufficient infrastructure, rapid urban expansion, climate-related variability in water resources, and persistent financial limitations. Even in regions where water resources are physically accessible, constraints in institutional capacity and technological readiness frequently hinder the development of treatment and distribution systems capable of meeting contemporary standards. International organizations such as the United Nations Development Programme (UNDP), the World Health Organization (WHO), and the Food and Agriculture Organization of the United Nations (FAO) consistently underline the necessity of integrated and sustainability-oriented approaches to water management in order to mitigate these challenges [2].

Although universal access to safe water is recognized as a prerequisite for public health and socio-economic stability, maintaining adequate water quality remains a significant challenge in many regions. Effective treatment often requires operational capacities, technological resources, and financial stability that exceed those available to local service providers, particularly where infrastructure has deteriorated or undergone prolonged stress. Elevated concentrations of dissolved inorganic and organic contaminants increase treatment complexity and operational costs, imposing additional burdens on municipal systems [2]. When critical components of supply networks experience large-scale disruption, the absence of reliable purification processes can rapidly compromise environmental conditions and reduce water safety at the household level. Under such conditions, communities frequently depend on temporary or decentralized solutions that are economically and logistically demanding.

A clear illustration of the combined effects of these systemic constraints can be observed in the case of Mykolaiv, Ukraine, where a major transmission pipeline supplying water from the Dnipro River suffered critical damage in April 2022. The resulting disruption left more than 400,000 inhabitants without stable access to adequately treated water, intensifying existing concerns related to water quality and household safety [3,4]. Temporary measures introduced by municipal services and external partners, such as emergency distribution points, mobile treatment units, and short-term filtration support, offered partial relief but highlighted the limited capacity of large urban systems to withstand sudden infrastructure failures. This situation underscored the importance of developing flexible, cost-effective purification options that can be implemented independently at the household scale. The experience of Mykolaiv, therefore, demonstrates both the technological and organizational vulnerabilities of urban water networks and the necessity of scalable solutions capable of improving resilience under conditions of prolonged supply instability.

In light of these considerations, the aim of the present study is to examine accessible and economically feasible household-level water purification methods applicable during periods of severe infrastructure malfunction, with particular reference to the circumstances observed in Mykolaiv.

2. Background and Water Supply Disruption Context

A major failure of the primary water transmission infrastructure occurred near the village of Kyselivka, where a key pipeline supplying Mykolaiv, Ukraine, sustained severe structural damage [3,4]. This event resulted in substantial water loss and significantly disrupted the municipal water supply system.

Following the interruption of centralized water delivery, the city experienced a prolonged period without stable access to treated water. As a consequence, residents relied on alternative sources, including rivers, springs, and artesian wells, as well as designated municipal distribution points providing technical water [5]. These observations are supported by both regional reports and international monitoring sources.

In response to the disruption, municipal and regional authorities implemented several emergency measures, including the drilling of additional groundwater wells, deployment of mobile water purification units, and technical support from neighboring regions [6–10]. Technical water was initially supplied from the Southern Buh River, characterized by elevated salinity and dissolved metals. Although potable water was gradually reintroduced with increasing groundwater extraction, supply remained insufficient to meet demand.

Subsequent assessments indicated that tap water exhibited extremely high mineralization (approximately 4080 mg/L total dissolved solids (TDS)), significantly exceeding drinking water standards. As a result, non-potable water continued to be distributed through the municipal network, while households relied on purchased drinking water.

In later stages, water from the Dnipro–Bug estuary was introduced to maintain system functionality, particularly for sewage transport. However, the high salinity of this water accelerated pipeline corrosion and further affected infrastructure performance. Despite temporary mitigation strategies, including tanker-based supply and partial system reconfiguration, overall water availability remained limited relative to urban demand.

Despite ongoing efforts to stabilize the system, water quality remains variable and sensitive to external factors such as upstream discharges. These conditions demonstrate that centralized water supply systems under prolonged stress may fail to ensure water of sufficient quality for domestic use in accordance with national sanitary standards [11,12].

Consequently, there is a clear need for accessible, low-cost household-level water treatment approaches that can be applied under conditions of limited infrastructure capacity, electricity constraints, and restricted access to safe water.

3. Contaminant Profile and Analytical Scope

Water sources used by residents of Mykolaiv under conditions of infrastructure disruption are characterized by a complex mixture of inorganic, organic, and microbiological contaminants. These contaminants originate from both natural processes and anthropogenic influences intensified by the failure of centralized water treatment and distribution systems.

One of the primary concerns is elevated mineralization resulting from the mixing of freshwater sources with highly mineralized estuarine water. This leads to increased concentrations of major ions, including calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfates (SO_4^{2-}), and chlorides (Cl^-), which contribute to water hardness, scaling, and corrosion processes affecting both infrastructure and household appliances [13,14].

In addition to mineralization, the decomposition of organic matter introduces a range of dissolved organic compounds that significantly influence water quality. These processes may generate substances such as ammonia, hydrogen sulfide, biogenic amines (e.g., cadaverine and putrescine), and low-molecular-weight organic compounds, which affect the odor, taste, and overall chemical stability of the water [15–17]. Many of these compounds are resistant to simple purification processes and may persist under typical household conditions.

Under anaerobic conditions, the decomposition of plant material may lead to the formation of short-chain organic acids and alcohols, accompanied by a decrease in pH. This acidification can disrupt natural self-purification processes, increase the solubility of metals, and further enhance the toxicity of the water [18,19].

The presence of dissolved metals, including iron and trace heavy metals such as Co, Ni, Zn, and Pb, represents an additional concern. These elements may originate from both natural geological sources and corrosion processes within the damaged distribution system. Their presence affects not only water safety but also its organoleptic properties and usability [20–24].

Microbiological contamination constitutes a critical risk factor, particularly under conditions where centralized disinfection is compromised. The presence of indicator organisms such as *Escherichia coli* reflects potential fecal contamination and poses direct health risks.

Given the analytical constraints associated with emergency and wartime conditions, the present study focuses on a set of key indicators that are both practically measurable and directly relevant for assessing water usability. These include total dissolved solids, major ions (Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}), permanganate oxidizability as an indicator of organic load, total iron, and microbiological indicators (*E. coli* and total microbial count).

These contaminant categories define the analytical scope of the study and provide the basis for the subsequent evaluation of household-level water treatment approaches presented in the Sections 5 and 6.

4. Materials and Methods

4.1. Data Collection and Sources

To characterize the conditions that led to prolonged disruption of water supply in Mykolaiv and evaluate water quality available to residents, multiple complementary data sources were examined. The interruption originated in early April 2022, when a major transmission pipeline conveying water from the Dnipro River to the city experienced critical damage near the village of Kyselivka [3]. To document the scale and progression of the resulting water deficit, information was collected from municipal and governmental communications, situation updates prepared by international organizations (including the International Committee of the Red Cross and the International Organization for Migration), and reports in regional media monitoring daily fluctuations in water quality and availability [4,5].

In addition to these secondary sources, an extensive program of empirical water sampling and laboratory testing was carried out in February 2024 to obtain a representative assessment of physicochemical and microbiological water characteristics across different city districts.

4.2. Sample Collection and Handling

Four water samples were collected on 21 February 2024 from intake points selected to represent diverse source origins and treatment histories:

- Sample 1: Groundwater obtained from a private well in the Zavodsky district;
- Sample 2: Water from the centralized distribution network in a district constructed in the 1950s–1960s (Inhulsky district), additionally treated with household filtration devices;
- Sample 3: Water from the centralized urban network in a district built during the 1980s–1990s (Korabelny district);
- Sample 4: Water from the centralized urban network in a different district of similar construction period (Tsentralny district).

The geographic distribution of sampling points is shown in Figure 1.

Collection protocol: To ensure comparative analysis, commercially bottled drinking water compliant with current sanitary standards was used as a control sample. Laboratory investigations included determination of total hardness, concentrations of iron, calcium, magnesium, sulfates, and chlorides, as well as organoleptic parameters such as odor and taste. In addition, microbiological analyses were performed to assess indicators of bacterial contamination.

Figure 1. Sampling points on the map of Mykolaiv, Ukraine.

All water samples were collected according to a standardized protocol. Samples were obtained in sterile 2 L polypropylene bottles pre-rinsed three times with the source water prior to final collection. For tap water samples, the water was allowed to run at full flow for three minutes to ensure representative sampling from the distribution system. Samples intended for microbiological analysis were collected in sterile containers containing sodium thiosulfate (10 mg/L) to neutralize residual active chlorine. All samples were transported to the laboratory in insulated coolers at 4 °C within four hours of collection. Upon arrival, samples were either processed immediately or stored at 4 °C for no longer than 24 h prior to analysis.

A comprehensive on-site chemical screening was additionally conducted using EPA-level semi-quantitative test strips to determine pH, total hardness, major ions (sulfates, chlorides, calcium, magnesium), selected cations (including iron), residual active chlorine, nitrites, nitrates, fluoride, and bromine. Sensory characteristics, including odor and taste, were evaluated concurrently. All physicochemical analyses were performed in triplicate for each sample, and results were reported as mean ± standard deviation.

The relative standard deviations (typically 3–6%) reflect the moderate precision of the analytical instruments and protocols; the minor variations are attributable to the compromised quality of analytical reagents available under wartime conditions, where reagents labeled "analytically pure" often did not meet the required standards and could not be further purified.

The integration of official data, international reports, media monitoring, and laboratory findings provided a comprehensive evidence base for assessing water quality under conditions of prolonged infrastructure disruption. This study was based on a single emergency sampling campaign conducted at four locations in Mykolaiv on 21 February 2024.

4.3. Physicochemical Analysis and Bacteriological Testing

All physicochemical analyses were performed in triplicate for each sample, with results reported as mean ± standard deviation.

pH measurements were performed using an EZDO MP-103 handheld pH meter (Gondo Electronic, Taipei, Taiwan) outfitted with a combined ceramic PY41 silver chloride electrode and PO50 ORP electrode. The meter was calibrated daily using standard buffer solutions (pH 4.0, 7.0, and 10.0) prior to measurements.

Turbidity and organoleptic properties (odor, color, taste) were evaluated visually and by sensory assessment according to standard methods [11]. Odor and taste were scored on a scale of 1–5 by a panel of three trained assessors; reported values represent the median score.

Comprehensive chemical screening was performed using EPA-level test strips (AquaChek, Hach Company, Loveland, CO, USA) compliant with Environmental Protection Agency standards. These test strips enabled semi-quantitative detection of pH, total hardness, lead, iron, copper, mercury, alkalinity, nitrites, nitrates, bromine, free chlorine, total chlorine, fluoride, chromium, carbonate, and cyanuric acid. Each strip provided results for up to 16 parameters, offering a detailed chemical profile. For each parameter, three test strips were used per sample and the results were averaged.

Quantitative analysis of selected parameters (chlorides, sulfates, calcium, magnesium, total hardness, permanganate oxidizability, and total dissolved solids) was conducted according to standard methods [11] at the Experimental Laboratory TOV NDC Afina Pallada (Ukraine). All quantitative analyses were performed in triplicate.

Microbiological analyses were conducted using standardized procedures in accordance with national sanitary regulations, including the State Sanitary Norms and Rules "Hygienic requirements for drinking water intended for human consumption" (DSanPiN 2.2.4-171-10) [11], approved by the Ministry of Health of Ukraine (Order No. 400, 12 May 2010, registered with the Ministry of Justice of Ukraine), as well as earlier sanitary provisions (Ministry of Health of Ukraine, Order No. 60, 3 February 2005). The analyses were further aligned with relevant international guidelines, including WHO recommendations and ISO standards (ISO 9308-1 [25], ISO 9308-2 [26], ISO 6222-2 [27]).

4.4. Statistical Analysis

All data are presented as mean ± standard deviation (SD) of three independent replicate measurements (n = 3) unless otherwise specified. Statistical analyses were performed using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). Comparisons between sample groups were conducted using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. Differences were considered statistically significant at $p < 0.05$.

4.5. Overview of Evaluated Methods

The following household-level treatment approaches were assessed based on their compatibility with the contaminant profile identified in Mykolaiv:

- Boiling with preliminary filtration: Thermal inactivation of microorganisms combined with cloth or sand filtration for particulate removal.
- Chemical oxidation ($KMnO_4$) combined with thermal softening: A multi-stage protocol involving sodium carbonate addition, boiling, and permanganate oxidation.
- Sorption on mineral-based media: Use of shungite, a naturally occurring carbon-rich mineral, as a filtration medium for organic compound and heavy metal adsorption.
- Commercial point-of-use devices: Activated carbon filter pitchers, ceramic candle filters, and UV disinfection pens.

Each method was evaluated against the specific contaminants identified in Mykolaiv water samples, with particular attention to removal efficiency for hardness ions, heavy metals, organic load, and microbial indicators.

5. Results

5.1. Water Quality Under Prolonged Infrastructure Disruptions: Evidence from Mykolaiv

The assessment of water samples collected in Mykolaiv demonstrated pronounced departures from parameters typically associated with potable water (Table 1).

Table 1. Results of water quality assessment based on analyses conducted by the Experimental Laboratory TOV NDC Afina Pallada (Ukraine).

Indicator	Units	Test Results (Mean ± SD)	Regulatory Limit (DSanPiN 2.2.4-171-10) [11]
pH	pH units	7.9 ± 0.5	6.5–8.5
Electrical Conductivity	mS cm	4.23 ± 0.02	Non specified *
Sodium (Na^+)	mmol/L	17.93 ± 0.71	Non specified **
Potassium (K^+)	mmol/L	0.28 ± 0.01	Non specified **
Magnesium (Mg^{2+})	mmol/L	18.13 ± 0.36	Non specified ***
Calcium (Ca^{2+})	mmol/L	7.81 ± 0.12	Non specified ***
Sulfates ($SO_4{}^{2-}$)	mmol/L	24.0 ± 0.6	≤2.6
Chlorides (Cl^-)	mmol/L	19.7 ± 0.35	≤7.0
Bicarbonates ($HCO_3{}^-$)	mmol/L	5.38 ± 0.08	Non specified

Notes: * The standard for tap water is TDS ≤ 1000 mg/L (approx. conductivity ≤ 1.5–2.0 mS/cm depending on ion composition). ** Sodium limit is indirectly regulated via TDS and taste thresholds. *** Regulated via total hardness (≤7.0 mmol/L for tap water).

Laboratory analyses of the four sampling points in Mykolaiv (Figure 1) indicated elevated mineralization and microbiological indicators that exceed recommended thresholds for safe domestic consumption, reflecting the cumulative effects of extended system stress and limited treatment efficiency. Table 2 presents the physicochemical, organoleptic, and microbiological parameters of the four samples, which were characterized by markedly reduced quality primarily associated with increased electrical conductivity and elevated concentrations of sodium, chlorides, magnesium, and sulfates. These parameters collectively reflect a high degree of mineralization, which significantly limits the suitability of the water for domestic use.

Sample 1 showed slightly elevated odor and taste scores. With a standard of 2 or fewer points, in the sample it is equal to 3. The total hardness is slightly increased, with a standard of 7 or less mmol/L in the sample it is 10.4. This also applies to the content of iron Fe (standard 0.2 mg/L or less, sample 1 contains 0.27), calcium and magnesium (see Table 1). The content of sulfates $SO_4{}^{2-}$ is three times higher than the standard (standard 250 or less mg/L in sample 730). The content of chlorides Cl^- almost doubled. The total microbial count was equal to 19 CFU per mL, respectively, and the coliform index exceeded the standard (absence) with a value of 4. According to the epidemiological criterion, no contamination was detected in the sample.

In sample 2, similar to sample 1, the data on smell and taste were slightly increased. With a norm of 2 or fewer points, in the sample it is equal to 3. The total hardness is slightly increased, with a norm of 7 or less mmol/L in the sample it is 9.2. This also applies to the content of iron Fe (norm 0.2 mg/L or less, sample 1 contains 0.26), calcium and magnesium (see Table 1). The content of sulfates $SO_4{}^{2-}$ is three times higher than the norm (norm 250 or less mg/L in sample 730). The chloride content Cl^- mg/L almost doubled (250 and 329, respectively). The total microbial count significantly exceeded the standard and was equal to 126 CFU/cm^3, respectively, and the coli-index slightly exceeded the standard (absence) and was 5. According to the epidemiological criterion, insignificant contamination was found in the sample.

Table 2. Comparison of water quality parameters from wells and centralized supply points in Mykolaiv against drinking water standards (ND).

No.	Water Quality Parameter (Unit)	Sample Identification				Regulatory Limit (DSanPiN 2.2.4-171-10) [11]	A Bottled Water Morshynska (Non-Carbonated)-Control Profile
		Test Results-Drinking Water					
		Sample 1	Sample 2	Sample 3	Sample 4		
1	Odor, scores: at 20 °C at 60 °C	3 3	3 3	4 4	3 4	≤2 ≤2	0 0
2	Taste and aftertaste, scores	3	3	3	3	≤2	0
3	A pH, units of pH	7.2 ± 0.5	7.1 ± 0.5	7.0 ± 0.5	7.1 ± 0.5	6.5–8.5	6.9 ± 0.5
4	Total hardness, mmol/L	10.4 ± 0.2	9.2 ± 0.1	0.5 ± 0.1	9.2 ± 0.1	1.5–7.0 (≤7) *	3.4 ± 0.1
5	Carbonate hardness (alkalinity), mmol/L	3.2 ± 0.1	3.6 ± 0.2	0.5 ± 0.1	3.7 ± 0.2	0.5–6.5 *	1.6 ± 0.1
6	Permanganate oxidizability, mg/L	27.5 ± 1.1	29.1 ± 1.2	15.6 ± 0.7	28.7 ± 1.0	≤5	1.3 ± 0.1
7	Total iron (Fe), mg/L	0.27 ± 0.03	0.26 ± 0.02	0.03 ± 0.01	0.26 ± 0.03	≤0.2	Less than 0.01
8	Nitrates (NO_3^-), mg/L	8.3 ± 0.7	4.2 ± 0.3	2.2 ± 0.1	4.2 ± 0.2	≤50	0.5 ± 0.1
9	Sulfates (SO_4^{2-}), mg/L	730 ± 29	720 ± 20	3 ± 1	780 ± 24	≤250	23 ± 1
10	Chlorides (Cl^-), mg/L	447 ± 8	329 ± 5	56 ± 1	324 ± 7	≤250	18 ± 1
11	Calcium content, mg/L	90.2 ± 1.5	80.2 ± 1.0	10.2 ± 0.4	80.2 ± 0.9	Non specified	60.3 ± 0.8
12	Magnesium content, mg/L	71.7 ± 3.4	63.2 ± 2.8	0.6 ± 0.1	63.2 ± 2.6	Non specified	5.0 ± 0.1
13	Total dissolved solids, mg/L	1420 ± 22	1020 ± 19	140 ± 2	980 ± 18	≤1000	214 ± 6
14	*E. coli*, CFU/100 mL	4	5	Absence	5	Absence	Absence
15	The total microbial count, CFU/cm^3 **	19	126	25	126	≤100	8

Notes: *—indicators of the physiological adequacy of the mineral composition of water according to DSanPiN 2.2.4-171-10. ** Bottled water—no more 20 CFU/cm^3 (DSanPiN 2.2.4-171-10) [11].

Sample 3 fully complies with both chemical and epidemiological standards.

In sample 4, similar to sample 2, the data on smell and taste were slightly increased. With a standard of 2 or fewer points, in the sample it is equal to 3. The total hardness is slightly increased, with a standard of 7 or less mmol/L in the sample it is 9.2. This also applies to the content of iron Fe (norm 0.2 mg/L or less, sample 1 contains 0.26), calcium and magnesium (see Table 1). The content of sulfates SO_4^{2-} is three times higher than the norm (norm 250 or less mg/L in sample 780). The content of chlorides Cl^- mg/L is almost twice as high (250 and 324, respectively). The total microbial count significantly exceeded the norm and was equal to 126 CFU/cm^3, respectively, and the coli-index slightly exceeded the norm (absence) and was 5. According to the epidemiological criterion, insignificant contamination was found in the sample.

In addition, under household conditions, the presence of coliform bacteria in water samples may be assessed using the Compact Dry™ EC system (Nissui Pharmaceutical Co., Ltd., Tokyo, Japan). These are ready-to-use chromogenic culture plates designed for the rapid detection and enumeration of coliform bacteria and *E. coli* in water. *E. coli* colonies develop a blue coloration, whereas other coliform bacteria produce red colonies (Figure 2), which facilitates straightforward visual differentiation and interpretation of results. Incubation is typically conducted for 24 h at 35 °C or 37 °C.

Overall, these results confirm that untreated or insufficiently treated municipal water sources are characterized by excessive mineralization and episodic microbiological contamination, whereas treated water meets established quality requirements. This differentiation highlights not only the scale of quality deterioration within centralized distribution systems but also the complexity of contaminants present in the water.

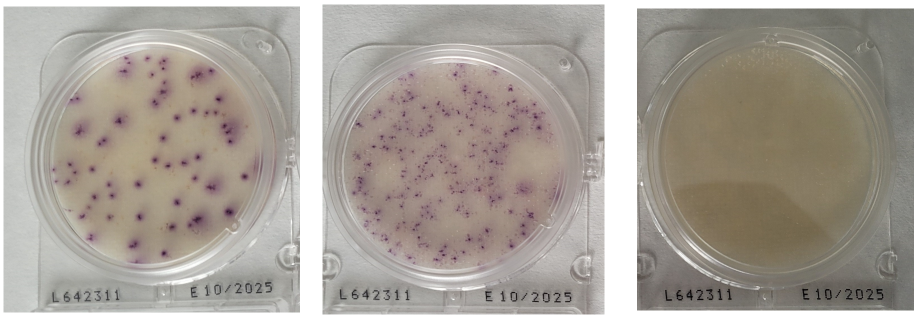

Figure 2. Example results of the Compact Dry EC test for the presence of coliform bacteria.

Physicochemical testing further revealed exceptionally high electrical conductivity values accompanied by increased turbidity across several sampling locations. Such characteristics are indicative of a substantial load of dissolved salts, metal ions, and suspended particulate matter. In parallel, sensory assessment identified unpleasant odors and visible impurities, which significantly limit the suitability of the water for routine household use, even in non-consumptive applications.

More detailed evaluation of physicochemical characteristics showed that conductivity values substantially exceeded recommended thresholds for potable water, reflecting the elevated mineral content observed in multiple samples. Deviations of pH from the neutral range were also detected in selected cases, suggesting the combined influence of natural geochemical conditions and external inputs affecting source water quality.

Chemical screening identified the presence of heavy metals, including trace amounts of lead and mercury, as well as elevated concentrations of nitrates and chlorides. These constituents pose direct health risks if ingested and are particularly challenging to remove without targeted treatment technologies. The coexistence of high mineralization, toxic metals, and microbiological indicators underscores that the observed water quality degradation is multifactorial in nature.

Taken together, the analytical findings provide a clear basis for examining the mechanisms of contamination and transformation occurring in water bodies affected by prolonged anthropogenic stress. This context forms the background for the approaches to water purification discussed in the following section.

The results of laboratory analyses indicate that the observed water quality degradation in Mykolaiv is driven not by a single contaminant group, but by the simultaneous presence of excessive mineralization, dissolved metals, organic compounds, and microbiological indicators. Under such conditions, single-mechanism treatment approaches are insufficient to improve water quality to a level suitable for domestic use.

5.2. Evaluation of Household Water Purification Methods

The water quality assessment presented in Section 5.1 demonstrates that the contamination profile in Mykolaiv is multifactorial, comprising elevated mineralization, dissolved metals, organic compounds, and microbiological indicators (Table 2). Under such conditions, single-mechanism treatment approaches are unlikely to restore water quality to a level suitable for domestic use. Given the limited availability of advanced centralized treatment technologies during prolonged supply disruption, this section evaluates the practical efficacy of several accessible, low-cost purification strategies that can be implemented at the household level.

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6. Discussion

6.1. Immediate and Short-Term Solutions for Water Purification

As a result of prolonged disruptions in the municipal water supply system, local authorities in Mykolaiv were compelled to introduce technical water sourced from the Southern Buh River estuary as a temporary measure. This water is characterized by elevated salinity and pronounced corrosive properties, which render it unsuitable for drinking and routine household applications. This observation is consistent with the analytical results presented in Tables 1 and 2, where elevated concentrations of sulfates, chlorides, total dissolved solids, and hardness were identified in multiple samples collected from the municipal distribution network. Continuous exposure to such water has contributed to accelerated degradation of distribution pipelines and has caused damage to domestic appliances, including washing machines and water heaters, thereby increasing maintenance requirements and repair costs.

Similar challenges related to water quality degradation and limited treatment capacity have been reported in various urban and environmentally stressed regions worldwide, particularly under conditions of infrastructure failure, climate variability, anthropogenic pressure, and conflict-related disruption [12,28,29]. In such contexts, decentralized and household-level water treatment approaches are increasingly recognized as important interim solutions that can partially mitigate health risks and improve water usability when access to safe centralized water supply is limited [29–32]. However, previous studies also emphasize that the effectiveness of such methods strongly depends on local water composition and therefore requires careful adaptation to site-specific contamination profiles [30,31].

Although more than 40 groundwater wells and permanent safe water distribution points have been established, access to potable water at the household level remains constrained. Residents continue to depend on purchased bottled water or supplies collected from designated distribution sites, which imposes a persistent financial burden and negatively affects everyday living conditions. The analytical results presented in Table 2 additionally demonstrate that several samples collected from the municipal distribution network were characterized by elevated mineralization, high sulfate and chloride concentrations, increased hardness, and episodic microbiological contamination. Tap water supplied through the municipal network also exhibited an unpleasant odor, elevated turbidity, and visible discoloration, which further limited its suitability not only for drinking purposes but also for basic domestic and hygienic activities. Despite the implementation of interim measures, stable and convenient access to safe drinking water has not yet been fully restored, underscoring the limitations of short-term solutions in addressing long-standing deficiencies in urban water infrastructure.

As a consequence of the inadequate quality of tap water, residents increasingly rely on external sources, particularly bottled water. While this alternative provides a temporary solution for drinking and cooking, it represents a costly and logistically inefficient option for a large urban population. Long-term dependence on bottled water places additional financial pressure on households and does not offer a sustainable solution to the underlying problem of water quality.

Health-related concerns further intensify the urgency of addressing water purification at the household level. Reports of potential microbiological contamination have heightened awareness of the risks associated with untreated or insufficiently treated water. In the absence of reliable centralized treatment, the need for effective purification methods becomes critical, as prolonged exposure to contaminated water may pose serious health hazards.

Although advanced water treatment technologies exist, their implementation remains limited under current local conditions. Consequently, attention has shifted toward simple and accessible approaches that can improve water quality at the household scale. The proposed measures focus on methods that can be applied within individual homes or apartments, aiming to enhance water safety for daily use while remaining technically feasible and economically accessible for residents.

In many regions of Ukraine, including Mykolaiv, water supplied through municipal distribution systems frequently exhibits unfavorable organoleptic characteristics, such as turbidity, reddish or brown discoloration, and an unpleasant odor. In addition, elevated salt concentrations are occasionally observed, further reducing the suitability of this water for everyday use. Even in the absence of detailed chemical analysis, these sensory indicators alone are sufficient to classify the water as inappropriate for hygienic and domestic purposes. As a result, residents typically restrict its use to non-contact applications, including toilet flushing, laundry, and floor cleaning, while relying on bottled water for drinking and food preparation. This practice imposes additional financial burdens on households and does not represent a sustainable long-term solution.

In response to these limitations, the present study proposes a set of practical and economically accessible water purification approaches that can be implemented at the household level. The proposed solutions differ in complexity and technological requirements, allowing users to select methods appropriate to their available resources and local conditions. Emphasis is placed on approaches that are simple, effective, and low-cost, thereby ensuring applicability for households with limited financial and technical capacity. In addition, for situations in which bacteriological contamination is suspected, the analysis also considers more advanced purification options.

Given the elevated risks associated with the current quality of water in Mykolaiv, several immediate purification strategies were evaluated. Each method was assessed with respect to accessibility, cost efficiency, and effectiveness in reducing the identified categories of contaminants. Thermal treatment combined with basic filtration was considered a fundamental option for reducing microbial load, although it does not address dissolved chemical constituents. Chemical disinfection methods, including the use of chlorine-based agents and iodine solutions, were examined for their effectiveness in neutralizing biological contaminants, with attention given to potential residual effects and the importance of controlled application.

In addition, selected natural substances were reviewed as supplementary hygienic agents. Essential oils derived from thyme, pine, and fir demonstrate documented bactericidal and fungicidal activity and may be applied in limited hygienic contexts. Similarly, hop extracts have been shown to inhibit the growth of a broad range of bacterial genera, including *Staphylococcus*, *Streptococcus*, *Bacillus*, *Listeria*, *Propionibacterium*, *Helicobacter*, *Escherichia*, *Salmonella*, *Pseudomonas*, and *Treponema*, with varying degrees of effectiveness. While these natural agents are not intended to replace conventional treatment methods, they may contribute to reducing microbial activity under specific household conditions.

In addition to the methods described above, mineral-based sorbents were considered as supplementary components of household water purification systems. Among these materials, shungite—a naturally occurring carbon-rich mineral—proved particularly relevant under the conditions observed in Mykolaiv. Shungite is characterized by a high specific surface area, a complex carbon structure, and documented sorption capacity toward organic compounds, heavy metals, and selected inorganic contaminants.

During practical application under household conditions, shungite demonstrated favorable performance as a filtration medium, contributing to improved water clarity and a noticeable reduction in unpleasant odor and taste. Its effectiveness was especially evident when used as part of multi-layer filtration systems, in combination with sand or activated carbon, where it enhanced overall sorption efficiency. Given its chemical stability, low cost, and availability, shungite emerged as a suitable material for interim water treatment in situations where access to advanced filtration technologies is limited.

Although shungite-based filtration does not replace comprehensive centralized treatment or advanced purification technologies, its application may significantly improve the physicochemical quality of water intended for non-potable and limited household uses. The observed performance confirms that mineral sorbents such as shungite can play a valuable supporting role in household-level water purification strategies under conditions of prolonged infrastructure disruption.

6.2. Experimental Validation of the Emergency Domestic Water Purification Procedure

6.2.1. Performance of the Four-Stage Purification Protocol

To assess the practical efficacy of the developed purification protocol under conditions that mimic those available to a non-professional consumer, an experimental validation was conducted. The procedure was designed to be executable with commonly available reagents and household equipment, and no specialized laboratory apparatus was employed. The aim was to determine whether the protocol could improve water quality parameters to within acceptable limits when applied to a representative contaminated sample from Mykolaiv.

To simulate a realistic household application, a four-stage protocol (Table 3) combining chemical oxidation, thermal treatment, sorption, and natural preservation (thyme tincture) was applied to a water sample collected from the most contaminated distribution point (Sample 4, Tables 2 and 4). The quality of the raw tap water, the water after applying the protocol, and a reference commercial bottled water (Morshynska, non-carbonated) were analyzed for a range of physicochemical and microbiological parameters. The results were compared against the national regulatory limits for drinking water (DSanPiN 2.2.4-171-10). The experiment was carried out in triplicate. The results of this validation are presented in Table 5.

Table 3. Protocol for Complex Water Purification (for 5 L of initially polluted water)—simulating a non-professional consumer's procedure.

Stage	Content of Action	Procedure	Duration	Result
1. Chemical oxidation and sedimentation	Strong oxidant reagent-$KMnO_4$	Add 50 mL of 5% solution until a light pink color is achieved.	30–60 min	A brown, viscous precipitate should form. This stage removes bacterial contamination and precipitates iron compounds. Critical step: Carefully decant the water into a container for boiling, ensuring the sediment is not poured out, or filter through three layers of cotton cloth.
2. Thermal treatment	Disinfection and softening	Moderate boiling. Add 3–5 small pieces of porous porcelain (e.g., from a broken cup) to ensure even boiling.	5 min	Complete inactivation of viruses and bacteria; evaporation of volatile organic matter; decomposition of temporary hardness salts (softening). Post-action: Cool the water to 40–50 °C (use kitchen thermometer).
3. Sorption and post-purification	Sorption of pollutants	Slow filtration or infusion by passing water through a layer of shungite stones (approx. 500 g).	0.5–2 h	Removal of heavy metals, manganese, and iron residues; improvement of turbidity, odor, and taste.
4. Final conservation	Addition of natural water preservative	Add 10–15 drops of thyme alcohol tincture or one tablespoon of water-based thyme extract to the cold, filtered water.	Mix and wait 20–30 min before using	Prevents microbial growth and provides a pleasant smell. The effect lasts 48–72 h, depending on light and temperature.

Due to the exploratory nature of the study and the constraints of emergency laboratory conditions, the experiment was conducted in triplicate (n = 3). Therefore, the results should be interpreted as preliminary observations rather than as a statistically robust evaluation.

Table 4. Reagents and equipment.

Item	Specification	Approximate Cost (€)
Potassium permanganate ($KMnO_4$) *	Pharmaceutical grade, 5 g package	0.50
Shungite stones	Over-the-counter, 500 g portion (two portions recommended)	1.00 (per portion)
Thyme alcoholic tincture	Over-the-counter, 50 mL bottle	2.70
Enameled saucepan	5.5 L capacity	10.00
Glass storage bottle	5 L capacity, with cork or stopper	2.80
Electronic kitchen thermometer	Needle-type, accuracy ±1 °C	1.70
Optional: Silver ionizer	As available commercially	Varies (minimal 35—silver ionizer devices designed for water purification)

Note: * Usually sold by prescription.

Table 5. Assessment of purification protocol efficiency. The tap water was sampled in point 4 (see Table 2) as the most polluted according to previous data).

No.	Water Quality Parameter (Unit)	Test Results		Regulatory Limit (DSanPiN 2.2.4-171-10) [11]	A Bottled Water Morshynska (Non-Carbonated)-Control Profile
		Initial Sample	Purified Sample	Tap Water (Distribution Points)	
1	Odor, scores: at 20 °C at 60 °C	3 4 (swam)	1 2 (slightly smell on thyme)	≤2 ≤2	00
2	Taste and aftertaste, scores	2	1	≤2	0
3	A pH, units of pH	7.5 ± 0.5	6.9 ± 0.5	6.5–8.5	6.9 ± 0.5
4	Total hardness, mmol/L	8.4 ± 0.2	5.1 ± 0.1	1.5–7.0 (≤7) *	3.4 ± 0.1
5	Carbonate hardness (alkalinity), mmol/L	3.2 ± 0.1	Less than 0.5	0.5–6.5 *	1.6 ± 0.1
6	Permanganate oxidizability, mg/L	31.0 ± 0.7	4.6 ± 0.1	≤5	1.3 ± 0.1
7	Total iron (Fe), mg/L	0.32 ± 0.03	Less than 0.05	≤0.2	Less than 0.01
8	Nitrates (NO_3^-), mg/L	3.6 ± 0.1	5.7 ± 0.1	≤50	0.5 ± 0.1
9	Sulfates (SO_4^{2-}), mg/L	690 ± 13	455 ± 8	≤250	23 ± 1
10	Chlorides (Cl^-), mg/L	297 ± 5	313 ± 6	≤250	18 ± 1
11	Calcium content, mg/L	140.0 ± 2.0	81.6 ± 1.6	Not specified	60.3 ± 0.8
12	Magnesium content, mg/L	16.8 ± 0.4	12.2 ± 0.1	Not specified	5.0 ± 0.1
13	Total dissolved solids, mg/L	1340 ± 20	1105 ± 18	≤1000	214 ± 6
14	*E. coli*, CFU/100 mL **	Presence	Absence	Absence	Absence

Notes: * indicators of the physiological adequacy of the mineral composition of water according to DSanPiN 2.2.4-171-10 [11]. **—qualitative test, used to test for the presence of coliform bacteria in water LaMotte Total Coliform/*E. coli*. Given the limited number of replicates, the reported values should be interpreted as indicative rather than statistically representative.

Health and Safety Recommendations

Allergy assessment: Confirm that the end-user does not exhibit hypersensitivity to thyme tincture. A simple skin patch test is recommended.

Form of thyme preservative: Do not employ essential oil, as it is immiscible with water and will form a superficial film.

Shungite maintenance: Rinse shungite in a citric acid solution every two weeks, followed by air-drying. When using newly purchased or thoroughly cleaned shungite, the initial 2–3 L of filtrate may appear grayish (due to stone dust); discard this water or reserve it for non-potable technical purposes. To ensure continuous operation, it is advisable to maintain two sets of shungite: one in service while the other undergoes cleaning and drying.

Indicator of sorbent saturation: If the filtered water retains a swampy odor or a residual scent of $KMnO_4$, the sorbent is exhausted and requires immediate cleaning or replacement.

Storage conditions: Preserve the treated water in glass bottles or food-grade plastic containers (PET 1 or HDPE 2) in a cool, dark place. Consume within 48–72 h.

Supplementary recommendation—silver ionizer: For extended microbiological stability, especially when storage beyond 48 h is anticipated, the use of a silver ionizer (e.g., silver jewelry items) is recommended. After completion of Stage 4, immerse a silver ionizer in the stored water according to the manufacturer's instructions. Silver ions provide sustained bacteriostatic and antiviral activity without altering taste or color, thereby prolonging potability. This measure is particularly valuable in settings without reliable refrigeration.

The proposed purification protocol (Table 5) was applied to a tap water sample collected from the most polluted distribution point (point 4, as identified by prior screening, see Table 2). The initial water exhibited several parameters exceeding the regulatory limits for drinking water (DSanPiN 2.2.4-171-10) [11], as well as the presence of *E. coli*.

The experimental validation was performed in triplicate ($n = 3$), which does not allow for full statistical analysis. Therefore, the results should be considered preliminary and indicative of treatment performance trends.

Despite the observed improvements in several parameters, the treated water does not meet drinking water standards, particularly with respect to total dissolved solids, sulfates, and chlorides. Therefore, it should be considered non-potable and suitable only for limited domestic or hygienic uses.

An increase in nitrate concentration was observed after treatment. This effect may be associated with oxidation processes or the release of nitrogen-containing compounds during treatment and requires further investigation.

The observed treatment effects can be explained by a combination of physicochemical and microbiological processes. Thermal treatment (boiling) contributes to the inactivation of vegetative microorganisms, although spore-forming bacteria may remain resistant under such conditions.

Thermal treatment and chemical oxidation are effective in reducing microbiological contamination and transforming certain organic compounds; however, they do not remove dissolved salts such as chlorides, sulfates, or nitrates. These ions remain in solution and require physical separation processes such as membrane filtration or ion exchange for effective removal.

Chemical oxidation using potassium permanganate ($KMnO_4$) and hydrogen peroxide (H_2O_2) facilitates the degradation of organic matter and improves organoleptic properties by reducing odor and color, as described in previous studies [15,18]. In addition, oxidation processes may contribute to the transformation of certain dissolved compounds under varying redox conditions [18,20].

The use of $KMnO_4$ as an oxidizing agent may be associated with certain limitations, including the potential presence of residual manganese, the formation of oxidation by-products, and the risk of over-oxidation if dosing is not properly controlled. These factors may limit its suitability for long-term or uncontrolled application.

The addition of sodium carbonate (Na_2CO_3) promotes the precipitation of hardness-causing ions such as calcium and magnesium, thereby reducing water hardness [19].

Sorption processes, particularly those associated with mineral-based materials such as shungite, play an important role in the removal of dissolved organic compounds and selected inorganic contaminants [32–35]. The efficiency of these processes depends on parameters such as contact time, particle size, and sorbent characteristics.

It should be noted that, due to the simplified design and emergency conditions under which the treatment was applied, the process parameters were not optimized, and the observed effects should be interpreted as indicative rather than fully controlled treatment outcomes.

The following discussion evaluates the effectiveness of each stage of the protocol based on the analytical data from Table 3.

Organoleptic parameters (odor, taste): Initial water had a distinct swampy odor (score 4 at 60 °C) and a taste score of 2. After purification, the odor at 20 °C decreased to score 1, and at 60 °C to score 2 (slight thyme smell). Taste improved to score 1. These improvements are primarily attributable to Stage 3 (sorption on shungite), which removes organic compounds responsible for musty odors, and Stage 4 (thyme tincture), which imparts a mild herbal note. The residual faint thyme odor is not considered a defect.

pH and hardness. The initial pH (7.5 ± 0.5) was within the acceptable range (6.5–8.5) and remained virtually unchanged (6.9 ± 0.5) after treatment. Total hardness decreased from 8.4 ± 0.2 to 5.1 ± 0.1 mmol/L, still slightly above the regulatory limit of ≤7 mmol/L but significantly improved. The marked reduction in carbonate hardness (from 3.2 ± 0.1 to < 0.5 mmol/L) confirms the effectiveness of Stage 2 (thermal treatment): boiling decomposes calcium and magnesium bicarbonates into insoluble carbonates, which precipitate or are retained during subsequent filtration. The remaining hardness is non-carbonate (permanent), which is not removable by boiling.

Organic matter (permanganate oxidizability): The permanganate oxidizability dropped from 31.0 ± 0.7 to 4.6 ± 0.1 mg/L, approaching the regulatory limit of ≤5 mg/L. This substantial reduction (≈85%) is a combined result of Stage 1 ($KMnO_4$ oxidation), which chemically oxidizes a wide range of organic pollutants, and Stage 3 (shungite sorption), which adsorbs residual organic molecules. The final value is slightly higher than that of the bottled water control (1.3 mg/L), indicating that further optimization (e.g., longer contact time with shungite) might yield additional improvement.

Iron: Total iron decreased from 0.32 ± 0.03 to less than 0.05 mg/L, well below the limit of 0.2 mg/L. This removal is achieved primarily during Stage 1, where $KMnO_4$ oxidizes soluble Fe^{2+} to insoluble Fe^{3+} hydroxides, which co-precipitate with MnO_2. The subsequent decantation or cloth filtration effectively separates these particles. Residual manganese and other heavy metals are further adsorbed by shungite in Stage 3.

Nitrates, sulfates, chlorides: Nitrates remained low (5.7 mg/L) and well below the limit (50 mg/L). However, sulfates (690 → 455 mg/L) and chlorides (297 → 313 mg/L) were not reduced to within the regulatory limits (≤250 mg/L for both). This is expected because the protocol does not include any ion-exchange, reverse osmosis, or distillation steps. Sulfates and chlorides are highly soluble and are not removed by oxidation, boiling, or adsorption on shungite. Users should be aware that this method is not suitable for waters with very high salinity or sulfate/chloride content. For such cases, additional treatment (e.g., blending with low-mineral water or using a reverse osmosis unit) would be necessary.

Calcium, magnesium, and Total dissolved solids: Calcium decreased from 140.0 to 81.6 mg/L, and magnesium from 16.8 to 12.2 mg/L, consistent with the reduction in carbonate hardness. Total dissolved solids dropped from 1340 to 1105 mg/L, still exceeding the guideline of ≤1000 mg/L. The persistent high total dissolved solids are again due to non-removable ions (sulfates, chlorides, sodium, etc.). The protocol thus improves water quality but does not fully demineralize it.

Microbiological safety: The initial sample tested positive for *E. coli* (coliform bacteria). After treatment, *E. coli* was absent. This outcome is due to the synergistic effect of Stage 1 ($KMnO_4$), which has bactericidal activity, and Stage 2 (boiling), which reliably inactivates all vegetative bacteria, viruses, and parasites. The optional silver ionizer provides residual protection during storage, although in this experiment it was not used (the test was performed immediately after cooling).

Comparison with bottled water. The purified water approached the quality of the reference bottled water (Morshynska) in terms of odor, taste, pH, iron, and microbiological safety. However, it remained inferior with respect to sulfate, chloride, and total dissolved solids levels. This is an inherent limitation of a simple, low-cost, non-professional procedure. The protocol is therefore recommended for emergency use or in settings where bottled water is unavailable, but not as a substitute for professional desalination.

The results confirm that the four-stage protocol effectively removes microbial contamination, organic pollutants, iron, and temporary hardness. It produces water that is suitable for hygiene, dishwashing, and limited domestic use. For regular drinking, users should be mindful of the residual sulfate and chloride content; if the raw water has very high levels of these ions, alternative treatment methods should be considered.

Sorption processes are widely used in water treatment and depend on parameters such as contact time, particle size, and sorbent properties [30,36].

6.2.2. Comparative Suitability for Mykolaiv Conditions

Similar observations regarding the practical role of decentralized household-level water treatment methods under conditions of limited infrastructure have been reported in previous studies [32,36]. Earlier research demonstrated that low-cost point-of-use treatment systems may substantially improve microbiological safety and selected physicochemical parameters, although their effectiveness strongly depends on local contaminant composition and operational conditions [36]. Table 6 provides a comparative assessment of each evaluated method against the contaminant categories identified in Section 5.1.

Table 6. Comparative assessment of the evaluated method.

Method	Microbial Reduction	Hardness Reduction	Heavy Metal Removal	SO_4^{2-}/Cl^- Removal	Relative Cost	Recommended Application
Boiling only	High	Partial (temporary)	None	None	Low	Emergency microbial disinfection only
Boiling and Na_2CO_3	High	High (temporary)	Low	None	Low	Softening for laundry/hygiene
$KMnO_4$ + boiling	Very High	Partial	Moderate	None	Low	Oxidation of organic pollutants and Iron
Shungite filtration	Low	None	Moderate	None	Low	Supplementary sorption of organic pollutants/metals
Four-stage protocol (Table 3)	Very high	High	High	None	Low	Recommended for comprehensive household treatment
UV disinfection	High	None	None	None	Medium/High	Microbial safety (requires clear water)
Reverse osmosis (RO)	Very high	High	High	High	High	Optimal but cost/energy intensive

Notes: Qualitative descriptors ("High", "Moderate", "None") are based on relative comparison of parameter exceedance with respect to drinking water standards and supported by literature data on typical concentration ranges in contaminated water sources. "High" indicates significant exceedance of recommended limits, "Moderate" indicates partial exceedance or borderline values, and "None" indicates compliance with drinking water standards.

The four-stage protocol emerges as the most balanced option for Mykolaiv households, offering significant improvement in microbial safety, organic load, iron, and temporary hardness at low cost and with moderate operational complexity. Its primary limitation, the inability to remove sulfates and chlorides, is shared by all non-membrane methods. For households with access to electricity and financial resources, reverse osmosis provides the most comprehensive solution, albeit with higher water wastage and maintenance requirements.

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These findings are generally consistent with previous reports indicating that household-level treatment systems are effective primarily for microbial reduction and partial removal of selected contaminants, while highly dissolved salts and mineralization remain difficult to address without membrane-based technologies [13,14,36].

The findings of this evaluation have direct implications for household water management in Mykolaiv and similar conflict-affected urban settings:

Immediate recommendation: The four-stage protocol (Table 3) is suitable for improving water quality for hygiene, dishwashing, and laundry. For drinking purposes, users should be aware of residual sulfate and chloride levels; where possible, blending with purchased low-mineral water or use of a point-of-use RO device is advisable.

Cost-effectiveness: The total cost of the basic reagent set (excluding the optional silver ionizer) is approximately €20 (≈1000 UAH) and is sufficient to treat several hundred liters of water, offering substantial savings compared to continuous bottled water purchases. For comparison, a standard 1.5 L bottle of commercial bottled water costs approximately €0.40 (≈22.5 UAH), which may represent a considerable long-term financial burden for households under prolonged infrastructure disruption.

Safety considerations: Proper execution of the protocol, particularly the complete reduction in residual permanganate with H_2O_2 and adequate filtration of MnO_2 precipitate, is essential to avoid manganese ingestion. The optional use of a silver ionizer or thyme tincture provides residual bacteriostatic protection during storage.

Limitations: The protocol does not desalinate water. In areas where raw water total dissolved solids exceed 1500 mg/L or where sulfate/chloride concentrations are acutely elevated, additional treatment (e.g., RO or blending) is required to meet drinking water standards.

In summary, the evaluated household-level methods offer a pragmatic interim solution for improving water usability under infrastructure disruption. The four-stage protocol, in particular, provides a scientifically grounded, low-cost approach that addresses the majority of contaminants identified in Mykolaiv, with performance validated through controlled experimentation.

6.3. Long-Term and Sustainable Solutions

The results presented in this study are based on a limited sampling design, consisting of four sampling points collected during a single emergency sampling campaign. Therefore, the findings should be interpreted as a case-based assessment reflecting water quality conditions under specific infrastructure-disruption circumstances, rather than as a comprehensive characterization of urban-scale water quality variability.

Temporal fluctuations, seasonal variability, and broader spatial heterogeneity across the city were not captured within the scope of this study. This limitation is directly related to the emergency and conflict-related context in which the study was conducted. Nevertheless, the obtained results provide a valuable snapshot of water quality under conditions of severe supply disruption and support the evaluation of practical, low-cost household-level treatment approaches.

To achieve a long-term improvement in water quality under conditions of persistent infrastructural limitations, the implementation of more advanced treatment solutions becomes necessary. Such approaches extend beyond household-level interventions and address water safety at the community or municipal scale:

- Mobile treatment units: Mobile water purification systems designed to process large volumes of water can serve as an effective intermediate solution at the community level. These units are capable of combining filtration and desalination processes to produce water suitable for consumption. Their modular design allows rapid deployment and flexible operation; however, their effectiveness depends on logistical coordination, technical maintenance, and sustained operational support.

- Desalination plants: In regions where elevated salinity constitutes a dominant water-quality challenge, desalination represents a technically viable option for producing potable water. While this technology requires substantial financial investment and ongoing maintenance, large-scale desalination facilities may provide a stable and controllable source of drinking water if integrated into broader water management strategies. The feasibility of such systems depends on infrastructure capacity, energy availability, and long-term operational planning.
- Community-based filtration systems: Decentralized filtration stations installed at the neighborhood level offer an alternative approach to improving access to safer water. Systems equipped with multi-layer sand filters and activated carbon can effectively reduce suspended solids, organic contaminants, and certain dissolved compounds. When connected to local groundwater sources, these installations can function as sustainable, low-maintenance solutions that complement centralized water supply networks.

7. Conclusions and Practical Implications

Using the case study of water conditions in Mykolaiv, the feasibility of applying adaptable and economically viable water purification strategies capable of functioning under conditions of sustained infrastructural stress was demonstrated. The results indicate that some of the analyzed samples exhibited elevated mineralization and episodic microbiological contamination.

It was further shown that, in the absence of centralized or systematic water treatment, short-term household-level practices such as thermal treatment and basic chemical disinfection can play an important role in reducing acute microbiological risks and limiting immediate exposure. However, these approaches are inherently limited in their capacity to address persistent chemical contamination, elevated mineralization, and system-wide degradation.

The study also provides practical recommendations that can be implemented by the population to improve water quality under conditions where systemic treatment is unavailable, allowing water to be used at least for technical purposes during periods of infrastructural disruption.

Beyond its local relevance, the situation analyzed in this study offers broader insights into the vulnerabilities of urban water systems exposed to extreme operational stress. The observed patterns of contamination, system degradation, and reliance on interim solutions are likely to be replicated in other regions facing similar constraints. Therefore, the conclusions drawn from the Mykolaiv case may serve as a practical reference for the development of flexible, multi-level water management frameworks aimed at safeguarding water quality and availability in similarly affected urban environments.

Based on the findings of this study, a set of practical recommendations can be formulated to support water management and public health protection under conditions of infrastructure disruption:

- Immediate Measures: It is recommended to ensure the wide availability of household water-purification agents, including chlorine-based disinfectants and purification tablets, in areas experiencing reduced water quality. Clear guidance on their correct and safe use should be provided, alongside general information on the effectiveness of thermal treatment methods such as boiling under conditions of elevated contamination risk.
- Expansion of Mobile Treatment Capacity: The deployment of mobile water-treatment units should be intensified to improve spatial coverage and continuity of supply.

These systems should be equipped with advanced filtration and, where necessary, desalination technologies to address elevated salinity and chemical contamination in raw water sources.

- Development of Community-Level Filtration Infrastructure: The establishment of decentralized, neighborhood-based filtration points is recommended as a sustainable intermediate solution. Systems based on sand and activated-carbon filtration, supported by routine technical maintenance, can improve access to safer water while reducing dependence on centralized distribution networks.
- International Technical and Financial Cooperation: Long-term stabilization of water supply systems requires external technical expertise and financial resources. Cooperation with international partners is recommended to support infrastructure upgrades, including the rehabilitation of groundwater wells and the implementation of large-scale treatment facilities. Such initiatives should prioritize technical feasibility, operational sustainability, and long-term maintenance capacity.
- Public Health Surveillance: Continuous monitoring of public-health indicators related to water quality is essential. Systematic surveillance enables early identification of potential waterborne health risks and supports timely intervention, particularly in densely populated urban areas.
- Research and Technological Development: Further research into low-cost, easily deployable water-treatment technologies is strongly encouraged. Particular attention should be given to modular systems, portable UV-based solutions, and other scalable technologies that can be adapted to household and community use under conditions of limited infrastructure availability.

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