

# Epidemiology of Parasitic Contamination in Ship Wastewater: A Cross-Sectional Study in Black Sea Ports

Mykola **Kucherenko**<sup>1\*</sup>, Lina **Kovalchuk**<sup>1</sup>, Elena **Bobro**<sup>2</sup>, Oleksandr **Oslavskiy**<sup>2</sup>, Tatyana **Oslavskaya**<sup>2</sup>, Igor **Romanenko**<sup>3</sup>, Iryna **Romanenko**<sup>4</sup>, Kira **Kompaniiets**<sup>5</sup>, Inna **Kovalova**<sup>6</sup>

<sup>1</sup>International Humanitarian University, Odessa, Ukraine.

<sup>2</sup>State Institution "South Ukrainian National Pedagogical University named after K. D. Ushynsky", Odessa, Ukraine.

<sup>3</sup>Ukrainian Scientific and Practical Center for Endocrine Surgery, Transplantation of Endocrine Organs and Tissues of the Ministry of Health of Ukraine, Kyiv, Ukraine.

<sup>4</sup>Lugansk State Medical University, Rubizhne, Ukraine.

<sup>5</sup>Kharkiv National Medical University, Kharkiv, Ukraine.

<sup>6</sup>National Medical University named after O.O. Bohomolets, Kyiv, Ukraine.

## ABSTRACT

**Introduction:** The impact of seawater on freshwater systems is well known. However, its role in the transmission of human diseases has not been sufficiently studied. Marine vessels entering tropical countries annually discharge thousands of tons of wastewater into water bodies. Although most vessels are equipped with wastewater treatment plants (WWTPs), the lack of regulations governing parasitological control creates significant risks of contamination of water bodies with pathogens causing parasitic diseases.

**Methods:** Between 2006 and 2011, 489 wastewater samples from WWTP-treated vessels arriving at Black Sea ports in Ukraine from parasitic disease-endemic tropical regions were collected. The samples were analyzed for the presence of tropical helminths and for compliance with the "State Sanitary Rules and Norms for the Discharge of Waste, Oil, Ballast Water and Garbage from Ships into Water Bodies" (July 9, 1997, No. 199). Sampling was conducted in accordance with the guidelines of the U.S. Environmental Protection Agency (U.S. EPA Guidance for Sampling and Analysis of Sludge for POTW Facilities, EPA/833/B-89/100). Wastewater analysis was carried out according to the "Standard Methods for the Examination of Water and Wastewater" (APHA, 1995), ecological standards, and technologies of the U.S. EPA — Control of Pathogens and Vector Attraction in Sewage Sludge, as well as the U.S. EPA guidance on the sampling and analysis of POTW sludge.

**Results:** The study results showed that 36.2% (95% CI: 36.1%–36.3%) of the wastewater samples did not meet bacteriological standards, 39.9% (95% CI: 39.8%–40.0%) did not meet chemical standards, and 32.5% (95% CI: 32.4%–32.6%) of the wastewater samples were contaminated with parasite eggs and cysts.

**Conclusion:** It has been demonstrated for the first time that the WWTPs of marine vessels arriving from tropical regions, which do not ensure the deworming of wastewater, pose a potential health risk to populations living in coastal areas.

**Key words:** Parasites; Contamination; Endemic; Marine vessel; Wastewater treatment plant

**\*Corresponding Author:**  
[dochnikolask@gmail.com](mailto:dochnikolask@gmail.com)



## INTRODUCTION

**A**nthropogenic pollution of seas and oceans poses a serious threat to the health of people living in coastal areas of maritime states. Pollutants enter water bodies not only from land-based sources but also from marine vessels.

Even after treatment in shipboard WWTPs, wastewater often contains pathogenic microorganisms and chemicals that are hazardous to human health.<sup>1-4</sup> It is known that global warming has numerous consequences for entire communities of organisms living both in the world ocean and on land. The rise in environmental temperature also favors the reproduction and completion of the life cycle of parasites.<sup>5-6</sup> Despite the growth of maritime trade and the global spread of diseases, very few epidemiological studies have assessed the risk of parasitic transmission through ship wastewater to date. Some parasites found in marine and coastal animals can infect humans, creating significant health risks. Parasites affect various hosts, including crabs, marine and freshwater fish. Roundworms are known to infect marine fish worldwide, while tapeworms are found on land, in oceans, and in freshwater bodies.<sup>7-8</sup> Helminthiasis are the most common parasitic diseases in humans.<sup>9</sup> About 300 species of helminths that cause diseases in humans are known, and 30 of them are found in Ukraine. The relevance of the helminthiasis problem is related to their widespread distribution, severe consequences for humans, the polymorphism of clinical manifestations that complicate diagnosis, immune suppression, and the lack of specific preventive methods. According to the WHO, around 4.5 billion people worldwide are infected with various parasites, including helminths. In Ukraine, 400,000 to 600,000 cases of helminthiasis are officially registered annually. At the same time, the total incidence of parasitic diseases is ten times higher than that of acute intestinal infections. Currently, helminthiasis has become one of the 'forgotten diseases'. Their medical and social significance is often underestimated.<sup>10-11</sup> The greatest diversity of human parasites is found on the Eurasian continent. Parasitic diseases are widespread not only in developing but also in economically developed countries. The most frequent transmission routes for parasitic diseases are alimentary, aspirational, and contact-domestic. The taxonomic distribution of etiological agents causing infectious and parasitic diseases in humans is presented in Figure 1.<sup>12</sup> 'Forgotten diseases' refer to a group of infectious and parasitic diseases primarily affecting the poorest communities in developing regions of Asia, Africa, Central and South America. The main list of WHO 'forgotten diseases' includes 17 human diseases with the highest prevalence, seven of which are caused by parasitic worms, three by protozoan parasites, and three by bacteria. Another twenty diseases are caused by fungi, viruses, and ectoparasites. 'Forgotten diseases' are contrasted with the 'three great killers' – AIDS, tuberculosis, and malaria.<sup>13-16</sup> According to the WHO, approximately every second person on the planet becomes infected with one of the three main types of helminths each year (enterobiasis – 1.2 billion people, hookworm – 900 million, and trichuriasis – up to 700 million). Parasitic diseases are especially widespread in tropical countries. For example, schistosomiasis is endemic in 74 countries, affecting about 207 million people, with around 700 million people at risk of infection.<sup>17-18</sup> Cysts of pathogenic protozoa also represent a serious epidemic threat. They can remain viable in coastal seawater for more than two months and play a significant role in the spread of intestinal protozoan invasions. *Giardia lamblia* cysts can remain viable in cold water for several months and are resistant to chlorine and ozonation. *Entamoeba*

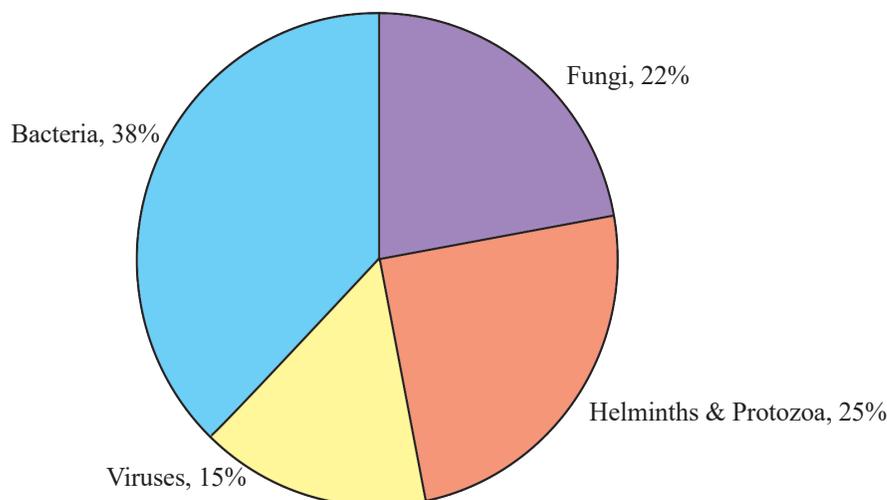


Figure 1. Taxonomic distribution of etiological agents causing infectious diseases in humans.<sup>12</sup>

histolytica is the second leading cause of death from parasitic infections worldwide. Eggs of *Ascaris lumbricoides* can remain pathogenic in the environment for up to 7 years or more. Approximately 95% of cutaneous leishmaniasis cases occur in countries in the Americas, the Mediterranean, the Middle East, and Central Asia. Experts estimate the annual number of new cases of this disease to be between 600,000 and 1 million, although the WHO reports only about 200,000 cases.<sup>19-21</sup> The sand on beaches constantly contains both symbiotic and pathogenic microorganisms, including staphylococci, *Escherichia coli*, enterobacteria, parasites, fungi, and viruses. Eggs of geohelminths found in beach sand and coastal soils develop into invasive larvae and remain viable for 17 months, while in seawater, they remain viable for more than 20 months, developing into larvae during the two summer months. People can become infected by swimming in any open water bodies. The tropical climate has a significant impact on the development of parasites.<sup>22-23</sup> It is no coincidence that parasitic diseases are attracting so much attention today. Their spread against the backdrop of global warming increases exponentially each year. At the same time, ships visiting tropical regions that discharge inadequately treated wastewater can contribute to the pollution of marine waters and coastal soils in maritime states with various pathogens, including parasites. It is known that the effectiveness of wastewater treatment by ship WWTPs is 80–85%.<sup>24-25</sup> Existing methods of disinfecting ship wastewater include ultraviolet radiation, ozonation, and various disinfectants. Chlorine, for example, can suppress the growth of microorganisms but often does not kill them. Chlorine dioxide is an effective disinfectant against *Giardia* and *Cryptosporidium*, capable of inactivating about 90% of cysts and oocysts. Selective methods for removing parasites from ship wastewater are currently experimental.<sup>26-30</sup>

We hypothesize that the sewage treatment systems installed on maritime vessels do not effectively remove parasitic contamination, thereby creating environmental and sanitary hazards, as well as health risks – especially when these vessels visit tropical countries where parasitic diseases are endemic.

The use of a cross-sectional study to assess the prevalence of parasites and analyze the risk factors of coastal contamination by sewage from vessels arriving from tropical countries is justified in terms of methodology, timeliness, and its ability to identify pressing issues that require immediate attention

in the fields of environmental protection and public health.

## METHODS

Between 2006 and 2011, a total of 489 wastewater samples treated in shipboard WWTPs were collected from vessels arriving at the Black Sea ports of Ukraine from tropical countries endemic for parasitic diseases. Of these, 163 samples were analyzed for compliance with bacteriological standards, 163 samples for chemical standards, and 163 samples for the presence of tropical helminths.

The samples collected consisted of numerous temporary subsamples from the WWTPs studied, which were combined into overall representative samples in accordance with the standards of 40 CFR Part 503.8, Appendix I - Test Method for Detecting, Enumerating, and Determining the Viability of *Ascaris ova* in Sludge, US EPA Environmental Regulations and Technology – Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage).<sup>31</sup>

Sampling was conducted at each vessel's WWTP in accordance with the U.S. Environmental Protection Agency's POTW Sediment Sampling and Analysis manual. EPA/833/B-89/100, US Environmental Protection Agency during 2006–2011 immediately upon the arrival of ships at the Black Sea ports of Ukraine.<sup>32</sup>

For each of the 489 wastewater samples treated at the ship's WWTP and submitted to the laboratory for analysis, composite samples were manually collected over a 5-day period during the vessel's stay in port to account for minor variations.

Effluent samples from onboard WWTPs were collected in 4 L sterile plastic bottles according to APHA 1995 standard methods.<sup>33</sup> All samples were delivered to the laboratory immediately after collection in thermally insulated containers, maintaining a temperature of 10 to 12°C. Samples were stored in a cold room (temperature 7°C ± 2°C) and analyzed within 24 hours from the moment of collection. Accordingly, control wastewater samples were sealed and left on the surveyed vessels for alternative studies.

### Three methods were used to analyze wastewater samples and detect parasitic contamination:

#### 1. A. Direct microscopy of a wastewater smear

With this method, wastewater samples were examined directly under a microscope without any pre-treatment.

#### 2. B. Waste water concentration method

This method was applied in several steps: a 4 L sample of wastewater was filtered using a Buchner funnel, a Bunsen flask and filter paper with a diameter 1-2 mm smaller than the diameter of the

funnel, connected to a vacuum pump. The sample was filtered, then the filter was dried. The dried filter was transferred to the side wall of a 200 ml beaker and washed repeatedly with a few milliliters of sterile distilled water. The solution obtained after washing was centrifuged at a speed of 2000 rpm. within 10 min. using 15 ml centrifuge tubes. The supernatant was discarded and the sediment was collected. One drop of sediment was placed in the center of the slide and covered with a coverslip. The resulting slide was studied under a light microscope with a magnification of 100x-200x. The sediment was stored in a labeled tube with a snap cap for staining and further examination.

The presence of intestinal helminth eggs was confirmed based on microscopic observations (magnification 100x-200x), and the viability of isolated eggs was assessed based on the results of incubation of filters in a humid chamber at 27°C ( $\pm 2^\circ\text{C}$ ) and periodic observations under a microscope with a magnification of 100x-200x at intervals 3-4 days for 3-4 weeks. Eggs from samples in which mobile larvae developed without deformation after the incubation period were considered viable.

### 3. C. Staining Technique

In the present study, Ziehl-Neelsen, Romanovsky-Giemsa staining was used.

Wastewater samples were collected from all listed vessels in the presence of the chief engineer. Control samples were sealed and, along with the sampling record signed by the chief engineer and the ship's captain, were left on board for alternative testing.

All wastewater samples were collected using the same methods and analyzed in the accredited laboratories of the State Sanitary and Epidemiological Service of Ukraine for water transport.

Wastewater samples were collected according to the vessels' arrival dates at the Black Sea ports of Ukraine, with records of vessel names, flags, and home ports.

No discrepancies were found in the laboratory test results, and no re-examination of control samples was conducted at the request of the ship captains. The results of the wastewater laboratory analyses, along with recommendations for addressing regulatory non-compliance, were conveyed to the captains of the inspected vessels.

According to official statistics, an analysis of infectious and parasitic disease incidence among the populations of the Black Sea coastal cities was conducted for the period from 2006 to 2011.

All sections of the manuscript have been reviewed using the STROBE checklist.

The design of the conducted study is a cross-sectional type, justified in terms of methodology, timeliness, and its ability to identify pressing issues that require immediate attention in the fields of environmental protection and public health.

An evaluation of potential bias and handling of missing data was conducted:

Potential bias was assessed by comparing the characteristics of the included vessels with the overall

fleet, as well as by verifying the uniformity of sampling conditions and laboratory analysis. Standard protocols were employed to minimize operational and selection bias, including strict adherence to storage and transportation conditions for the samples.

No missing data were identified during the study. This ensured the preservation of the statistical power of the analysis and facilitated accurate interpretation of the results.

All vessels arriving at Ukrainian Black Sea ports from tropical countries endemic for parasitic diseases were inspected for the presence of certified sewage treatment systems. No instances of discrepancies between the ship documentation and the actual condition of the onboard systems, or any other distorting factors, were recorded.

For the purpose of conducting the study and collecting samples, all vessels arriving from tropical countries endemic for parasitic diseases that were equipped with certified sewage treatment systems were selected.

There was no data loss or issues with the laboratory analysis of the samples during the study.

Standardized protocols, validated methods, and calibration of the equipment used in the study were employed to minimize measurement error.

Table 1. Results of bacteriological, chemical, and parasitological analysis of wastewater samples treated at shipboard WWTPs on vessels arriving at the Black Sea ports of Ukraine from tropical countries endemic to parasitic diseases in 2006-2011.

N	Laboratory study	2006-2011										2006-2011	2006-2011			
		2006	2007	2008	2009	2010	2011	2006-2011	2006-2011							
		The number of surveyed vessels														
		The number of collected samples														
		The number of samples not meeting the standards														
		The number of collected samples														
		The number of samples not meeting the standards														
		The number of collected samples														
		The number of samples not meeting the standards														
		The number of collected samples														
		The number of samples not meeting the standards														
		The number of collected samples														
		The number of samples not meeting the standards														
		The total number of samples not meeting the standards														
		% ratio														
.1	Bacteriological	163	26	9	28	10	26	9	29	11	26	10	28	10	59	36,2
.2	Chemical	163	26	10	28	11	26	10	29	12	26	11	28	11	65	39,9
.3	Parazitological	163	26	8	28	9	26	8	29	10	26	9	28	9	53	32,5

## RESULTS

The results of parasitological analysis of wastewater samples, as well as their examination for compliance with the requirements of the "State Sanitary Rules and Norms for the Discharge of Waste, Oil, Ballast Water, and Garbage from Ships into Water Bodies" (dated 09.07.1997, No. 199), (34) are presented. These samples were collected from 163 ships, arriving from ports endemic to parasitic diseases in tropical countries to the Black Sea ports of Ukraine between 2006 and 2011. Laboratory studies showed that of all the wastewater samples from the mentioned vessels,  $36.2\% \pm 0.1\%$  did not meet bacteriological standards, and  $39.9\% \pm 0.1\%$  of the samples did not meet chemical standards. At the same time,  $32.5\% \pm 0.1\%$  of the wastewater samples were contaminated with parasite eggs and cysts. The results are presented in Table 1. The relationship between bacterial and parasitic contamination and non-standard chemical indicators of treatment are presented in Figure 2.

Brief results of the multivariate logistic regression analysis for vessels that visited tropical countries endemic for parasitic diseases have been added. The analysis aimed to assess the impact of water treatment quality parameters on the likelihood of detecting parasitic contamination in sewage samples. The results are presented in Table 2.

Table 2. Regression Analysis Results

Variable	$\beta$ (coefficient)	SE	OR (95% CI)	p-value
Bacteriological noncompliance	0,850	0,180	2,34 (1,56-3,50)	<0,001
Chemical noncompliance	0,720	0,170	2,05 (1,40-3,00)	<0,001
Outdated treatment system	0,680	0,160	1,98 (1,40-2,80)	<0,001
Constant	-1,95	0,50	-	<0,001

Interpretation of results: Violation of bacteriological standards increases the probability of detecting parasitic contamination by 2.34 times (OR = 2.34,  $p < 0.001$ ), chemical standard violations by 2.05 times (OR = 2.05,  $p < 0.001$ ), and deviations in treatment system performance by nearly 2 times (OR = 1.98,  $p < 0.001$ ).

The reported effect size measures (OR, RR, 95% CI) confirm that noncompliance with standards significantly elevates the risk of parasitic contamination in wastewater samples.

The types of parasites found in the collected wastewater samples and identified using three research methods (direct smear, concentration, and staining) are presented in Table 3.

During the research period from 2006 to 2011, according to official statistics, the incidence of helminthiasis among the population of Black Sea cities in Ukraine was  $312.4 \pm 0.2$  cases per 100,000 people. The incidence of protozoan infections during this period was  $30.2 \pm 0.2$  cases per 100,000 people. The results of the conducted studies were processed using correlation-regression analysis. (35) A review of specialized literature on human parasitology was conducted, and the incidence of parasitic infections and protozoan diseases, as well as global trends in the spread of parasitic diseases

and the preventive measures employed, were analyzed. Technologies for treating ship wastewater, disinfection methods capable of destroying the causative agents of parasitic diseases and their cysts,

Table 3. Types of parasites found in wastewater samples after treatment at shipboard WWTPs on vessels arriving at the Black Sea ports of Ukraine from tropical countries endemic to parasitic diseases in 2006-2011.

Sample No.	Type of parasite						
	Trichocephalus trichiurus (eggs)	Entamoeba (cysts)	Cryptosporidium parvum (cysts)	Lambliia intestinalis (cysts)	Strongyloides stercoralis (eggs)	Ascaris lumbricoides (eggs)	Enterobius vermicularis (eggs)
1	2						2
2		2		3		3	
3	1			2			1
4		3			1	2	
5	1		1			3	
6			1	3		2	
7		3			2	2	
8	2			1		3	
9			3				2
10		3	2			1	
11		2		3	4		1
12	3			1		4	
13		3	4				3
14			2		1	1	
15		2		4	1		1
16			3			4	
17			2		2		1
18		3				3	
19			a lot		1		3
20	3						5 (inside eggs - live larvae, 5 - 10/l)
21			4			1	
22		4		3		viable, fertilized and unfertilized 5-6/l	
23		3 (1-2 nuclear cysts)					1
24		4 (many 1-2 nuclear cysts)		2	2		3
25	1			2			1
26		2		4	1		1
27	1		1			3	
28	3			1		4	
29			1	3		2	
30			a lot		1		3
31		2		4	1		1
32	3			1		4	
33	3						5 (inside eggs - live larvae, 5 - 10/l)
34		3	4				3
35		3 (1-2 nuclear cysts)					1
36		3				3	
37		2		3	4		1
38	1			2			1

Table 3 continued.

Sample No.	Type of parasite						
	Trichocephalus trichiurus (eggs)	Entamoeba (cysts)	Cryptosporidium parvum (cysts)	Lambliia intestinalis (cysts)	Strongyloides stercoralis (eggs)	Ascaris lumbricoides (eggs)	Enterobius vermicularis (eggs)
39			2		2		1
40		4		3		viable, fertilized and unfertilized 5-6/1	
41			4			1	
42	2						2
43		3 (1-2 nuclear cysts)					1
44	2			1		3	
45	3						5 (inside eggs - live larvae, 5 - 10/1)
46		2		4	1		1
47	2			1		3	
48		3	4				3
49			a lot		1		3
50	1		1			3	
51		3 (1-2 nuclear cysts)					1
52		4		3		viable, fertilized and unfertilized 5-6/1	
53	3			1		4	

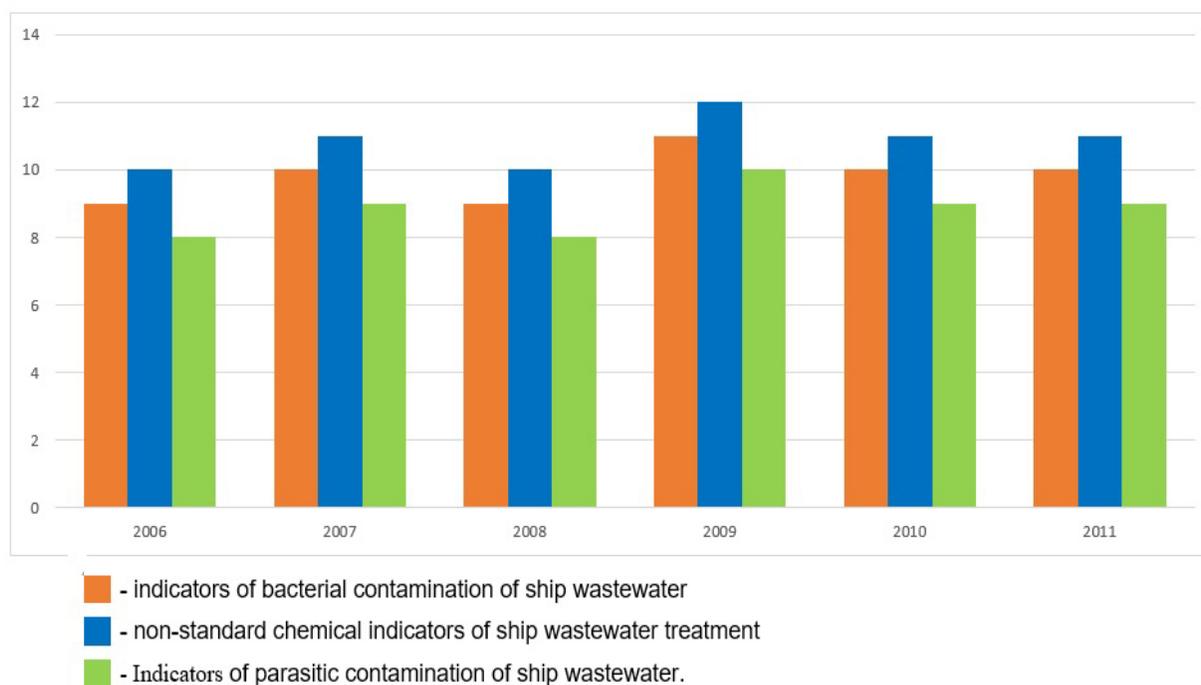


Figure 2. The relations between bacterial and parasitic contamination and non-standard chemical indicators of treatment based on laboratory research results of ship wastewater from to 2011

and methods for their selective removal were examined.

## DISCUSSION

The conceptual idea for this study was formed as a result of years of practical experience working with vessels in Black Sea ports, medical practice onboard ships visiting ports in tropical countries, and interactions with ship administrations and representatives of shipping companies. This experience enabled an examination of the issue of aquatic ecosystem pollution by dangerous parasites, protozoa, other pathogens, and microorganisms from an epidemiological, sanitary-hygienic, and parasitological perspective.

The authors selected the period from 2006 to 2011 for this study, as it represents the period of highest shipping intensity and cargo turnover with tropical regions over the past 20 years. The study addresses one of the most pressing issues in sanitary safety, environmental sustainability, and public health protection.

During the study, wastewater samples from 163 vessels arriving from ports in tropical regions endemic for parasitic diseases were analyzed. One of the most alarming findings was the detection of parasite eggs and cysts in 32.5% of the wastewater samples examined. The identified parasites are causative agents of various diseases, which may pose serious risks to the health of populations in the coastal regions of maritime countries.

It is important to note that parasite cysts and eggs exhibit high resistance to external environmental conditions and can persist in water bodies for extended periods, posing a threat to anyone who comes into contact with contaminated water.

The studies revealed that 36.2% of the wastewater samples did not meet bacteriological standards, and 39.9% did not comply with chemical norms, which also raises concerns regarding sanitary safety.

The authors analyzed the materials from a sanitary and epidemiological survey of 2,171 foreign vessels with a total crew of 44,380 people that visited the Black Sea ports of Ukraine during 2009–2010, the period of the most intensive navigation in recent years. On these vessels, wastewater treatment plants (WWTP) were examined for compliance with operational standards, and wastewater samples were collected for laboratory analysis in accordance with regulatory requirements.

The findings of this study were previously published in the article *Biosecurity of Marine Vessels: Current Trends and Prospects* (Kucherenko et al., *International Maritime Health*, Vol. 74, No. 2, June 2023, pp. 98–104).<sup>36</sup> In addition, the authors reviewed data<sup>37</sup> from similar studies on this issue carried out by international experts during various time periods, allowing for a broader comparative analysis of global trends and challenges in maritime biosecurity.<sup>37-39</sup>

## Causal Relationships

The study found strong associations between breaches of bacteriological and chemical standards, inadequate treatment systems, and parasitic contamination. These findings suggest that deficiencies in treatment processes may contribute to contamination, but further research is required to confirm direct causality.

## Potential Systematic Errors

**Sample Selection:** Vessels were exclusively selected from tropical countries endemic for parasitic diseases, introducing potential selection bias.

**Measurement Error:** Sampling followed U.S. EPA guidelines and wastewater analysis was conducted using APHA Standard Methods (1995) and EPA protocols. No laboratory or methodological errors were observed (information bias).

**Incomplete Control of Confounding Factors:** Unaccounted variables (e.g., seasonality, vessel routes, operational conditions) are unlikely to significantly affect the results (confounding bias).

Thus, despite significant associations, further research is needed to interpret causal relationships and account for potential systematic errors when generalizing the findings.

Measurement error in epidemiological studies can arise due to inaccuracies in laboratory methods used to assess vessel wastewater contamination. The main factors affecting measurement quality include sensitivity and specificity, systematic measurement error, and random errors.

Considering the possible measurement errors listed above, standardized protocols, validated methods, and calibration of the equipment used were employed to minimize measurement error during this study.

Studies have shown that wastewater treated on shipboard treatment systems consistently fails to meet regulatory requirements. Sanitary and environmental services in Ukraine and other maritime states do not have statistical data on the parasitological contamination of ship wastewater. In Ukraine, there is a complete lack of parasitological control over the discharge of ship wastewater, and the supervision of recreational areas is ineffective.

Neither Ukrainian nor international regulatory documents address the issue of parasitological contamination of marine and coastal zones.

The results of the conducted study confirm the existing risks of potential impact of ship wastewater on the health of populations in coastal areas of maritime countries.

The recorded cases of helminthiasis and protozoan infections in the Black Sea region from 2006 to 2011 indicate a significant prevalence of parasitic diseases, which is due to both internal sources of infection and external factors. Given that a significant portion of wastewater entering the Black Sea comes from vessels arriving from endemic regions, this study confirms the need for strict monitoring and improvement of ship wastewater treatment systems, with a focus on their effectiveness in eliminating the causative agents of parasitic diseases.

Based on the study, the following policy recommendations are proposed to control wastewater contamination from vessels visiting tropical regions endemic for parasitic diseases:

1. Tighten wastewater treatment standards and regularly assess treatment efficiency with modern, high-sensitivity laboratory methods.
2. Enhance monitoring by using molecular and microbiological diagnostics and establish international databases to track contamination and pathogen spread.
3. Develop effective protocols for disinfecting wastewater prior to discharge, with mandatory multi-stage treatment in endemic areas.
4. Incorporate the risks of bacterial and chemical contamination into global regulatory frameworks such as MARPOL and WHO guidelines.
5. Implement training programs for ship crews on safe wastewater disposal and raise awareness among shipowners and port services about contamination risks.

These measures will help reduce the spread of infections through the marine environment and improve sanitary and epidemiological conditions in coastal areas.

## CONCLUSION

For the first time, the process of wastewater treatment on shipboard WWTPs was investigated using parasitological laboratory methods aboard 163 marine vessels arriving at the Black Sea ports of Ukraine from tropical countries endemic for parasitic diseases during the period from 2006 to 2011. The results showed that more than 36% of wastewater samples treated on shipboard WWTPs did not meet bacteriological standards, and nearly 40% of the samples did not comply with chemical norms. At the same time, 32.5% of the wastewater samples examined were contaminated with parasite eggs and cysts.

A correlation was established between bacteriological and parasitological contamination of wastewater and non-compliance with chemical treatment standards, indicating the inefficiency of disinfection processes on the examined shipboard WWTP installations. In contrast, no parasite eggs or cysts were detected in samples that met the regulatory requirements for both bacteriological and chemical parameters. The parasite eggs and cysts detected in the wastewater of these vessels may serve as a source of dangerous parasitic diseases for individuals coming into contact with contaminated water in coastal areas of Ukraine and other maritime states.

The incidence rates of helminthiasis and protozoan infections among the population of the Black Sea region of Ukraine from 2006 to 2011, which exceed the national averages for Ukraine, indicate an increased risk of parasitic infections. This situation may be associated with the contamination

of wastewater by the pathogens causing parasitic diseases and their cysts, as well as with other ecological and sanitary factors.

The study indicates potential epidemiological risks associated with vessels arriving from tropical countries not only to the Black Sea ports of Ukraine but also to other maritime ports. The results confirm the relevance of further investigating wastewater treatment and disinfection technologies, as well as methods for the selective removal of parasites (their cysts and eggs) from wastewater after treatment on shipboard WWTPs.

An analysis of global trends in parasitic disease spread underscores the importance of enhancing the sanitary and epidemiological safety of marine vessels. The evaluation of the data indicates the need for continued research in this area and the implementation of comprehensive measures in marine medical and sanitary practice at the legislative level.

Long-term planning and support for infection prevention programs, combined with accurate and timely reporting, will help detect parasitic diseases not only in tropical regions but also in developed countries of Europe and America.

### **Conflict of interest**

The authors declare no conflict of interests.

### **ACKNOWLEDGEMENTS**

The authors express their gratitude to the captains of foreign vessels, ship mechanics, port service personnel who assisted in conducting surveys on ships in the Black Sea ports of Ukraine, employees of the Sanitary and Epidemiological Service, laboratory specialists, and other departmental organizations.

### **REFERENCES**

1. The Biology of Parasites. Richard Lucius, Brigitte Loos-Frank, Richard P. Lane, Robert Poulin, Craig Roberts, Richard K. Grensis. John Wiley & Sons. 2017. – 472 p.
2. A Century of Parasitology: Discoveries, Ideas and Lessons Learned by Scientists Who Published in The Journal of Parasitology, 1914 – 2014. John Janovy, Jr., Gerald W. Esch, John Wiley & Sons. – 2016. – 376 p.
3. Ecological Parasitology: Reflections on 50 Years of Research in Aquatic Ecosystems. Gerald W. Esch, John Wiley & Sons. - 2015. - 200 p.

4. A Functional Biology of Parasitism: Ecological and evolutionary implications. G.W. Esch, J.C. Fernandez. Springer Science & Business Media. 2013 – 337 p.
5. Traill LW, Lim ML, Sodhi NS, Bradshaw CJ. Mechanisms driving change: altered species interactions and ecosystem function through global warming. *J Anim Ecol.* 2010; 79:937–947.
6. Esch. GW. *Parasite Communities: Patterns and Processes.* Springer Science & Business Media. - – 335 p. London, England ; New York, New York: London, England ; New York, New York : Chapman and Hall; 2012.
7. Rhode Klaus. *Marine parasitology.* CABI, New York. 2005 – 592 p.
8. *Parasites in Marine Systems.* R. Poulin, Leslie H. Chappell. Cambridge University Press, 2002 – 207 p.
9. Efstratiou A, Ongerth JE, Karanis P. Waterborne transmission of protozoan parasites: review of worldwide outbreaks—an update 2011–2015. *Water Research.* 2017; 114:14–22. 10.1016/j.watres.2017.01.036.
10. Human Helminthiasis. Luis Rodrigo. Published February 15th, 2017.158 p. DOI 10.5772/62673.
11. Protozoan infestations. Helminthiasis: a study guide for candidates for the degree of doctor of philosophy at the third educational and scientific level / O. V. Ryabokon, N. S. Ushenina, O. O. Furyk, D. A. Zadyrak, T.E. Onishchenko - Zaporizhzhia: [ZD. .
12. S. Cleaveland, M.K. Laurenson, L.H. Taylor. Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence. *Phil Trans R Soc Lond B,* 356 (2001), pp. 991-999.
13. Souza AA, Ducker C, Argaw D et al. Diagnostics and the neglected tropical diseases roadmap: setting the agenda for 2030. *Trans R Soc Trop Med Hyg.* 2021; 115: 129-135.
14. Feldmeier H, Heukelbach J, Ugbomoiko US, Sentongo E, Mbabazi P, Samson-Himmelstjerna G, Krantz I. Tungiasis—A Neglected Disease with Many Challenges for Global Public Health. *PLoS Negl Trop Dis.* 2014;8(10):e3133.
15. World Health Organization. *Sustaining the Drive to Overcome the Global Impact of Neglected Diseases: Second WHO Report on Neglected Diseases.* Geneva, Switzerland: World Health Organization; 2013.
16. The Lancet Neglected tropical diseases: becoming less neglected. *Lancet.* 2014;383:1269.

17. Parasites and their vectors: A special focus on Southeast Asia. Yvonne Ai Lian Lim, Indra Vythilingam. Springer Science & Business Media. 2014 - 263 p.
18. EFSA Panel on Biological Hazards (BIOHAZ). Scientific opinion on risk assessment of parasites in fishery products. 2010. EFSA Journal. 2010; 8(1543): 91.
19. Studer A, Thieltges D, Poulin R. Parasites and global warming: net effects of temperature on an intertidal host–parasite system. *Mar Ecol Prog Ser.* 2010;415: 11–22.
20. Adekiya TA AROBOKKA. The effect of climate change and the snail-schistosome cycle in transmission and bio-control of schistosomiasis in Sub-Saharan Africa. *Int J Environ Res Public Health.* 2020; 17: 181.
21. Medical Parasitology: A Textbook. Rohela Mahmud, Yvonne Ai Lian Lim, Amirah Amir. Springer. 2018 – 191 p.
22. Lucy FE GTTLMAMD. Biomonitoring of surface and coastal water for *Cryptosporidium*, *Giardia*, and human-virulent microsporidia using molluscan shellfish. *Parasitol Res.* 2008;(103): 1369–1375.
23. Graczyk TK, Sunderland D, Awantang GN, Mashinski Y, Lucy FE, Graczyk Z, Chomicz L, Breyse PN. Relationships among bather density, levels of human waterborne pathogens, and fecal coliform counts in marine recreational beach water. 2010. *Parasitol Res.*
24. Biological and Chemical Wastewater Treatment. In book Edited by Mohamed Samer, Wastewater Treatment Engineering. Published October 14th, 2015, 212 p., ISBN 978-953-51-2179-4.
25. Pistocchi A, Andersen HR, Bertanza G, Brander A, Choubert JM, Cimbritz M, et al. Treatment of micropollutants in wastewater: Balancing effectiveness, costs and implications. *Science of The Total Environment.* 2022 Dec; 850.
26. JT P, Costa AO dOSM, W S, SC O, de Castro EA ea. Comparing the efficacy of chlorine, chlorine dioxide, and ozone in the inactivation of *Cryptosporidium parvum* in water from Parana State, Southern Brazil. *Biochemistry and Biotechnology.* 2008 June.
27. Sabbahi S, Ben Ayed L, Trad M, Berndtsson R, Karanis P. Parasitological Assessment of Sewage Sludge Samples for Potential Agricultural Reuse in Tunisia. *Int. J. Environ. Res. Public Health* 2022, 19, 1657. <https://doi.org/10.3390/ijerph1903165>. *International Journal of Environmental Research and Public Health.* 2022;(1657).
28. Folasade Esther Adeyemo, Gulshan Singh, Poovendhree Reddy, Supervision, Faizal Bux, Thor Axel Stenström, Adelaide Almeida. Efficiency of chlorine and UV in the inactivation of

Cryptosporidium and Giardia in wastewater. Published online 2019 May 13. do.

29. A.M. N. Removal of Cryptosporidium by wastewater treatment processes: a review. *Journal of water and health*. 2016;14(1):1–13. Epub 2016/02/04. 10.2166/wh.2015.131. *Journal of Water and Health*. 2016.
30. Landry FA, Aghaindum AG, Dennis AI, Nadège OT, Pierre. T. Evaluation of the efficiency of some disinfectants on the viability of *Hymenolepis nana* eggs isolated from wastewater and faecal sludge in Yaounde (Cameroon): importance of some abiotic variables. *Water Science & Technology*. 2021; 84(9): 2499-2518.
31. US EPA Environmental Regulations and Technology—Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage). Under 40 CFR Part 503. Appendix I—Test Method for Detecting, Enumerating, and Determining the Viability of Ascaris.
32. US EPA POTW sludge sampling and analysis guidance document. EPA/833/B-89/100 USEPAOoW(...; 1989. Available from:  
<https://www.epa.gov/biosolids/potw-sludge-sampling-and-analysis-guidance-document>.
33. APHA: Microbiological examination of water in: Standard Methods for the Examination of Water and Wastewater. 19<sup>a</sup> ed. Washington: APHA AW.; 1995.
34. State Sanitary Rules and Norms for the Discharge of Waste, Oil, Ballast Water, and Garbage from Ships into Water Bodies". Ukraine. 09.07.1997. 199.
35. Calder M. CC,CD,ea. Computational modelling for decision-making: where, why, what, who and how. *Royal Society Open Science*. 2018; 5(6) doi: 10.1098/rsos.172096.
36. Kucherenko M, Kovalchuk L, Strus O, Bobro E, Oslavskaya T, Oslavskiy O, et al. Biosafety of marine vessels: current trends and prospects. *International Maritime Health*. 2023 June; Vol.74(№2): 98-104.
37. Colford JM, Wade TJ, Schiff KC, Wright CC, Griffith JF, Sandhu SK, et al. Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. DOI: <https://doi.org/10.1097/01.ede.0000249425.32990.b9>. *Epidemiology*. 2007 January; 18(1): 27-35.
38. Nagata Y. Microbial Degradation of Xenobiotics. *Microorganisms*. 2020 April; 8(4): 487.
39. Thompson KA, Shimabuku KK, Kearns JP, Knappe DRU, Summers RS, Cook SM. Environmental comparison of biochar and activated carbon for tertiary wastewater treatment. *Environ. Sci. Technol.*, 50 (20) (2016). *Environmental Science & Technology*. 2016 September, 22; 50(20): p.p. 11253-11262.