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Wastewater pollution from cruise ships in coastal sea area of the Republic of Croatia

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ABSTRACT

Marine pollution from wastewater is a problem especially pronounced on large cruise ships. There is a great disproportion in quality of discharged wastewater directly related to the type of wastewater treatment system installed on cruise ships. To obtain exact empirical data case study was done which included one-year monitoring of cruise ships in the Adriatic Sea, their routes and retention times in defined navigation zones. The aim of this paper is to present data related to the coastal sea area of the Republic of Croatia and display results of marine pollution for that area. The scientific contribution of the research can be recognized in the evaluation of pollution of coastal areas in the Republic of Croatia in different scenarios of wastewater discharge and identification of gray water as a pollutant which is not recognized by the international legal regulations.

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1 Introduction

Previous studies in the world have proven that sanitary wastewater has negative impact on the marine environment. The problem is particularly pronounced on large cruise ships where the number of persons on board reaches 8000. To evaluate the contamination of a specific sea area with sanitary wastewater from cruise ships two original models have been developed: a model of movement of cruise ships in the Adriatic Sea [Perić, Komadina, Račić, 2016: 430] and evaluation model of sanitary wastewater pollution from cruise ships in the Adriatic sea [Perić, 2016: 54]. The purpose of this paper is to present the results of the pollution of coastal areas of Republic of Croatia for a period of one year provided with use of above models.

2 Research analyses

Detailed research of cruise ship traffic in the Adriatic sea was done by monitoring cruise ships in the Adriatic Sea in one year period (1.8.2014 – 31.7.2015) in which empirical data on the routes of the ships in the Adriatic and their retention times in MARPOL[1] Annex IV areas of limited wastewater discharges were obtained.

For the purpose of this scientific research paper empirical data on retention times in the coastal area of the Republic of Croatia was selected. Also, sanitary wastewater properties, international legal regulations and quality and quantity of generated wastewater on cruise ships were analyzed.

2.1 Wastewater on ships

Wastewater on cruise ships are generated in large quantities. Therefor, method of wastewater management on board and the quality of wastewater discharged into the sea is very important. Wastewater on ships can be divided into sanitary and bilge waste water. Sanitary wastewater, for more efficient treatment and disposal, are divided into black water and gray water. Blackwater or faecal wastewater comes from toilets and medical facility sinks. Gray water comes from cabin sinks and showers, laundering, galley sinks, air conditioning condensate, and salon sinks.

Black water may host many pathogens of concern to human health, including *Salmonella*, *shigella*, *hepatitis A* and *E*, and gastro-intestinal viruses. Sewage contamination in swimming areas and shellfish beds pose potential risks to human health and the environment by increasing the rate of waterborne illnesses [United States Environmental Protection Agency, 2008: 2–26].

[1] MARPOL is acronym for International Convention for the Prevention of Pollution from Ships

Table 1 Comparison of quality of discharged sanitary wastewater due to type of wastewater treatment system and their operation mode

Sanitary wastewater pollutants		MSD		AWT		Annex IV quality criteria for coastal sea area	
		Treated black water	Untreated gray water	Treated black and gray water	Partially treated black and gray water	For system installed prior to 1.1.2010	For system installed after 1.1.2010
Faecal Coliforms	FK/100 ml	2,040,000	36,000,000	14.5	25,500	250	100
BOD_5	mg/l	133	1,140	7.99	7.99	50	$25 \cdot Q_i/Q_e$*
TSS	mg/l	627	704	4.49	4.49	100	$35 \cdot Q_i/Q_e$*
Chlor residual	µg/l	1,070	372	338	338	/	0.5
* dilution compensation factor Q_i/Q_e is used to take account of dilution, where Q_i is influent, liquid containing sewage, gray water or other liquid streams and Q_e is effluent, treated wastewater produced by the sewage treatment plant.							

Source: data obtained from United States Environmental Protection Agency: Cruise Ship Discharge Assessment Report; IMO: 2012 Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants

Gray tank chemicals contain an array of pollutants from the highly chemical (bleach, strong acids from some cleaning products giving water high pH) or strong alkalis (including many detergents, phosphates, whiteners, and foaming agents giving water low pH), to oil and grease, suspended solids and organic particles. In addition, degreasers found in washing up liquids and soaps strip the natural oils from fish gills making it difficult for them to breathe [Hoskins, 2011: 1]. In adition, researches have proven that untreated graywater containes bacteria and suspended solids concentrations equal to or exceeding blackwater [Eley, Morehouse, 2003: 748].

If large quantities of wastewater and waste matter are brought to water systems, particularly semi-closed and closed water systems, the amount of nutrients (nitrogen and phosphorus) substantially increases which increases primary production (phytoplankton). However, there is no increase in consumption which may result in water system becoming eutrophic [Tušar, 2009: 30].

Regarding the criteria for discharge of sanitary wastewater, Annex IV of MARPOL Convention divides the sea into four zones:

- Port/anchorage – zone 1,
- Sea area at distance less than 3 M from the nearest land – zone 2,
- Sea area at distance 3-12 M from the nearest land – zone 3 and
- Sea area beyond 12 M from the nearest land – zone 4.

For each of these zones Annex IV defines quality criteria for discharged sanitary wastewater from ships. The are two types of sanitary wastewater treatment systems available: marine sanitation device, MSD and advanced wastewater treatment system, AWT. MSD handles only black water while in AWT systems black and gray water are collected and processed together. Table 1 shows a comparison of quality of discharged sanitary wastewater from the treatment system considering quality criteria and minimum requirements of MARPOL Convention for the coastal area of the sea.

Table 1 shows that treated black water from MSD has about 2 million faecal coliform while treated sanitary wastewater from AWT plant has 14.5 faecal coliforms. The values of other quality factors of sanitary wastewater are also several times higher at the exit of the MSD compared to the output from the AWT system. It can be concluded that there is great disproportion in quality of discharged wastewater directly related to the type of wastewater treatment system installed on cruise ships. However, it is important to emphasize that the requirements of Annex IV refer only to black water while discharge of gray water has no limitations despite the fact that quality of discharged untreated gray water exceeds quality factors of treated black water in both systems.

2.2 Case study analyses

For the purposes of this paper the coastal sea area includes internal waters and the sea area at a distance less than 3 M from the nearest land (zone 2) shown in Figure 1. The light gray area markes the sea area at a distance less than 3 M from the nearest land and the dark gray area markes sea area 3 M from the baseline that divides the internal waters and territorial sea of the Republic of Croatia.

The results of the case study gave information on the retention time of ships in ports and in areas of limited discharge of sanitary wastewater in accordance with Annex IV of MARPOL Convention.

In the year of monitoring 63 cruise ships carrying 500 or more passengers arrived in the Adriatic Sea. Out of the 34 world cruise companies (refers to cruise companies that have two or more cruisers with passenger capacity of 500 or more), mentioned ships represent 26 of them. During their stay in the Adriatic, cruisers had 21 different ports of call, of which eleven Croatian: Dubrovnik, Split, Zadar, Korčula, Hvar, Rijeka, Šibenik, Hvar, Trogir, Pula and Supetar. Port of call number, retention time in port/anchorage and in the corresponding zone 2 in function of wastewater treatment system installed on cruise ships is given in table 2.

From mentioned 63 cruise ships, only two did not have Croatian ports of call in their itinerary. Cruise ships

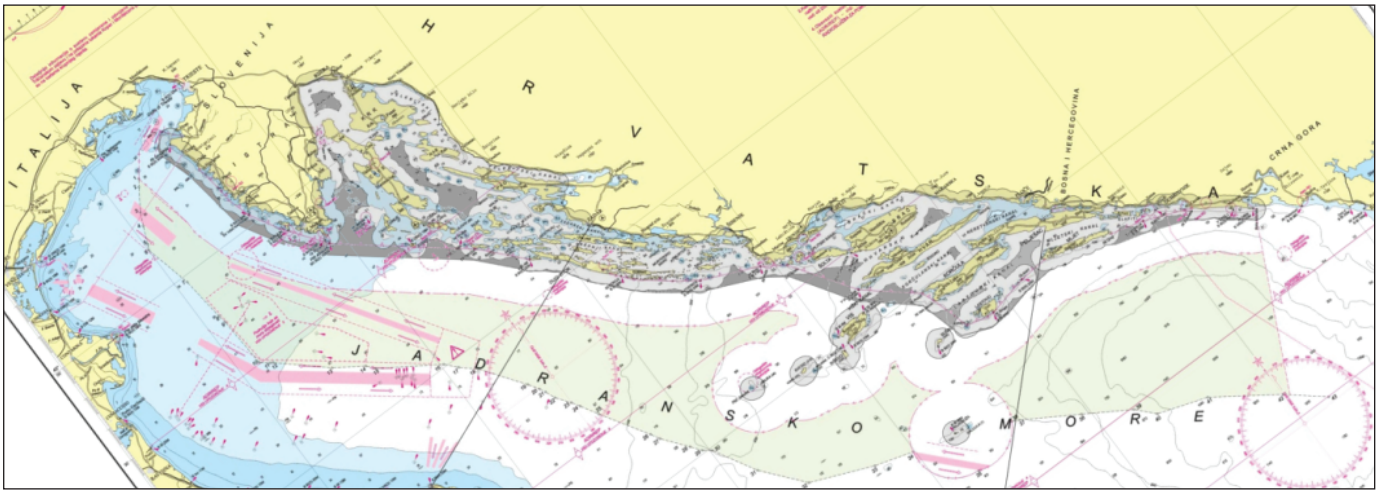


Figure 1 Zone 2 of MARPOL Annex IV

Table 2 Case study data regarding number of arrivals in ports and retention time distribution in function of wastewater treatment system

One-year monitoring data	Treatment system	Dubrovnik	Split	Zadar	Korčula	Hvar	Rijeka	Šibenik	Rovinj	Trogir	Pula	Total
Number of arrivals in port	AWT	161	47	38	13	13	0	0	1	1	1	**275**
	MSD	177	64	14	7	4	4	4	3	0	0	**277**
Total		338	111	52	20	17	4	4	4	1	1	**552**
Retention time in port [h]	AWT	1686	460	363	117	166	0	0	13	10	11	**2826**
	MSD	1442	564	145	61	42	43	38	44	0	0	**2378**
Total		**3128**	**999**	**508**	**179**	**208**	**43**	**38**	**57**	**10**	**11**	**5193**
Retention time in zone 2 [h]	AWT	248	156	195	65	26	0	0	3	3	1	**697**
	MSD	267	189	68	33	7	8	14	3	0	0	**589**
Total		**515**	**344**	**263**	**99**	**32**	**8**	**14**	**6**	**3**	**1**	**1286**

had Croatian ports as port of call 552 times and they have spent 5193 hours in Croatian ports and 1286 hours in the coastal sea area. Distribution of retention time in ports and in zone 2 is shown in Figure 2.

From the presented retention times in Croatian ports and in zone 2 and with the knowledge of the average number of people on each of the ships in the observed research year, generated black water, GCV and generated

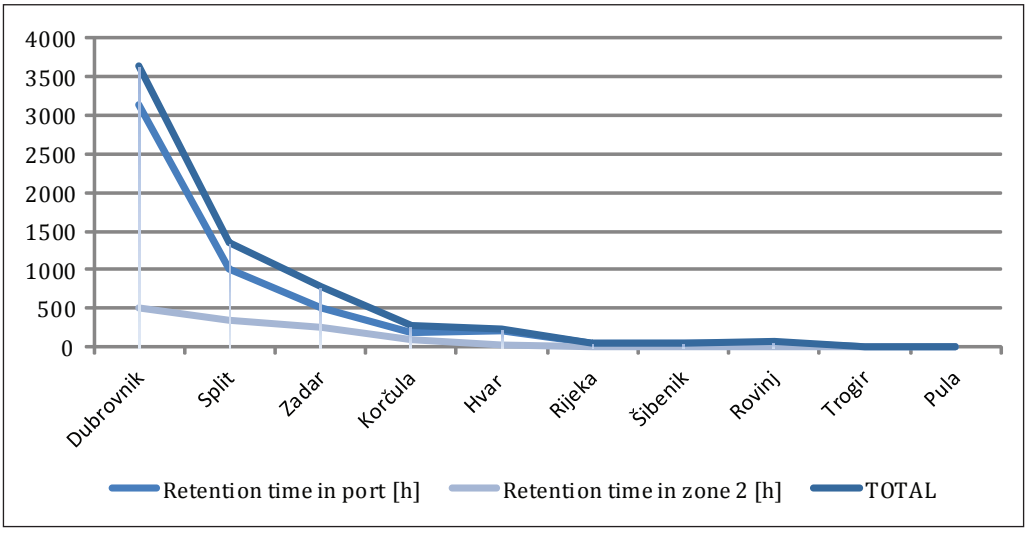


Figure 2 Distribution of retention time in ports and in zone 2

gray water, GSV is calculated according to the following formula [Perić, 2016: 57]:

$$GCV = \frac{K \cdot F_{CV} \cdot t}{1000} \quad [m^3]$$
$$GSV = \frac{K \cdot F_{SV} \cdot t}{1000} \quad [m^3] \qquad (1)$$

where:

GCV is generated black water
GSV is generated gray water
K is average number of persons on the ship,
F_{CV} is black water constant and it is 1,325 l/person/h,
F_{SV} is black water constant and it is 10,54 l/person/h,
t is retention time in sea area [h].

3 Results of wastewater pollution in different operational modes

Generated gray and black water can be discharged arbitrarily if minimum requirements of Annex IV are respected. It means that there is a range of various operational modes ie. scenarios that can be used while discharging wastewater which are simulated using evaluation model of wastewater pollution [Perić, 2016: 59] and are summarized below.

In all scenarios ships with AWT plant discharge treated wastewater continuously while ships with MSD store their black water in holding tanks (treated black water with MSD does not meet Annex IV requirements for discharge). Changes in the scenarios are therefore only in discharge of untreated gray water on ships with MSD system. Following scenarios where simulated:

- Scenario 1: gray water is discharged continuously in the port/anchorage and in the zone 2
- Scenario 2: gray water is not discharged in port/anchorage while the ship is stationary and is stored in holding tanks. Discharge begins with departure of the ship in zone 2.
- Scenario 3: gray water is not discharged neither in port/anchorage nor in zone 2. It is stored in holding for discharge in zones 3 and 4.

Regarding treatment system installed on ships, AWT to MSD ratio is 54.4:46.6 in percentage of total retention time in Croatian ports. The ratio of retention time in the zone 2 is 54.2 % of the time for AWT. Regarding the amount of generated wastewater, ratio is again on the side of AWT, even in a higher percentage (55.8 % in the port and 54.3 % in zone 2) as ships with AWT generally have bigger capacity. The distribution of generated wastewater according to the area of navigation and wastewater treatment system is given in Table 3.

After calculation of generated wastewater for each scenario quantity and quality of discharged sanitary wastewater is calculated according to area of navigation and an overview is given in Figures 3 and 4.

From Figure 4, it can be concluded that the quality of discharged wastewater after treatment with AWT system which is presented in scenario 3 (since in this scenario, there are no discharges from MSD) is satisfactory and is insignificant in comparition with the quality of discharged untreated gray water from the MSD.

Previous studies have already concluded that untreated gray water has negative impact on the environment if released near the coast, and with the evaluation model application in this paper that was only confirmed.

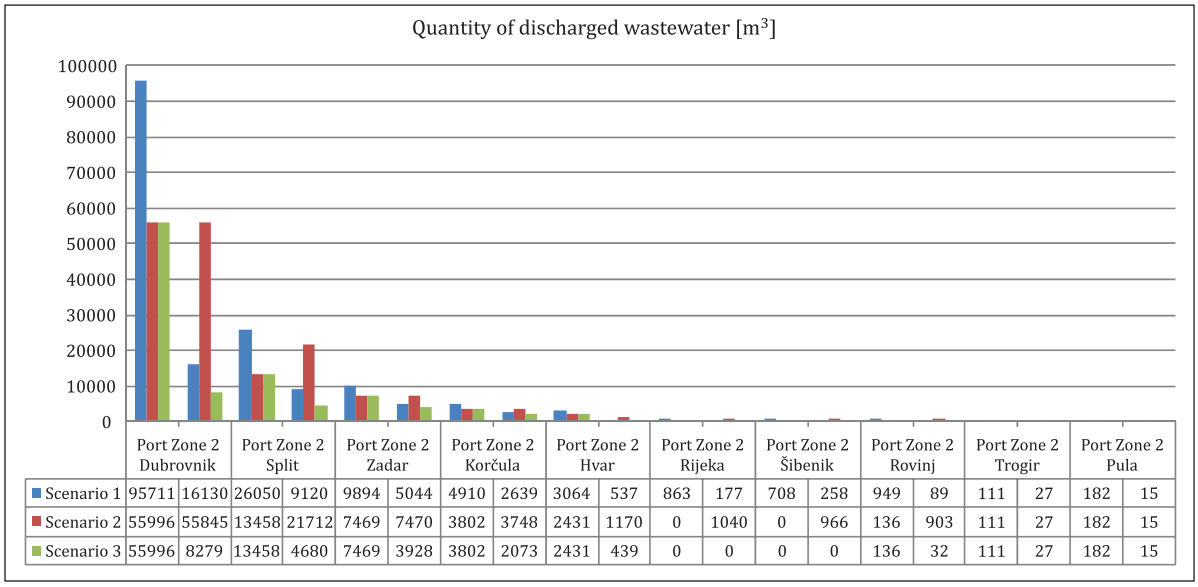
4 Conclusion

Sanitary wastewater has negative impact on the environment. It has been shown that there is disproportion in the quality of discharged wastewater depending on the treatment system installed on cruise ships. This paper demonstrated that ships with AWT system have minimal impact on the environment regarding wastewater pollution.

Legal regulations recognize only black water as a contaminant. Research results have also proven that pollution

Table 3 Generated sanitary wastewater distribution

Port	Generated wastewater in port				Generated wastewater in zone 2			
	Generated black water [m³]		Generated gray water [m³]		Generated black water [m³]		Generated gray water [m³]	
	AWT	MSD	AWT	MSD	AWT	MSD	AWT	MSD
Dubrovnik	6,253	4,993	49,743	39,714	925	987	7,355	7,851
Split	1,503	1,583	11,955	12,592	523	558	4,157	4,440
Zadar	834	305	6,635	2,426	439	140	3,490	1,116
Korčula	425	139	3,377	1,108	232	71	1,842	566
Hvar	271	80	2,159	633	49	12	390	98
Rijeka	0	108	0	863	0	22	0	177
Šibenik	0	89	0	708	0	32	0	258
Rovinj	15	102	121	813	4	7	28	58
Trogir	12	0	99	0	3	0	24	0
Pula	20	0	162	0	2	0	13	0
Total	9,334	7,399	74,251	58,858	2,175	1,831	17,299	14,564



	Port Zone 2 Dubrovnik		Port Zone 2 Split		Port Zone 2 Zadar		Port Zone 2 Korčula		Port Zone 2 Hvar		Port Zone 2 Rijeka		Port Zone 2 Šibenik		Port Zone 2 Rovinj		Port Zone 2 Trogir		Port Zone 2 Pula	
Scenario 1	95711	16130	26050	9120	9894	5044	4910	2639	3064	537	863	177	708	258	949	89	111	27	182	15
Scenario 2	55996	55845	13458	21712	7469	7470	3802	3748	2431	1170	0	1040	0	966	136	903	111	27	182	15
Scenario 3	55996	8279	13458	4680	7469	3928	3802	2073	2431	439	0	0	0	0	136	32	111	27	182	15

Figure 3 Quantity of discharged wastewater in port and zone 2 following defined scenarios

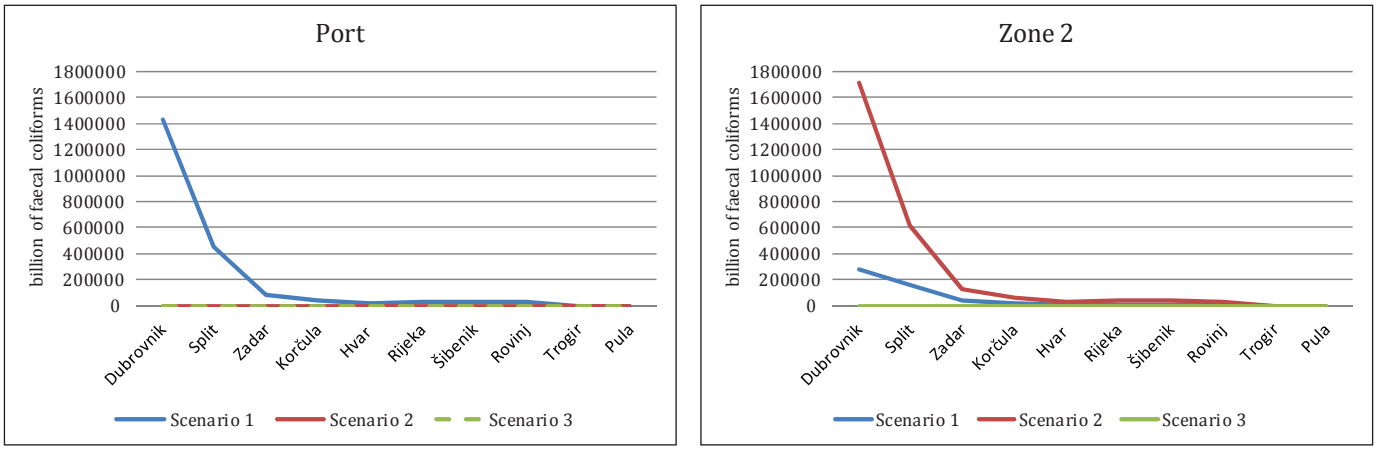


Figure 4 Quality of discharged wastewater in port and zone 2 following defined scenarios

in ports and coastal areas is not coming from the black water but from gray water which is not recognized as a pollutant in the MARPOL Convention. It is therefore considered necessary to introduce legislative measures limiting the discharge of untreated gray water into the ports and sea area up to 3 M from the nearest land.

Future research on this subject should focus on establishing limits of wastewater pollutants for specific sea areas that ships should not exceed in order to protect marine environment and also on the cumulative effect of marine pollution by wastewater that includes other ship types and land-based pollution.

References

[1] Eley, W. D., Morehouse, C. H.: *Evaluation of new technology for shipboard wastewater treatment*; Proceedings, Oceans 2003 Conference, Marine Technology Society, Columbia, Maryland, 2003.

[2] Hoskins, J.: *Grey Water – The Silent Killer*, 2011, available at: http://www.pya.org/ article/Grey-Water_-The-Silent-Killer.

[3] International Maritime Organization (IMO), Marine Environment Protection Committee: *Resolution MEPC.227(64): 2012 Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants*, 2012.

[4] Perić, T.: Model vrednovanja onečišćenja Jadranskog mora sanitarnim otpadnim vodama s brodova za kružna putovanja (*Evaluation Model of Sanitary Wastewater Pollution from Cruise Ships in the Adriatic Sea*), doctoral dissertation, Rijeka, 2016.

[5] Perić, T., Komadina, P., Račić, N.: Onečišćenje Jadranskog mora sanitarnim otpadnim vodama s brodova za kružna putovanja (*Wastewater Pollution from Cruise Ships in the Adriatic sea*), Promet – Traffic&Transportation, Vol. 28, No. 4, Zagreb, 2016.

[6] Tušar, B.: Pročišćavanje otpadnih voda (*Wastewater treatment*), Kigen, Zagreb, 2009.

[7] United States Environmental Protection Agency: *Cruise Ship Discharge Assessment Report*, 2008.