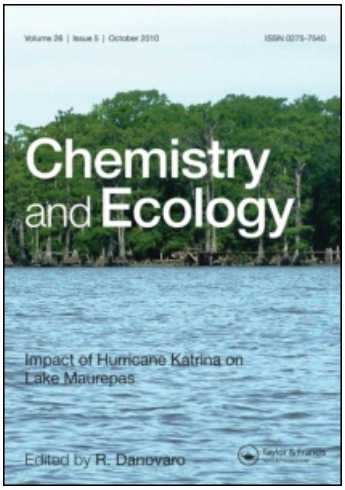

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Estimate of sea loading by pollutants originating from the littoral counties in the Republic of Croatia

B. Sekulić[a]; M. Martinis[b]; K. Nađ[c]
[a] Centre for Marine Research and Environmental Protection, Rudjer Bošković Institute, Zagreb, Croatia [b] Theoretical Physics Division, Rudjer Bošković Institute, Zagreb, Croatia [c] Experimental Physics Department, Rudjer Bošković Institute, Zagreb, Croatia

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ESTIMATE OF SEA LOADING BY POLLUTANTS ORIGINATING FROM THE LITTORAL COUNTIES IN THE REPUBLIC OF CROATIA

B. SEKULIĆ[a,*], M. MARTINIS[b] and K. NAĐ[c]

[a]*Centre for Marine Research and Environmental Protection, Rudjer Bošković Institute, POB 180, 10000 Zagreb, Croatia;* [b]*Theoretical Physics Division, Rudjer Bošković Institute, POB 180, 10000 Zagreb, Croatia;* [c]*Experimental Physics Department, Rudjer Bošković Institute, POB 180, 10000 Zagreb, Croatia*

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The paper reviews the data of 10 yr of following up sewage (waste water) inflows of anthropological origin into the sea from all the coastal settlements in Croatia. In particular, we report the sea loading by biochemical oxygen demand (BOD_5), expressed by the inhabitant equivalent (I.E.), for seven littoral counties. We estimated the loading of a coastal sea area for each county separately. The objective was to avoid any over- or underestimation of amounts and significance of sewage inflows into the seawater. For this purpose, a precisely determined sea volume up to the 10 m isobath has been chosen. Because of the inadequate treatment of wastewater, the total loading of that maritime territory expressed in terms of i.e. was found to be 26% higher than expected from the actual number of inhabitants. However, daily input represents only 12‰ of the considered volume of the sea. Recipient spent only 0.7% of the disposable oxygen quantity in the sea.

Keywords: Sewage; Croatia; Sea loading; Pollutants; Littoral counties; BOD_5; Inhabitant equivalent

1 INTRODUCTION

Croatia has the longest seashore on the east side of the Adriatic Sea. With a total coast length of 2092.4 km, Croatia accounts for 85% or 1778 km (Rodić, 1981; Ljevak and Lončarević, 2001). Presently, the Croatian coastal region is divided into seven seashore counties, with about 1.4 million inhabitants, including seashore, inland and island areas. A total of 179 settlements with about 830,000 inhabitants are situated on the continental part of the counties, constituting 58% of the population of all the littoral counties. The six biggest coastal settlements (Pula, Rijeka, Zadar, Šibenik, Split and Dubrovnik, ranging from 40,000 to

* Corresponding author. E-mail: bane@irb.hr

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200,000 inhabitants each) make up the greatest proportion of the population. Almost 587,000 inhabitants or 71% of the population of all littoral counties live in these towns. Another 173 settlements make up the remaining 29% of the population. Among these settlements, only 13 have 5000–10,000 or more inhabitants. All other settlements have considerably fewer inhabitants (Gredelj, 2002).

Therefore, the main inflow of sewage is expected to be from the six largest settlements. They can be considered primary sources of pollution of the Croatian maritime territory. Other smaller settlements represent dot-like sources, the pollution of which has a minor influence on the loading of the sea. The Croatian coastal region is sparsely populated, and the problem of sea loading is mainly associated with an unresolved or improper wastewater treatment.

The wastewater is discharged directly into the sea with either no prior treatment or only mechanical treatment. The percentage of drained wastewater without purification varies from county to county, ranging from 60% to more than 90% (Šobot, 1998). However, the receiving capacity of the sea is large. This is due to the comparatively good sea mixing caused by the wind, sea currents and daily tide cycle (Buljan, 1976).

A large part of the sea along the coastline, outside the settlements, is clean and extremely attractive for tourists. It should be emphasized that the coastal region (seashore and islands) is important in the summer, constituting almost 75% of total tourist traffic in Croatia.

Tourist valorization of the coast has reduced industrial activities significantly on the coast. This has resulted in a decreased inflow of industrial wastewater. Although the total amount of wastewater was not reduced substantially, the quality of effluent has changed for the better.

In this paper, the biochemical oxygen demand (BOD_5) in sewage from the local and tourist populations as well as from the industrial waters along the east coast of the Adriatic Sea was analysed. The purpose was to establish the receiving capacity of the sea under the sewage load. The objective was to avoid any over- or underestimation of amounts and the significance of sewage inflows into the seawater (Sekulić and Sondi, 1997; Sekulić and Vertačnik, 1997). For this purpose, a precisely determined sea volume up to the 10 m isobath has been chosen. The total loading of that maritime territory was expressed in terms of inhabitant equivalent (I.E.).

The biochemical oxygen demand, BOD_5, is a standard measure of effluent quality. It is also a very important parameter, indicating the level of the receiving capacity of the recipient. The more organic materials in the sewage require a greater amount of oxygen extracted from water by bacteria during sewage decomposition. The values of the BOD_5 in the sewage vary from source to source, within the period of time and space. We have observed that daily values of BOD_5 are high in the morning and evening. The concentrations of BOD_5 in urban sewage range from 200 to 500 mg/l. Values over 4000 mg/l, depending on the type of sources, might be expected in paper mills, for example (Ivanović *et al.*, 2002).

Most sewage in large and medium-sized settlements is subjected only to mechanical treatments. Smaller settlements usually have septic holes or distribute their sewage directly to the sea. According to the data collected during the last 10 yr, we have estimated the average yearly value of BOD_5 to be 250 mg/l (Sekulić, 2001). This value is larger than expected for medium-sized and small settlements, which are the most numerous on the coast. Hotels usually discharge their sewage far from the shore, at depths of more than 10 m (http://www.domzale.si/okoljeinprostor/projekti/okolje; http://www.swbic.org/education/env-engr/biochem/biological.htm).

Inhabitant equivalent (I.E.) is a conventional concept, which defines specific inhabitant discharges in terms of both water consumption and loads of organic pollutants. It was calculated for each county.

2 MATERIALS AND METHODS

To determine the associated sea volume up to the 10 m isobath for each littoral county, we used sections of the charts at a scale of 1:100,000 (Gržetić, 2001). On shorter segments, usually in the range of 5–30 km, depending on the shore morphology, a curve meter was used to measure the coastal length. Three to five profiles were defined for each shore segment, from which a mean value of coast distance to the 10 m isobath line was calculated. In this way, the average sea depth in a given segment as well as the average distance from the coast to the 10 m isobath was obtained. Then, the average associated sea volume, up to the 10 m isobath line, was calculated.

A measure expressing the maritime region loading is based on the inhabitant equivalent (I.E.) concept:

$$\text{I.E.} = \frac{\text{BOD}_5 \text{ untreated effluent (250 mg/l)} \times Q \text{ (daily discharge of effluent)}}{\text{BOD}_5 \text{ inhabitant/d (60 mg/l)}}. \quad (1)$$

This conventional concept defines specific inhabitant discharges in terms of both water consumption and loads of organic pollutants. The wastewater amounts are different for each settlement. The water load and the polluting load of every I.E. have been assumed to be equal to 200 l/d and 60 g/d of BOD_5, respectively, (http://www.greywater.com/pollution.htm).

The inflow and associated sea volume loading by all littoral settlements have been obtained in this way as well as the inflow and sea loading by the greatest settlements ashore for each littoral county separately. The yearly loading of the corresponding volume of the sea is presented in graphic and tabular form in the following section. Daily input is not shown graphically because the values were too low to be visualized.

3 RESULTS AND DISCUSSION

Figure 1 shows the loading of sea water by sewage from all settlements, including the largest. In Figures 1 and 2, the yearly input from main settlements is emphasized, separately from other settlements within counties.

On the charts, the coast length for each county was measured at a scale of 1:100,000, and accordingly, the associated sea volume up to the 10 m isobath was calculated. The total coastal length was estimated to be 1795.6 km (see Tab. I). The average distances from the coastline to the 10 m isobath vary from county to county. The greatest distances are in Istria County because Istria is laid down mildly toward the shallowest part of the north Adriatic Sea, where depths never exceed 30 m. The shortest distances are in the counties of Rijeka, Lika and Senj, where the shore slopes steeply, and the 10 m isobath is close to the shore. In addition, the volume of the sea is lower in those counties than in others.

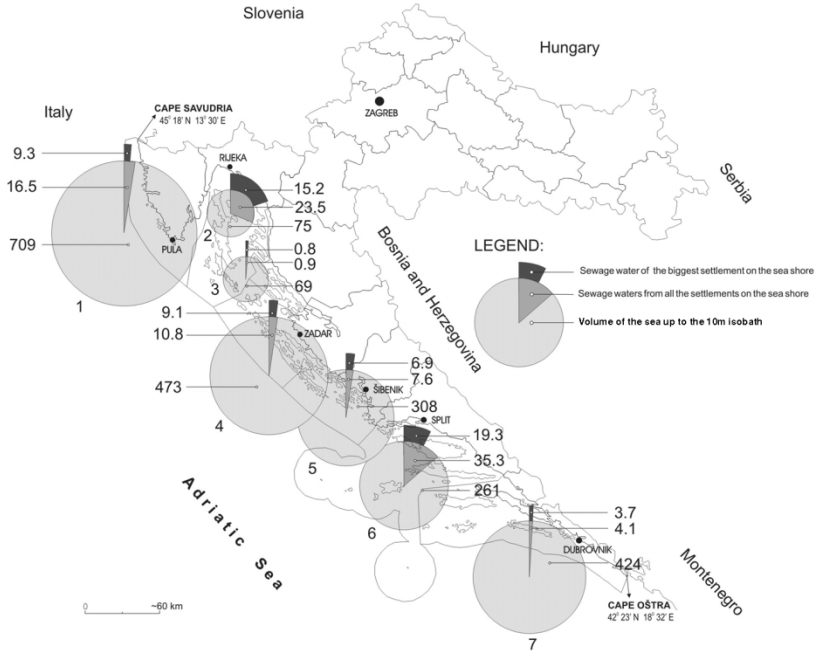

FIGURE 1 Input of wastewater into the Adriatic sea from settlements of the Croatian littoral counties. 1: Istra County; 2: Rijeka County; 3: Lika and Senj County; 4: Zadar County; 5: Šibenik and Knin County; 6: Split and Dalmatia County; 7: Dubrovnik and Neretva County (sea volume: 10^6 m^3; sewage: 10^6 m^3/yr).

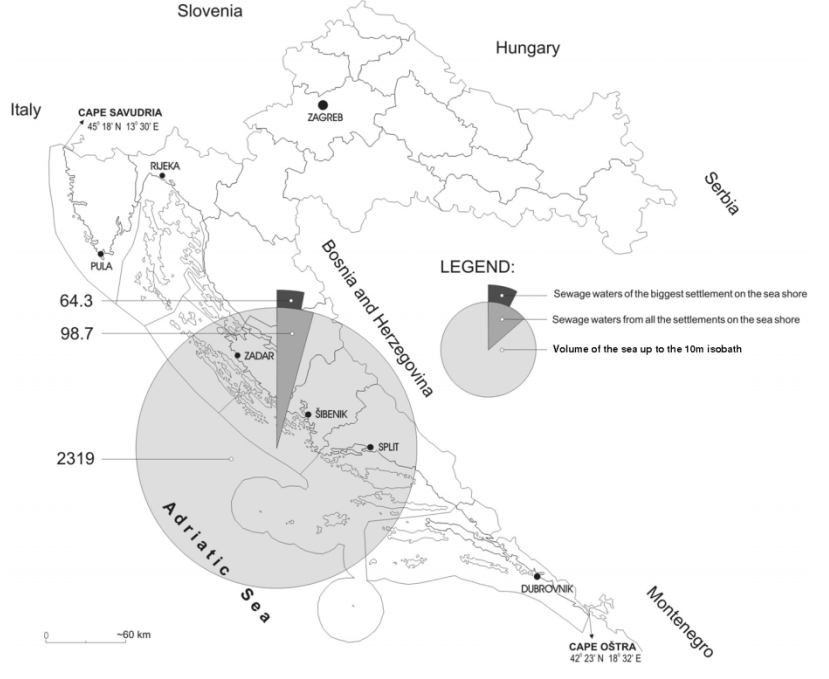

FIGURE 2 Yearly sewage contribution to the sea volume from all the seashore counties of Croatia (sea volume: 10^6 m^3; sewage: 10^6 m^3/yr).

TABLE I Sea volume up to the 10 m isobath belonging to the adriatic seashore counties of Croatia.

Seashore counties	*Coast length (km)*	*Average distance from the coast up to the 10 m isobath (m)*	*Sea volume between the coast and the 10 m isobath (10^9 m^3)*	*Average sea depth of the coast areas up to the 10 m isobath (m)*	*Standard deviation for a distance from the coast up to the 10 m isobath (m)*	*Standard deviation of a sea depth in the range from the coast up to the 10 m isobath (m)*	*Variability coefficient* (distance)*	*Variability coefficient* (depth)*
Istra County	389.0	516.4	0.709	5.18	423.7	0.995	82	19
Rijeka County	120.0	78.3	0.075	8.27	25.7	0.404	33	5
Lika and Senj County	125.0	66.7	0.069	8.07	16.1	0.231	24	3
Zadar County	246.2	275.7	0.473	6.26	247.5	1.313	90	21
Šibenik and Knin County	216.0	250.0	0.308	6.81	196.4	1.059	79	16
Split and Dalmatia County	236.7	172.1	0.250	6.80	146.7	1.495	85	22
Dubrovnik and Neretva County	465.5	158.4	0.430	7.20	95.3	1.004	60	14
Total	1795.6[†]	216.8	2.318	6.94				

* Variability coefficients are higher for distances than for depths of the sea. It is due to a very diverse coast morphology of Croatia.

The sea volume up to the 10 m isobath was chosen because it is a primary part of the maritime territory receiving most of the anthropogenic pollution from the land and the most sensitive part from an ecological standpoint. This part of the coastal region is also the most important habitat for littoral phytocenosis and a hatching ground for ichthyofauna.

We compared sea volume with estimated wastewater inflow, from the littoral settlements, and the results are listed separately for each county in Table II and Figure 1. The total inflow of wastewaters for all counties is shown in Figure 2.

The ratio between yearly sewage inflow from littoral settlements and associated sea volume was found to be greatest in the Rijeka County and in the Split and Dalmatian Counties. In these two counties, the port of Rijeka and the port of Split are the two largest settlements on the coast and have the highest amounts of wastewater inflow. Their sea volumes up to the 10 m isobath are modest, especially in Rijeka County. Istra, Dubrovnik and Neretva Counties have considerably greater sea volumes and also a considerably smaller sewage inflow, especially in Dubrovnik and Neterva Counties.

It should be emphasized that daily sewage inflows, in comparison with the sea volume, range from 37‰ for the Split and Dalmatia Counties to 86‰ for the Rijeka County. In other counties, the daily sewage inflows range from 3 to 7‰. This ratio is 12‰ for the whole coast (Tab. II). In comparison with all other littoral settlements, the sewage inflow for the largest settlements is very high, ranging from over 55% in Istria County to over 88% in Lika and Senj County (see Fig. 1). Hence, the associated sea volume in a given length of coast receives the greatest loading from dot-like sources, which is the site with the largest settlement of the littoral counties.

The I.E. was used to provide a global insight into the actual loading of the associated sea volume by littoral settlements (Tab. III). The I.E. values in Table III show that the total population of the littoral settlements load the associated sea recipient 26% more than the actual number of inhabitants.

The sea loading expressed by BOD_5 ranges from 220 tons yearly in the Lika and Senj County to over 8800 tons yearly in the Split and Dalmatia Counties. We find that the I.E., presented in Table III and Figures 3 and 4, show larger values in relation to the virtual number of inhabitants, except for Dubrovnik and Neretva Counties. The highest I.E. is in Istria County and Šibenik and Knin County, and the lowest is in Zadar County.

Figure 3 shows that if the I.E. circle (dotted line) is closer to the circle (full line) of the total number of inhabitants in the county, the loading of its maritime territory is higher. If the I.E. circle is further away from the circle of the actual number of inhabitants, the loading of the sea is lower.

The above analyses show that the coastal region of the Adriatic Sea is exposed mainly to localized sources of sea pollution sited in the largest settlements. However, the loading of the sea volume considered (up to the 10 m isobath, expressed in BOD_5), 24,654 tons/yr or 67.5 tons/d, is negligible (0.7%) in comparison with the available oxygen in the sea (9276 tons; see Tab. IV).

The highest daily sea loading by BOD_5 in comparison with the associated sea volume and their available oxygen capacity is 5.4% in Rijeka County and 2.3% in Split and Dalmatia Counties. In other counties, this ratio ranges from 0.2% for (Lika and Senj Counties and Dubrovnik and Neretva Counties) to 0.4% in the remaining counties.

We use the average oxygen value in the sea (4 mg/l; see Tab. IV). This value is actually underestimated in the summer period. The sea volume up to a depth of 10 m is biologically and dynamically the most productive, and the oxygen value ranges between 5 and 6 mg/l (Vukadin, 1981). Even in the summer period, this seashore aquatory is saturated with oxygen over 110% (Artegiani *et al.*, 2001).

TABLE II Input of sewage into the Adriatic Sea from Croatian littoral counties.

Seashore counties	*Sea volume between coast and the 10 m isobath (10^6 m^3)*	*Sewage from all settlements on the seashore (inhabitants, tourists and industry) (10^6 m^3/yr)*	*Sewage from the biggest settlement on the seashore (1–7) (10^6 m^3/yr)*	*Daily loading of sewage from all settlements on the seashore (inhabitants, tourists and industry) (10^6 m^3/d)*	*Daily inflow of sewage in comparison with the sea volume up to the 10 m isobath (‰)*
Istra County	709	16.5	9.3 [1]	0.05	6
Rijeka County	75	23.5	15.2 [2]	0.06	86
Lika and Senj County	69	0.9	0.8 [3]	0.002	3
Zadar County	473	10.8	9.1 [4]	0.03	6
Šibenik and Knin County	308	7.6	6.9 [5]	0.02	7
Split & Dalmatia County	261	35.3	19.3 [6]	0.1	37
Dubrovnik and Neretva County	424	4.1	3.7 [7]	0.01	3
Total	2319	98.7	64.3	0.27	12

Note: The largest settlements in the seashore counties: [1] Pula; [2] Rijeka; [3] Senj; [4] Zadar; [5] Šibenik; [6] Split; [7] Dubrovnik. Data for the quantity of sewage are from Sekulić (1992, unpublished). The average rate of the sewage inflow into sea from all the seashore settlements is 3.1 m^3/s. Sewage from the seashore counties in comparison with the total sewage production of Croatia is 38.2%. From the total sewage production of Croatia, which is 258×10^6 m^3/yr (Statistical Information, Republic of Croatia, Central Bureau of Statistics, Zagreb, 2002), treated = 33.6% and untreated = 66.4%.

TABLE III Sea pollution expressed as a biological oxygen demand (BOD_5 tons/yr) and inhabitant equivalent (I.E.).

Seashore counties	*Sewage from all settlements in the seashore* (inhabitants, tourists and industry) (10^6 m^3/yr)*	*Number of inhabitants in seashore counties with islands (2001) (thousands)*	*Number of inhabitants in seashore settlements without islands (2001) (thousands)*	*Sea loading expressed as BOD_5 (tons/yr) (in thousands)*	*Sea loading expressed as inhabitant equivalent (I.E.) † (thousands)*	*Inhabitant equivalent (I.E.) in comparison with the number of inhabitants in seashore settlements (%)*
Istra County	16.5	206.3	106.8	4.1	188.0	>43
Rijeka County	23.5	305.5	206.1	5.9	268.1	>23
Lika and Senj County	0.9	53.7	7.9	0.2	10.0	>21
Zadar County	10.8	162.0	102.5	2.7	122.8	>17
Šibenik and Knin County	7.6	112.9	54.5	1.9	86.9	>37
Split and Dalmatia County	35.3	463.7	295.4	8.8	402.6	>27
Dubrovnik and Neretva County	4.1	122.9	55.9	1.0	47.1	<16
Total	98.7	1427.0	829.1	24.6	1125.5	>26

* Sekulić (1992, unpublished data).

† The inhabitant equivalent (I.E.) was calculated using a BOD_5 of 250 mg/l for untreated effluent and an average BOD_5 of 60 g/inhabitant/d.

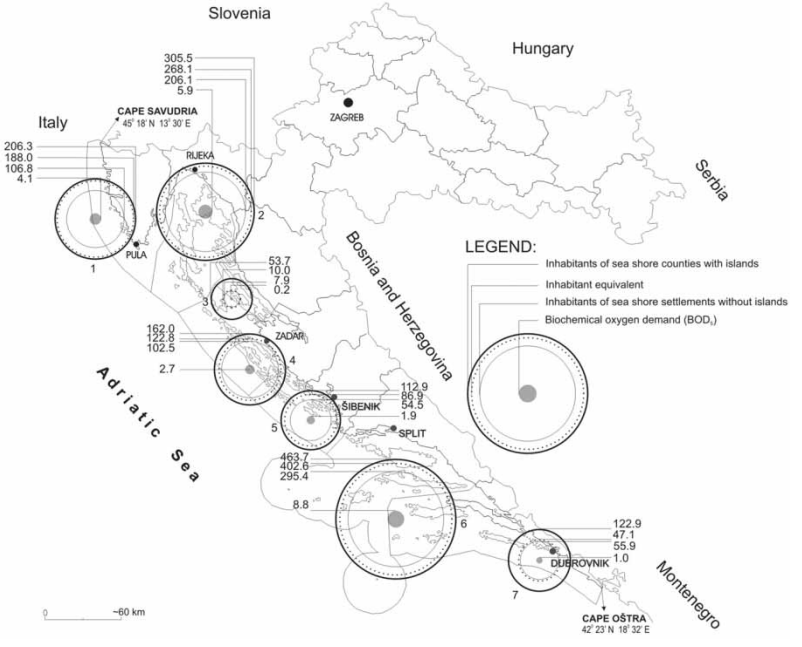

FIGURE 3 Yearly sea pollution expressed as a biological oxygen demand (BOD_5 in t/yr) and inhabitant equivalent (I.E.) for each seashore county in Croatia separately. 1: Istra County; 2: Rijeka County; 3: Lika and Senj County; 4: Zadar County; 5: Šibenik and Knin County; 6: Split and Dalmatia County; 7: Dubrovnik and Neretva County (inhabitants, inhabitant equivalent and BOD_5 in thousand); BOD_5 in t/yr.

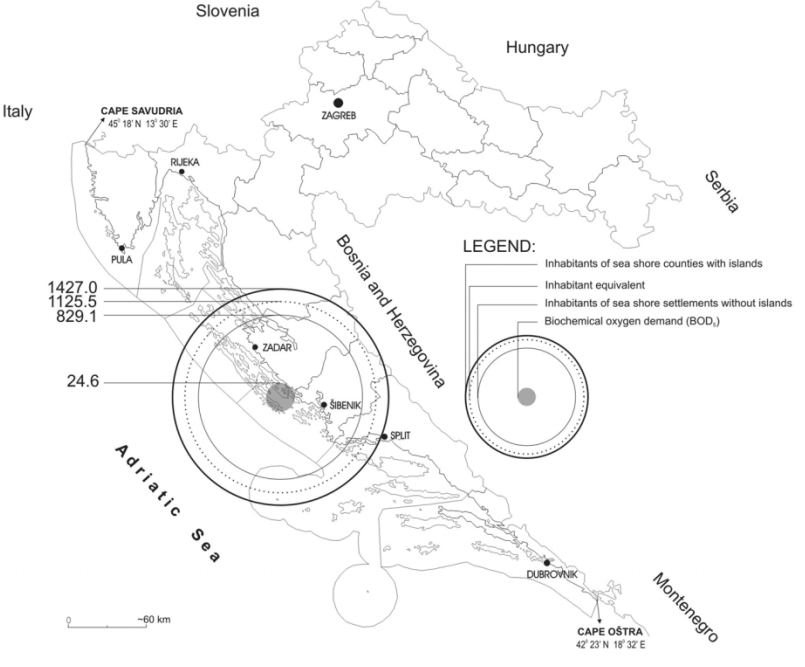

FIGURE 4 Total yearly sea pollution in Croatia expressed as biological oxygen demand (BOD_5t/yr) and inhabitant equivalent (I.E.). Sea volume: 10^6 m^3; inhabitants, inhabitant equivalent and BOD_5 in thousand; BOD_5 in t/yr.

TABLE IV Biological oxygen demand (BOD_5) *vs.* oxygen content in the associated sea volume.

Seashore counties	*Sea volume up to the 10 m isobath (10^6 m^3)*	*Content of oxygen (O_2) in the sea volume up to the 10 m isobath (tons)*	*Yearly sea loading expressed as BOD_5 (tons/yr)*	*Daily sea loading expressed as BOD_5 (tons/d)*	*BOD_5 (daily)/ O_2 ratio (%)*
Istra County	709	2800	4100	11.3	0.4
Rijeka County	75	300	5900	16.1	5.4
Lika and Senj County	69	280	220	0.6	0.2
Zadar County	473	1900	2700	7.4	0.4
Šibenik and Knin County	308	1200	1900	5.2	0.4
Split and Dalmatia County	261	1000	8800	24.2	2.3
Dubrovnik and Neretva County	424	1700	1000	2.8	0.2
Total	2319	9300	25,000	67.5	0.7

Note: The average concentration of oxygen in the Adriatic sea is 4 mg/l.

4 CONCLUSION

Seven littoral counties with 179 settlements are situated in the coastal region of Croatia. Nearly 830,000 inhabitants live there, and only six settlements constitute 71% of population. The total coastal length is 1795.6 km with an associated sea volume of 2319×10^6 m^3 up to the 10 m isobath. The total loading of that maritime territory expressed by BOD_5 is about 245,000 tons/yr, and the inhabitant equivalent (I.E.) is more than a million, or 26% more than the actual number of inhabitants. The main reason for this is insufficient treatment of wastewater from the settlements, although significant improvements have been noted recently. Although these I.E. values seem high, it should be emphasized that the greatest part of the loading comes from six dot-like sources, just those connected to the largest settlements. The wastewater proportion for those settlements in comparison with the total input is more than 65%. The sea loading BOD_5 in the amount (67.5 tons/d), in comparison with available oxygen (9300 tons) in the sea volume up to the 10 m isobath, constitutes only 0.7% of consumed oxygen. The amounts of daily wastewater input of all littoral counties in comparison with the associated sea volume range within an order of magnitude of about ten per thousand.

The loading of the corresponding volume of the sea is presented graphically in relation to yearly input. Daily input is not presented because the values were too low to be visualized graphically.

The sea along the eastern coast of the Adriatic is of a high quality in terms of ecology. The Adriatic is an oligotrophic sea, and we conclude that the modest input from anthropogenic sewage waters did not modify the oligotrophic status of the Adriatic Sea.

Future research should focus on choosing the best solutions for proper wastewater treatment for the largest coastal settlements and for others known to contribute to more substantial sea pollution.

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