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Aspects of the Impact of Municipal Wastewaters on the Quality of Marine Ecosystems

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Discharge of municipal wastewaters from Montenegrin coastal cities by outfall, is the main pollution source of coastal waters, as its recipient. Results of the analysis indicate that the load of municipial wastewaters TN 120 kg/day, TP 10 kg/day, BOD_5 570 kg/day, COD 810 kg/day, TSS 420 kg/day. So it is designed the sea water ecosystem monitoring program near end-of-pipe of outfall, to provide needed number of data and information for valid assessment of effects of municipial wastewaters on sea ecosystem.

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Introduction

Concentration of pollutants in wastewaters depends of quantity of delivered and consumend waters per capita and day. Some polluters can have the hazardous or potentially hazardous effects on ecosystem and human health. Municipial wastewaters mainly consists of biodegradable organic materials. The basic parameters - indicators for these waters are biological oxygen demand - BOD5, chemical oxygen demand - COD, total suspended solids - TSS and nutrients (nitrogen N and phosphorus P) [1,2]. Presence of nutrients in municipial wastewaters is mainly linked with organic materials, which increases a presence in ecosystem, leads to increasing of primary production, known as eutrophication process [3-5].

The sea is a specific environment and outstanding natural resource and the base for development of economic activities (bathing and nautical tourism, shipping, shipbuilding, fishing and mariculture). Coastal marine environments are usually influenced by human- induced and natural pressures, which may alter their functioning, and finally contribute to ecosystem degradation and pollution problems [4]. The influence of untreated municipial wastewaters can affect a negative effects on fishes and the other sea organisms, consumption of the oxygen content, pollution of bathing waters with closure of beaches, also other limitations of water use for recreation, limitations in catch of fish and use of waters for food of fishes and shelfishes etc. Some polluters can have the hazardous or potentially hazardous effects on ecosystem and human health [2,6].

Discharge of municipial wastewaters from Montenegrin coastal cities by outfall, is the main pollution source of coastal waters, as its recipient. There is not any big industrial objects - pollution sources at the coast. Because that, the most valuable touristic offer is a high quality of the coastal sea waters, dedicated to bathing. High quality of sea waters is good base for another activities, mariculture and fishery. In this constellation, the main land-based pollution source is discharge of the municipial

wastewater, that are multiply own quantity during the touristic season. In accordance with the such situation it is designed the sea water ecosystem monitoring program near end-of-pipe of outfall. Data collected during a monitoring program serve a number of objectives [7]. The task of sea ecosystem monitoring is to provide needed number of data and information for valid assessment of effects of municipial wastewaters on sea ecosystem.

Materials and methods

The sea water ecosystem monitoring program is obtained the purposeful hydrographical and oceanographical measurements, including CTD probe and current profiler measurements, scaning by remote operated vehicle, as well as physical, chemical and microbiological measurements of waters in three depth layers, measurements of sediment and macrozoobentos analysis [8]. Defined sampling frequency obtained two sampling campaigns of the sea, during the summer, when expects a maximal pressure of emmision during touristic season, and the winter, out of touristic season, when the influence of emission reduced on contribution of permanent inhabitants. Assessment of emission effects, first of all to natural conditions, which dimenzioned a municipial wastewaters discharge influence.

Sampling of sea water at 3 depth is done by Ruttner bottle. Sediment samples are captured by Van Veen Graab.

Temperature of water, transparency (Secchi disk 30cm), pH, salinity (with conductivity) are measured in situ. The samples for the other parameters (turbidity, oxygen parameters, silicates, nutrients, TOC, heavy metals and chlorophyll-a) are preparing in situ and transported to laboratory, as it is requested.

Most of physical and chemical parameters are analysed by standard volumetric and spetrophotometric methods. Heavy metals in water and sediment (after adequate preparation) are measured by ICP-OES. TOC and TN are measured by thermocatalitic oxydation method.

Hydrographic measurement: Sea currents are measured by accustic dopler profyler, at areas of outfall, adjusted at bottom, with vertical resolution of 2 m.

Measurement by CTD probe: Measurement of temperature, optical density and salinity through the water column, from the surface to 2m from the bottom, are carried out by CTD probe with vertical resolution of 1m.

Biological measurement: Analysis of abundance and taxa of the macrozoobentos at radius of 300 m around of outfall is done.

In purpose to analysis of chlorophyll-a samples are filtered through net with size pore of 300 µm. Further, it was done a standard procedure of preparation the samples and the analysis [8].

In aim of trophic state asessment it was calculated a TRIX-index [9,10].

Considering the nature of the wastewaters, they are analysed a microbiological parameters, indicators of faecal pollution: number of total coliform bacteria (in 100ml), number of total faecal bacteria (in 100ml) and number of intestinal enterococci (in 100ml). The method of selective membrane filtration is used for analysis of samples.

Measuring network consisted of 6 stations: 3 points at transect close the end-of-pipe - T0, T1 and T2, control station - R1 and R2, coastal station - R3 , (Tab. 1).

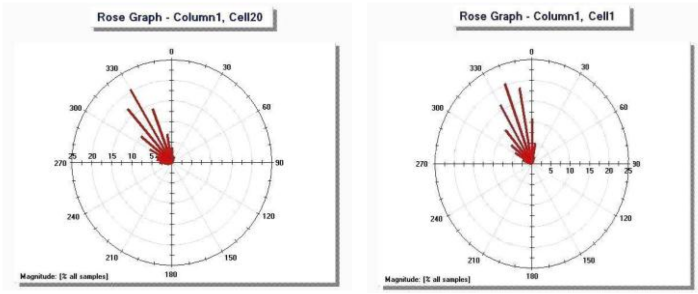
Tab 1: Data of coordinates of the measuring station, depth of water and sampling depth

Measuring station	Coordinates of the measuring station		Depth of water, m	Sampling depth, m	
	φ	λ		summer	winter
T0	42° 21.189' N	18° 39.641' E	44	1	1
				18	20
				42	40
T1	42° 21.266'N	18° 39.395'E	45	1	1
				18	20
				40	40
T2	42° 21.211'N	18° 39.856'E	43	1	1
				20	20
				38	40
R1	42° 21.623'N	18° 37.247'E	46	1	1
				18	21
				40	42
R2	42° 20.168'N	18° 41.730' E	40	1	1
				18	20
				35	35
R3	42° 22.862'N	18° 40.322' E	14	1	1
				7	7
				12	12

Results and discussion

Investigation of physical state of outfall pipe, done by remotely operated underwater vehicle (ROV) equipment, are shown an important damage of the submarine pipe at about 1500 m from the coast line, at 20 m depth. It is determined a missing of over 100 m of the pipe. The damage is probabely a consequence of improper anchoring of a boat. On the base of sort of damage, it can be conclude that the municipial wastewaters do not come to end of pipe, but they are discharge at the site of damage. This predict has a repercution to explanation of measuring results, first of all for transect area. Results of the analysis indicate that the load of municipial wastewater total nitrogen (TN) 120 kg/day, total phosphorus (TP) 10 kg/day, biological oxygen demand (BOD_5) 570 kg/day, chemical oxygen demand (COD) 810 kg/day, total suspended solids (TSS) 420 kg/day.

Sea currents measurements are done in period november - february. The basic characteristic of this area is appearance of inflow currents during winter. The direction of currant course in whole profile, from surface to bottom, is aproximately paralell with direction of coast line from SE to NW (Fig. 1). Intensity of dynamic varies by months, climatological type of year and the depth. By winter, the general direction is NW, resulting velocity 0.4-0.7 knots (1 knot = 0.5144 m/sec). Maximal registered velocities during the season comes to 0.99 knots, but most often maximal values are 0.5-0.8 knots. Minimal velocities were not lower than 0.2 knots.



(a) (b)

Fig. 1. Current roses for the surface (a) and bottom (b) layer

By CTD measurements (in summer) it is determined a termohaline (Tab. 2). Termohaline begin at 10m depth, and the depth of its layer is 30m. Temperature difference in termohaline layer is 10°C. The water with higher salinity and density is in depth layer at all station sites, but picnohaline is practicaly overlape with termohaline. All these factors are appropriate to stop the pollution difusion toward the surface. By CTD measurement is identified a layer of fresh water, at 10-15m depth, at all stations except R3. It can be a consequence of collection of wastewaters which is concentrated in the layer, determined by stratification of density and temperature. In winter campaign is determined an uniform temperature through water column, what is also an expected phenomenon. By this is made a possibility to mix the pollution through whole volume of water. Water temperature was low, in acordance with winter conditions, and uniform within 1 °C at all stations and layers. The same can say for salinity and density. Except significantly low average temperature in winter, average salinity was almost the same in both season. Average density was a little bit higher and uniform in winter, than in summer.

Tab 2: CTD probe data average values

Measuring station	**t,** °C		**Sal,** psu		**Density,** kg/m³	
	summer	winter	summer	winter	summer	winter
T0	20.75	14.41	38.41	38.66	27.20	29.02
T1	20.96	14.46	38.39	38.67	27.12	29.03
T2	20.86	14.40	38.38	38.63	27.14	29.01
R1	20.96	14.59	38.37	38.68	27.10	29.00
R2	21.39	14.66	38.19	38.70	26.84	29.00
R3	25.84	13.78	38.06	38.50	25.42	28.99

Tab 3: Results of physical and chemical parameters, nutrients, chlorophyl-a and TRIX in water column; summer

Measuring station	Water layer	t, °C	pH	BOD_5, mg/l	Sat, %	TOC, mg/l	TN, mg/l	TP, µg/l	Chl-a µg/l	TRIX
T0	S	26	8.20	0.33	84	1.56	0.132	12	0.474	4.65
	M	19.4	8.16	1.56	93	1.52	0.193	15	0.206	2.25
	B	17	8.10	0.60	83	1.23	0.158	6	0.339	4.36
T1	S	26	8.21	0.44	86	1.74	0.143	8	0.306	4.27
	M	19.1	8.18	1.00	92	1.69	0.119	25	0.221	4.12
	B	17.1	8.15	1.97	87	1.31	0.113	2	0.220	3.43
T2	S	26	8.22	1.27	90	1.58	0.095	1	0.338	3.33
	M	18.8	8.18	1.07	93	1.43	0.082	6	0.205	3.62
	B	17	8.16	0.97	85	1.49	0.093	11	0.220	4.19
R1	S	26.1	8.21	0.47	86	1.59	0.146	17	0.267	4.55
	M	19.1	8.18	0.93	90	1.76	0.153	20	0.188	4.36
	B	16.7	8.17	0.85	83	1.40	0.077	6	0.221	3.93
R2	S	26.1	8.21	0.73	85	1.55	0.080	4	0.204	3.75
	M	20.1	8.20	0.93	94	1.64	0.089	11	0.220	3.86
	B	18	8.17	0.96	90	1.65	0.081	13	0.102	3.78
R3	S	26	8.20	1.00	86	2.25	0.097	7	0.203	3.97
	M	25.8	8.22	0.54	89	1.10	0.046	20	0.187	3.95
	B	24.8	8.22	1.57	91	1.08	0.087	20	0.102	3.85

S – surface; M – middle; B – bottom;

Temperature difference in surface and bottom layers was 9-10 degrees. pH were the highest in surface layer, where phitoplancton activity is the highest (Tab. 3). The exceptance is site R3 near coast, where pH is increased with depth. Concentrations and saturation of oxygen were the highest in middle layer, except at R3, but here the water depth corresponds to depth of middle layer of the rest of stations. In surface and bottom layers saturation is 90% or smaller. All values of saturation were bellow 100% and indicate on prevaling organic substances destruction processes. BOD5 was relatively low. TOC was over the prescribed A1 class [11]. Total nitrogen was the highest at T0, than at T1 and R1. Concentrations of total phosphorus (TP) were increased in deeper layers, mainly in the middle. Chlorophyill-a was the highest at transect in surface layer, specially at T0. Index TRIX, as indicator of eutrophication, was the highest at T0, than at R1, T1. The values were not variable so much and indicate on developed eutrophication proces, that comes to moderate eutrophication level. Number of bacteria, specially faecal originated bacteria was very low. The worst bacteriological state was at R3, first of all in bottom layer, where obviously direct influence of communal waste waters discharge at broken submarine pipe, was the highest. Generally, water quality is good and by most of parameters corresponded to prescribed A1 class. Sometimes, ussualy in deeper layers, came to increased concentration of some parameters, which than exceedes the A1 class.

In winter, transparency was significantly lower, probabely due to water density and isothermy, which are approved pollution dispersion through the column. pH (Tab. 4) was higher than in summer, and the highest at transect and R1. Oxygen saturation was lower than in summer, due to missing of production. BOD5 was very low and corresponded to very low amount of organic substances. TOC was significantly higher in winter. At transect, it is related to bottom layer, and to other points, mainly in surface. Concentration of phosphorus was significantly higher as average, than in summer. Increased content of phosphorus can indicate a low phytoplankton activity. Chlorophyll-a was lower in winter and relativelly uniformed by surface and depth. TRIX was higher in winter, than in summer, and indicates a stabile trophic state. At T1 and T2 the highest values of TRIX were at bottom layer, what probably indicates the direction of bottom currant, from coast to open sea.

Concentration of heavy metals in water column was very low in summer, mainly under detection limit. Measurable but the low values had mercury at T1(0.0005 mg/l) and T2 (0.0009 mg/l) in bottom layer, led at T2 (0.044 mg/l) in middle layer, cadmium at R2 (0.001 mg/l) in bottom layer. Arsenic did not measurable. Chromium had the highest concentrations, at R1(0.002 mg/l in middle layer; 0.059 mg/l in bottom layer) and R2 (0.003 mg/l in surface layer; 0.014 mg/l in bottom layer).

Tab 4: Results of physical and chemical parameters, nutrients, chlorophyl-a and TRIX in water column; winter

Measuring station	Water layer	t, °C	pH	BOD_5, mg/l	Sat, %	TOC, mg/l	TN, mg/l	TP, µg/l	Chl-a µg/l	TRIX
T0	S	14.5	8.25	0.2	79	4.89	0.154	40	0.103	4.63
	M	14.2	8.24	0.7	78	4.2	0.113	84	0.102	4.9
	B	13.8	8.21	1.1	83	5.46	0.333	24	0.118	4.41
T1	S	14.9	8.19	0.6	80	6	0.116	76	0.086	4.71
	M	14.7	8.20	0.4	82	3.87	0.051	50	0.118	4.19
	B	13.9	8.25	0.3	80	4.91	0.295	56	0.544	5.62
T2	S	14.2	8.25	0.2	79	6.71	0.120	96	0.118	4.94
	M	14.2	8.23	0.5	78	4.56	0.126	54	0.102	4.73
	B	13.8	8.17	0.2	75	5.31	0.205	52	0.205	5.19
R1	S	14.2	8.25	0.3	76	5.75	0.118	32	0.102	4.54
	M	14.2	8.25	0.4	78	5.63	0.144	20	0.102	4.36
	B	14	8.24	0.3	77	4.7	0.121	30	0.102	4.51
R2	S	14.8	8.21	0.2	78	9.25	0.131	48	0.102	4.66
	M	14.8	8.22	0.2	77	7.5	0.154	62	0.102	4.78
	B	14.4	8.22	0.4	77	5.97	0.138	98	0.102	4.97
R3	S	13.7	8.23	0.3	79	5.59	0.127	64	0.098	4.75
	M	13.7	8.23	0.4	78	5.57	0.131	48	0.221	4.97
	B	13.5	8.21	0.4	80	4.21	0.125	54	0.117	4.94

S – surface; M – middle; B – bottom;

Concentrations of heavy metals in winter were higher, in general. Mercury was measurable at all stations: T0 – 0.0012 mg/l, T1 – 0.0017 mg/l, T2 – 0.0006 mg/l, R1 – 0.0003 mg/l, R2 – 0.0008mg/l and R3 – 0.0113 mg/l. Led is measured at T0 (0.006-0.043 mg/l), T2 (0.007 mg/l) and R3 (0.007 mg/l), cadmium (0.004 mg/l) and arsenic (0.002 mg/l) at R3. In difference, only chromium was not in measurable amount, but in summer this metal was of the highest presence. It can say that the temperature stratification, the sea currants communal waste discharge near the coast, influenced on distribution of heavy metals through water column, as well removing of metals by biota and sediment-water phase equilibrium processes.

Number of bacteria, specially faecal originated bacteria, in summer was very low. The worst bacteriological state was at R3, first of all in bottom layer, where obviously direct influence of municipial wastewater discharge at broken submarine pipe, was the highest. The worst bacteriological state in winter was at transect, first of all at T1 and T2, in bottom layer. Maximal values measured at T1. The state improved toward to surface, at all stations.

Measurements of sediment

Content of chromium in sediment (Tab. 5) was the highest of all other metals, in summer, so that it can cause of increased content of this metal in water. The highest values are measured at transect and R2, and the lowest at R3. Cadmium and arsenic were the highest at R3, but mercury measured at T only. Led was under detection limit.

Tab 5: Concentration of heavy metals in sediment

Measuring station	**Hg**, mg/kg		**Cd**, mg/kg		**Pb**, mg/kg		**Cr**, mg/kg		**As**, mg/kg	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
T	0.02	0.02	0.07	0.10	DL	4.13	736.08	44.71	0.43	0.69
R1	DL	0.13	0.05	0.08	DL	3.31	551.11	57.05	0.38	0.67
R2	DL	0.03	0.04	0.08	DL	3.41	624.35	31.33	0.31	0.59
R3	DL	0.05	0.10	0.10	DL	2.32	420.79	55.65	0.41	0.49

Most of metals in winter had increased content, specially led, which in sumer was under detection limit (Tab. 5). Also, mercury had higher content, measured at R1, R2 and R3, where its content did not measurable in summer. Content of cadmium was stabile in both campaigns. Content of arsenic was higher a little bit in winter. Only content of chromium was higher for a unit of order lower in winter than in summer.

Content of mercury was the highest at R1, led and arsenic at transect (T), cadmium at T and R3 and chromium at R1 and R3. Content of metals in measuring network did not difference significantly, but however indicates that the prevaling distribution done in zone between T, R3 and R1. This can explaned by direction of dominant currants and damage of submarine pipe, because waste waters discharges much more close the coast. Posibility of unic explanation is complicated by complex of processes of adsorption, sedimentation of metals at the bottom, transport of metals through the solid and the liquid phases, dynamics of processes at the border of the solid-liquid phases and resuspension through the water column.

TOC also measured. Low values indicate that sediment is mainly of mineral composition, with very low amount of organic component. It is possible that this is a consequence of lack of waste waters discharge at the zone, also erosion by bottom currants, and fast degradation of organic materials in sediment.

Biological measurements

Photos of sea bottom around outfall and the of damage of the pipe do not give the best possibilities for quality analysis of macrozoobentos, because they are unclear. On the base of available photos it can conclude that at location of end-of-pipe, the sea sediment is sandy and mudy. Bigger macroscopic organisms are not seen, nor at the bottom and pipe. It can not determine with certainty, that at this location there is not smaller organisms, but it can conclude that the sea bottom is depleted and degraded. It was seen a small cover at the damaged part of pipe, who it can expect at the rest part of the pipe. Probabely it is a species of algae Cystoseira foeniculacea. Also, at photos of damaged pipe it looms a community of sea grass Posidonia oceanica, which is a protected species. It is assessed that the long-term waste waters discharge can affect a regresive changes of the community, which live close the site of discharge.

Conclusions

In regular conditions and correct operation of submarine infrastructure, emitted pollution by municipial wastewaters would be most probabely distributed at savefull way, without significant impact to the sea ecosystem, because high depth, direct contact with open sea waters and capture and transport of pollution by dominant sea currants. Determined damage of the pipe at cca 1500m, conditions discharge of wastewaters much more closer to the coast and at lower depth (20m), practicaly in the middle of the bay, so the pollution has transformed under quite other circumstances. In these circumstances, pollutatnts distribute around the bay, where concentrated and transformed in accordance with phisical and biochemical egularities. Bay-currants are much more worse and of opposite direction then general currants at open sea infront of the bay, so the pollution mainly stay captured in frame of

badly mixed bay waters. Obvious consequence of that is increasing of trophic level of waters to moderate eutrophy, the state which is stabile during almost all the year. Furthermore, the effects of wastewaters emission are evidented in bentic biota. In aim to prevent eventual, first of all accidental pollution in this sence is recommended a establishment of permanent monitoring station near end of outfall.

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