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Seawater Quality Measurements at the Two Ports of Patras, Greece †

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Abstract: A monitoring program of seawater quality was conducted during the October 2013–June 2016 period at the port city of Patras. A total of fourteen sampling campaigns were conducted. Eleven sampling sites were selected at the Southern New Port and at the Northern Old Port of Patras, namely at the discharge point of the south outlet of the collecting storm water conduit and at the two river mouths discharging at both sides of the Southern New Port, to evaluate the contribution of surface runoff and harbor activities on seawater pollution. At each site, water quality parameters were determined in situ, and water samples were transferred and analyzed at the laboratory. Taking into consideration the whole set of measurements, it can be concluded that the seawater quality of the two ports is satisfactory in comparison to other coastal zones in the area around Patras and other ports.

Keywords: harbor; seawater quality; physicochemical characteristics; heavy metals; monitoring

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1. Introduction

The city of Patras has two ports, the Southern New Port (SNP) and the Northern Old Port (NOP), serving domestic maritime transport between Patras and the Ionian Islands and foreign maritime transport between Patras and Italy. The SNP of Patras is located at the SW side of Patras city and on the SW shoreline of the Patraikos Gulf, between the rivers Diakoniaris and Glafkos. The SNP has been in operation since July 2011. By the 1980s, along the Patras shoreline, south of the Cathedral Church of Agios Andreas, more than two hundred factories were in operation, discharging mainly raw wastewater into the Patraikos Gulf. Since the 1990s, most of these factories have been relocated to the industrial zone, approximately 20 km further south. Today, in the SNP neighborhood, light industrial and wastewater treatment facilities of Patras are in operation. However, the streams of Diakoniaris and Glafkos receive and transport wastewater from illegal activities in households and other sources that lie along these rivers.

SNP has a platform with a total length of 992 m, built with caissons of reinforced concrete in a zigzag line. It consists of four dock stations with a total of 15 docks (11 for mooring and 4 for side-mooring). The breakwaters of the New Port are 1236 m in total length and are built with caissons of reinforced concrete. The building infrastructure of the port has a total coverage area of 6974 m^2 and includes the passenger terminal station, the port administration building, the fire station, as well as other services and facilities. The New Port serves maritime transport between Patras and Italy.

The NOP of Patras is placed at the shoreline of Patraikos Gulf, NW of the center of Patras City. It has four main piers and wharves of approximately 3 km in total length, with

fourteen mooring waterfronts and a total of eight docks. The breakwater of the Northern Port is 1565 m in total length.

The Technical Department of the Patras Port Authority S.A. assigned a program monitoring the seawater quality to the Environmental Engineering Laboratory (EEL) of the Civil Engineering Department of the University of Patras. Phase I of the program [1] started in October 2013 and finished in January 2015; seven campaigns (Table 1) were carried out in at the SNP area. Phase II started in June 2016 and finished in August 2016; seven campaigns (Table 1) were conducted at both ports.

Table 1. Monitoring campaign schedules.

Monitoring Program Phase	Campaign Number/Date						
I	1st 25 October 2013	2nd 10 February 2014	3rd 12 April 2014	4th 11 June 2014	5th 26 August 2014	6th 30 October 2014	7th 10 December 2014
II	8th 21 June 2015	9th 29 September 2015	10th 8 December 2015	11th 12 February 2016	12th 10 March 2016	13th 8 April 2016	14th 2 June 2016

2. Materials and Methods

2.1. Study Area

After an exploratory visit to the monitoring area, the sampling sites A, A1, A2, B, C, D, E, F1, F2, G1, and G2 were determined (Figure 1). Sites A–C were in the SNP area. Site B was at the discharge point of the southern outlet of the storm water collection conduit. Sites D and E were at the two rivers, which discharge on both sides of the port, namely the Glafkos River and the Diakoniaris River, respectively, to evaluate the contribution of surface runoff and harbor activities to seawater pollution. Site C was a manhole in the southern storm water collection conduit. A visit to this site showed that the flow inside the manhole was insignificant; thus, no samples were collected. Sites F1, F2, G1, and G2 were in the NOP area. Sites F2 and G2 were alternative sites to F1 and G1, respectively. The location and characteristics of the sampling sites are summarized in Table 2.

Figure 1. Map of the sampling sites: A, A1, and A2 inside the SNP of Patras. B—discharge point of the southern outlet of the storm water collection conduit; C—manhole of the southern outlet of the storm water collection conduit; D—on the bank of the Glafkos River; E—discharge point of the Diakoniaris River; F1, F2, G1, and G2—inside the NOP of Patras (Source: www.google.maps.com; access Date: 1 May 2023).

Table 2. Location of sampling sites and their characteristics.

Site	Southern New Port (SNP)	Northern Old Port (NOP)	Glafkos River	Diakoniaris River
Site	A—between docks and breakwater A1—breakwater A2—docks B—storm water pipe outlet C—manhole	F1—between docks and breakwater F2 *—between docks and breakwater G1—docks G2 **—docks	D	E

* Site F2 is an alternative to Site F1. ** Site G2 is an alternative to Site G1.

2.2. Methodology

The sampling procedures and measurements of physicochemical parameters were conducted according to Grasshoff et al. [2]. Especially when examining soluble heavy metals in seawater samples, the methods for seawater analysis proposed by Bloutsos et al. [3] were followed. Soluble heavy metals in river water samples were examined according to Aravantinou et al. [4]. The water temperature (T_{wat}), pH, dissolved oxygen (DO), electrical conductivity (EC), and turbidity (TU) were determined immediately after the collection of the sample or directly by immersing the appropriate probe into the water. In addition, the clarity of the seawater was determined using a Secchi disk. The determination of total nitrogen concentrations (Total N) based on a 2,6-Dimethylphenol spectrometric method [5], while total phosphorus (Total P) and chlorophyll a concentrations were measured according to Grasshoff et al. [2]. More details about analysis and instrumentation are given in APHA et al. [1].

3. Results and Discussion

The results of the in situ measurements of the physicochemical parameters (T_{wat}, pH, DO, EC, and TU) for all sampling sites in each campaign are presented in Figure 2. The seawater results refer to samples from a depth of 1 m. The T_{wat} values of seawater in some sites ranged from 13.9 to 26.1 °C and in other sites from 11.5 to 26.8 °C. pH values from the seawater samples at SNP (Sites A, A1, A2) were very stable (8.1 to 8.4), while those from the sampling sites at NOP (F1/2, G1/2) ranged from 7.8 to 8.4. pH values ranged from 6.8–7.7 at Site B, while pH values from freshwater samples ranged from 6.9–8.2 and 7.1–7.8 at Site D and Site E, respectively. pH levels at Patraikos Gulf were measured in a range of 8.1 to 8.3 [6]. In the seawater in the Rion–Antirrion Bridge area, T_{wat} values were in the range 12.8–24.0 °C and pH values were in the range 8.0–8.4, as reported by [7]. In the seawater of Piraeus and Perama ports, the corresponding values were 8.4 and 8.6, respectively [8]. pH levels at Glafkos River (Site D) measured at a range of 7.3–8.5 during 2014–2015 [9].

TU values in SNP's seawater samples ranged from 0.1 to 45.3 NTU, while those in NOP ranged from 0.9 to 9.9 NTU. During the sampling periods, infrastructure work was in progress in SNP's area. The levels of seawater clarity were observed in the range 0.2–9.9 m. In the seawater at the Rion–Antirrion Bridge area, the turbidity values ranged from 0.4 to 1.2 NTU and the seawater clarity values from 7.5 to 14.5 m [7]. In the seawater of Patraikos Gulf, the clarity measured 5.0–18.0 m in the 2014–2019 period [9].

DO values in the seawater samples from the SNP ranged from 5.1 to 10.1 mg/L, while those in the seawater from the NOP ranged from 4.7 to 9.8 NTU. At Site B, these ranged from 4.8 to 5.9 mg/L, in Glafkos River from 6.3 to 13.5 mg/L, and in Diakoniaris River from 0.5 to 7.7 mg/L. DO values for the Patraikos Gulf reported by [6] ranged from 6.92 to 7.86 mg/L. In the Rion–Antirrion Bridge area, DO values reported by [7] ranged from 5.2 to 9.5 mg/L. In the seawater of the Patraikos Gulf, DO levels ranged from 5.8 to 7.9 mg/L during the 2014–2019 period [9]. As reported by [8], mean DO values were 9.7 and 10.0 mg/L in the seawater of Piraeus Port and Perama Port, respectively. DO levels measured during the 2014–2015 period at the Glafkos River site were in the range 7.2–11.7 mg/L [9].

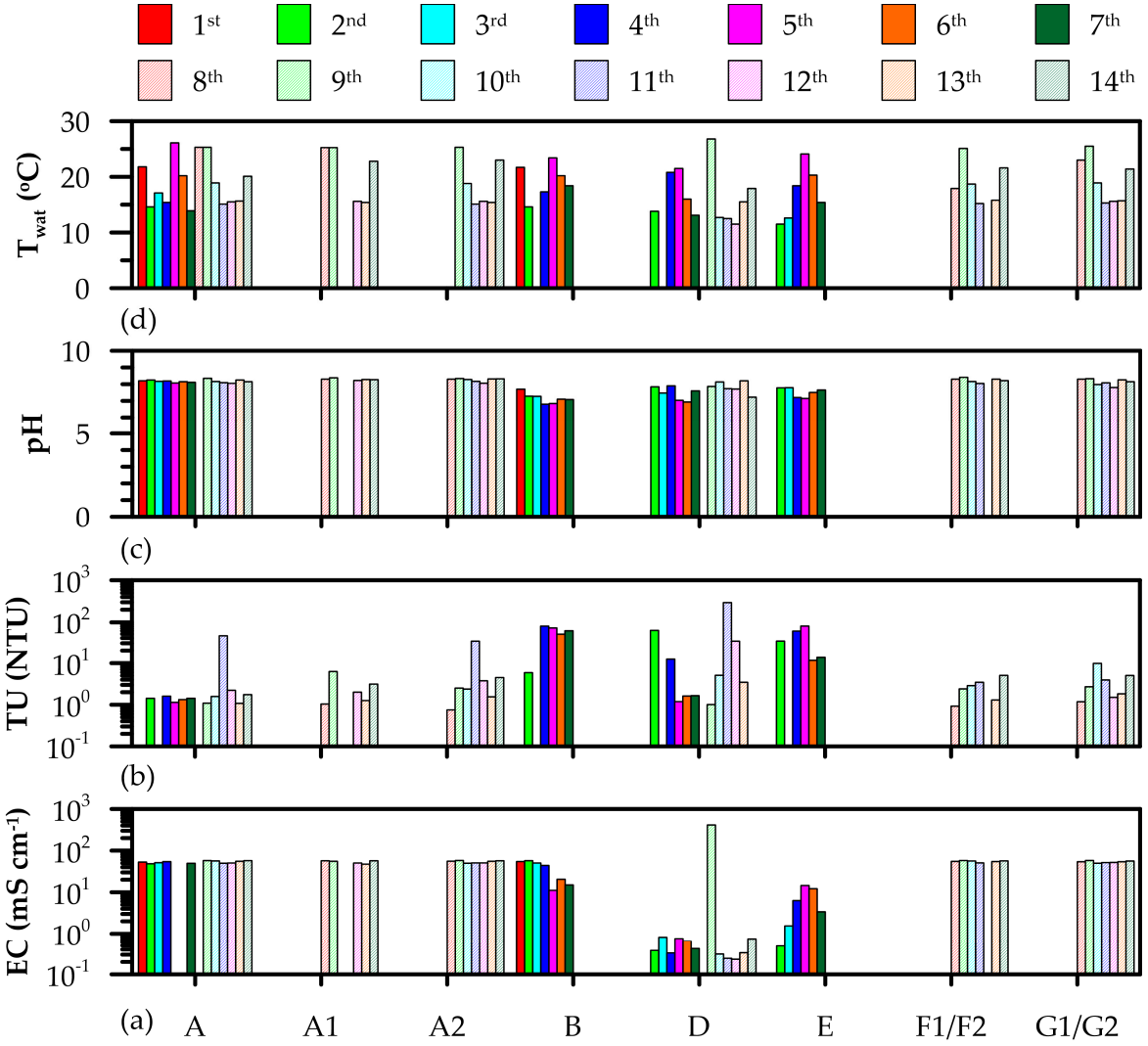

Figure 2. In situ measurements of (**a**) electrical conductivity (EC), (**b**) turbidity (TU), (**c**) pH, and (**d**) water temperature (T_{wat}) at sampling sites of each campaign shown in color.

The EC values at the two ports were almost the same. Seawater samples ranged from 45.6 to 58.6 mS/cm and 45.6 to 58.5 mS/cm at SNP and NOP, respectively. In the Rion–Antirrion Bridge area, the EC values ranged from 56.4 to 58.7 mS/cm [7]. The mean values of EC were 43.5 and 43.8 mS/cm at the Piraeus and Perama ports, respectively [8]. EC values at the Glafkos River ranged from 0.2 to 0.80 mS/cm. An extremely large EC value of 413.5 mS/cm was measured in the 9th campaign. The relative levels in 2014–2015 were 0.3–1.0 mS/cm [9]. At the remaining sites, intermediate EC values were measured due to interactions between sea and fresh water.

The concentration range of heavy metals (Pb, Cu, As, and Sn), total N, total P and chlorophyll a at the sampling areas is presented in Table 3. Total N values in seawater were up to 1.5 mg/L. Higher values were observed at Site B (0.80–7.30 mg/L). According to [9], in 2014–2015, Total N ranged from 0.060 to 0.110 mg/L at Patraikos Gulf. Total P values in seawater were up to 3.35 mg/L, while higher values were observed at Site B (0.14–20.30 mg/L). Total P ranged from 0.004 to 0.007 mg/L in the Patraikos Gulf during 2014–2015 [9].

Table 3. Heavy metals (Pb, Cu, As, and Sn), total N, total P and chlorophyll a concentration ranges at the sampling areas.

Area (Sampling Site)	Element						
	Pb (μg/L)	Cu (μg/L)	As (μg/L)	Sn * (μg/L)	Total N (mg/L)	Total P (mg/L)	Chlorophyll a (μg/L)
Southern New Port (A, A1, A2)	<10	<5–8	<3–5.8	<3–6.6	<0.5–1.2	0.02–3.35	0.00–2.90
Southern New Port (B)	<10	<10	<3	-	0.8–7.3	0.14–20.30	0.73–4.00
Northern Old Port (F1, F2, G1, G2)	<3	<5	<3	<3–5.7	<0.5–2.2	0.02–0.73	0.11–0.98
Glafkos River (D)	<10–15	2–18	4–15	212–360	<0.5–20.5	0.02–2.5	0.00–10.8
Diakoniaris River (E)	<10	<10	<10	-	0.5–6.7	0.11–11.00	0.03–1.72

* Sn sampled only during monitoring period of Phase II.

Total N concentrations ranged from 1.2 to 20.5 mg/L and from 1.2 to 6.7 mg/L at the sampling sites of the Glafkos River and the Diakoniaris River, respectively. Total P concentrations ranged from 0.02 to 2.5 mg/L and from 0.11 to 11.00 mg/L at the sampling sites of the Glafkos River and the Diakoniaris River, respectively. According to [9], during the 2018–2021 period, Total P ranged from 0.002 to 0.013 mg/L in the Glafkos River.

Chlorophyll a concentrations in seawater ranged from 0 to 2.9 μg/L at both ports. Higher values were observed at sampling site B (0.73–4.00 μg/L) due to the discharge of the storm water conduit. Regarding [9], during 2014–2015, chlorophyll a ranged from 0.16 to 0.28 μg/L in the Patraikos Gulf. Chlorophyll a levels outside the port areas ranged from 0.07 to 6.06 μg/L [10]. Chlorophyll a values in Glafkos River were up to 10.8 μg/L.

Pb concentrations were below the detection limit (LOD) in seawater samples during the two monitoring periods (Phase I: LOD = 10 μg/L; Phase II: LOD = 3 μg/L). According to [9], the Pb concentration was 0.06 μg/L at Patraikos Gulf in September 2014. Pb concentration values at the ports of Piraeus and Perama ranged from 72 to 360 μg/L [8]. At the New Port, Cu values ranged from LOD = 5 μg/L up to 8 μg/L, while at the Old Port all values where below the LOD. In September 2014, Cu concentration was 0.31 μg/L in the Patraikos Gulf [9]. These concentrations were much lower compared to Cu concentrations at the Ports of Piraeus and Perama (29–65 μg/L). Similarly, As ranged from ≤3 to 5.8 μg/L in all seawater samples, while the corresponding values in the Glafkos River ranged from 4 to 15 μg/L, confirming that arsenic in coastal regions originates primarily from the surrounding rivers, as shown in the results of previous studies [11].

Sn concentration values were slightly lower at the Old Port (<3–5.7 μg/L) compared to Sn levels at the New Port (<3–6.6 μg/L). Sn concentration levels in the Glafkos River were higher, ranging from 212–360 μg/L. Sn levels in seawater are higher compared to typical seawater Sn levels [12]. Sn levels in freshwater are higher than in seawater. These high concentrations are associated with industrial waste discharges into the river [12].

4. Conclusions

The results of seawater quality measurements at the Southern New Port (SNP) and Northern Old Port (NOP) of Patras, Greece, during the fourteen campaigns, and when compared to each other, both the older or more recent measurements at approximately the same locations at the ports and in the Patraikos Gulf, as well as in other port areas of Greece, showed that the maritime area of the SNP and NOP had satisfactory DO levels. The pH of seawater was in the same range as previously reported measurements in the major Patraikos Gulf area. Infrastructure work activities in the maritime and seacoast areas of the Patras SNP areas contributed to an increase in turbidity and a decrease in water clarity levels in comparison with other areas of the Patraikos Gulf. However, this effect is temporary. The Glafkos River also contributes to clarity reduction. EC values of the SNP seawater samples were about 17% lower than those measured previously in

the Rion–Antirrion Bridge area, which may be attributed to the inflow of freshwater from the Glafkos River and the Diakoniaris River, which have significantly lower pollution. The EC seawater values were about 15% lower than those measured previously in the Rion–Antirrion Bridge area.

Additionally, lower EC values in freshwater discharge (Glafkos River and Diakoniaris River) contribute to decreased EC concentrations in seawater samples. The heavy metal (Pb, Cu, and As) concentration levels in both seawater and freshwater samples were quite low. In contrast, Sn levels in seawater and freshwater samples were 2–3 and 3–4 times higher than the typical values.

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