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# Application of a multiparameter sonde for real-time monitoring of seawater quality in Durrës Bay in Albania

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## ABSTRACT

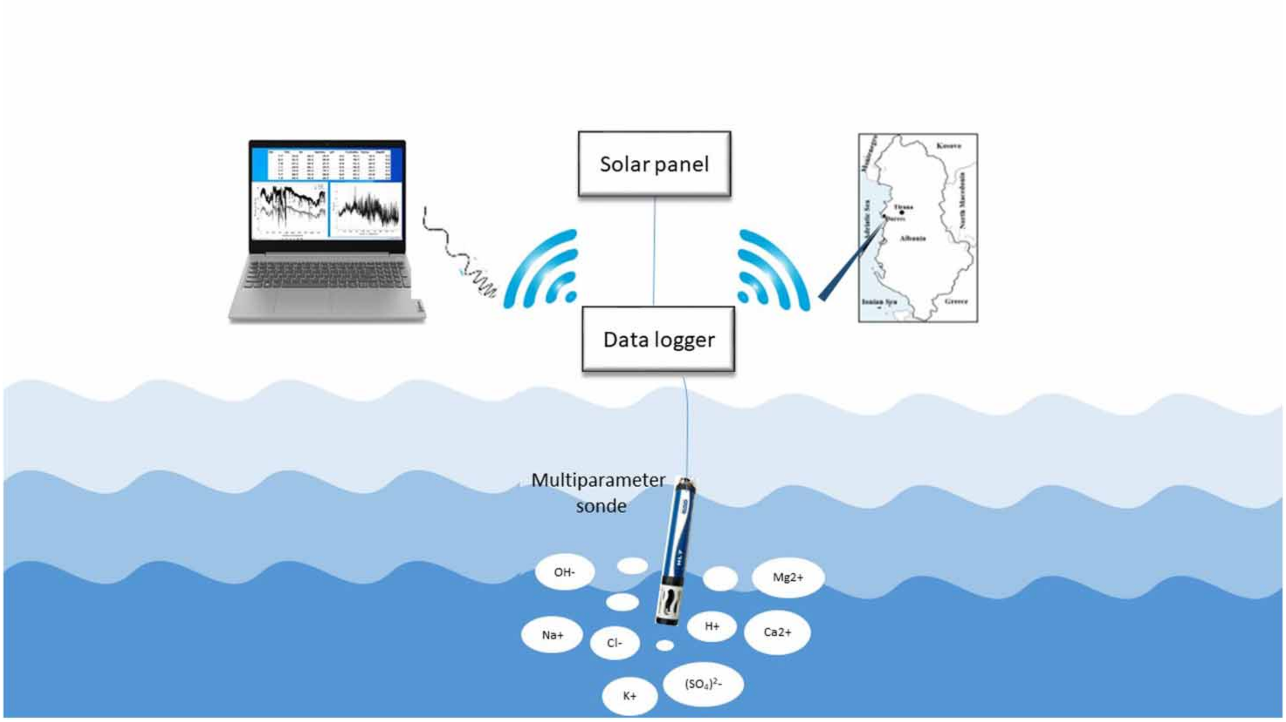
Coastal areas are characterized by a high population and a wide range of industrial and agricultural activities, which puts them under high pressure and continuous pollution from anthropogenic activities. This research focuses on the application of HYDROLAB HL7 multiparameter sonde equipped with smart sensors for the measurement of physical–chemical parameters in marine waters in the Durrës Bay. The sonde is part of a transnational repository network that receives, stores, and analyzes data about seawater quality, serving as an early warning system for preventing the diffusion of marine pollution. This sophisticated instrument can thrive in demanding environmental conditions for long-term continuous monitoring. It maximizes deployment lifespan, and provides traceable data for high-quality, reliable monitoring of vital changes in water quality. Low variability on the measured parameters indicates a stable status in the water quality of the Durrës site. Time series revealed small seasonal variations on all parameters, except turbidity and water temperature. Total dissolved solids, salinity, and electrical conductivity revealed similar temporal trends over the monitoring period by indicating strong relationships between them. The obtained data for the physical–chemical parameters in this study align with the recommended values. Ensuring water quality in the Durrës Bay requires advanced monitoring, regulatory measures, and community engagement.

**Key words:** coastal area, Durrës Bay, marine water quality, multiparameter sonde, physical–chemical parameters

## HIGHLIGHTS

- A real-time multi-sensor probe was used to measure the physical–chemical parameters in marine water.
- Temperature, conductivity, pH, DO, turbidity, and depth were measured directly.
- Total dissolved solids and salinity were calculated through built-in correlations.
- Physical–chemical parameters provided valuable information on water quality.
- The measured parameters revealed good water quality in the Durrës Bay.

## GRAPHICAL ABSTRACT



## 1. INTRODUCTION

Coastal areas are the most developed regions, characterized by a high population and a wide range of industrial and agricultural activity, which puts them under high pressure and pollution from various natural and anthropogenic hazards. Those have large social, economic, and environmental values and are pointed out as the most productive zones that provide social and economic benefits to humans (Melet *et al.* 2020). Among natural hazards, the extreme heat waves that cause fish mortality, large sea waves and changes in sea levels, erosion and salinization of aquifers, low oxygen content, and acidic degradation are dangerous phenomena (Melet *et al.* 2020). At the same time, anthropogenic activities like maritime pollution, eutrophication, overfishing, degradation or loss of marine and coastal ecosystems and habitats (Melet *et al.* 2020), and uncontrolled urban and industrial discharges degrade the water quality. The quality of coastal water plays an important role in the sustainable development of coastal areas, particularly from the point of view of aquatic life and tourist activity. Coastal areas are very important as they have been associated with depressive tendencies in sea surface warming trends over the past few decades. This association is related to the ability of coastal areas to slow down global warming trends and reduce the extreme events of marine heatwaves (Marin *et al.* 2021). For this reason, monitoring and understanding marine coastal environmental status and hazards are of increasing interest. A variety of instruments and sensors have been developed and have been used to monitor the characteristic parameters of coastal water essential for indicating the pollution level.

Seawater monitoring represents a fundamental component in the field of marine science. It offers a systematic and data-based approach for comprehending the complex interactions within aquatic ecosystems. The significance of monitoring seawater extends far beyond the scientific realm, as it underpins our ability to comprehensively assess the health of marine ecosystems, track climate change effects, and manage vital coastal resources. Monitoring and assessing marine water quality is a paramount concern due to its implications for public health, ecosystem sustainability, and the economic well-being of the region.

The Mediterranean Sea is the most densely populated closed sea in the world. This concentration is intensifying year after year and generating more pollution and disturbance, leading to environmental degradation and increased risks for coastal populations and infrastructure (UNEP/MAP & Plan Bleu 2020). The Mediterranean Sea has approximately 150 million inhabitants on its coasts. In addition to numerous tourists, high levels of industrial and shipping activities are causing a rapid increase in marine pollution. This is combined with other anthropogenic drivers of environmental change, including climate change (e.g., seawater temperature, heatwaves, salinity, acidification, extreme events, and sea-level rise), unsustainable land- and sea-use practices, and non-indigenous species (Ziveri *et al.* 2023). Intensive human activities along the coastlines of the Mediterranean Sea increase the pressure on its marine environment, making it one of the most polluted sea environments in the world (Karadirek *et al.* 2019). Pollution in this area can harm aquatic life, degrade water resources, and undermine the very foundations of a thriving maritime economy. Therefore, understanding the main pollution sources, trends, and impacts is essential for formulating effective mitigation strategies and safeguarding the Mediterranean environment.

Marine pollution from the growing urbanization of coastal areas has increased the number of land- and sea-based pollution sources, including shipping and the exploitation of marine resources. The effects of growing marine and coastal tourism have caused different negative impacts, like increasing amounts of untreated sewage and waste, the degradation and loss of coastal habitats, and a loss of biodiversity (World Bank Report 2020).

Rapid urban developments have affected the cleanliness of the Albanian coast. The Adriatic and Ionian Seas have become hosts for urban, industrial, agricultural, and livestock discharges. Numerous spills occur from pesticides, raw chemicals from agricultural lands, organic waste containing phosphorus and nitrogen, viruses and pathogenic bacteria, heavy metals, etc. In addition to this, the increased number of inhabitants in the urban centers has made the process of self-cleaning the sea impossible (WFD and Eco Albania 2021).

The importance of marine water monitoring in mitigating marine incidents lies in its ability to quickly detect and prevent problems such as oil spills, waste dumping, thermal pollution, and harmful algal blooms. This facilitates a prompt reaction to such incidents, reducing their negative effects on marine ecosystems, coastal communities, and the economy. Although there has not been any major maritime oil spill incident within the Mediterranean region, accidents are considered inevitable occurrences, and the risk of one happening in the near future cannot be ruled out (Bellefontaine *et al.* 2016). The research data presented in this paper were obtained during the implementation of the Interreg ADRION project SEAVIEWS (SEctor Adaptive VIrtual Early Warning System for Marine Pollution), aiming at the development of a transnational repository network that receives, stores, and analyzes data about seawater quality from a network of smart sensors installed in the Adriatic and Ionian Seas (Interreg ADRION n.d.). The core of this network is the innovative web-based platform that reads, stores, and analyzes the input data from three main categories: data from the smart sensor network allocated in critical points in the ADRION area; data from the users of developed mobile application (photographs, videos, and GPS coordinates related to oil spills, marine litter, industrial discharges, or other relevant observations); and data from available databases in the area. The analyses applied to the data within the platform include descriptive statistics, which involve calculating statistical measures as a basis for more advanced types of analyses. In addition, big data analytic techniques are implemented, utilizing smart algorithms for managing and discovering patterns and relationships within large datasets, which may otherwise be overlooked or ignored. By leveraging these analyses, the web-based platform aims to uncover hidden patterns, provides a solid foundation for data-driven decision-making, and helps facilitate proactive measures to address environmental pollution in the ADRION area. The SEAVIEWS web platform enables different levels of access and involvement for the marine stakeholders, like Marinas and Port authorities, other marine organizations, civil emergencies authorities, NGOs, and so on.

In this paper, we will utilize comprehensive monitoring data, scientific analysis, and the latest research findings to evaluate the state of water quality in the area of the Port of Durrës, on the Albanian Adriatic coast, offering valuable insights for decision-makers, environmental authorities, and port operators.

## 2. MATERIALS AND METHODS

### 2.1. Monitoring site

Durrës Bay is about 18 km long from north to south, with a coastline of about 20 km to the east. To the west, the waterline is more than 10 m deep. The Durrës Bay is well protected by the Durrës Cape, which provides shelter from the east through to the northwest, but the main breakwater, which was built in a southeastern direction from the shore, extends that shelter through to the south. The City of Durrës lies in the geographical position latitude 41°19′ North and longitude 19° 27′ East. It is about 35 km away from the capital Tirana, 300 km from the port of Bari, and 200 km from Brindisi, Italy. Durrës city has 292,029 inhabitants (INSTAT 2021) and represents the most important transport, maritime, road, and touristic hub in the country (WBG 2016). Most environmental problems on the coast are caused by poor wastewater treatment, the lack of effective municipal waste collection and recycling, and intense port activities.

The Port of Durrës is an important maritime hub that serves not only as a crucial gateway for the Albanian economy but also plays a pivotal role in the broader context of Adriatic maritime commerce. It is the principal port in Albania, handling roughly 90% of the country's international maritime trade tonnage and 85% of all the country's export and import trade. As a vital interface for the country on the Adriatic coast, linking Albania with other Mediterranean and Balkan countries, it opens up the country to an additional market of 40 million people. The current level of traffic is about 3.8 million tons of cargo per year and approximately 80,000 passengers (Metalla *et al.* 2016). The ferry terminal in Durrës is the gateway to Albania and the Balkan region, with ferry connections to Italy. More than 850,000 passengers, 185,000 cars, and 76,000 cargo units pass the terminal annually (AFTO n.d.). Seaports and terminals are major hubs of economic activity and major sources of pollution. Port operations can cause significant damage to water quality and, subsequently, to marine life and ecosystems. These effects may include contamination of commercial fish and shellfish, depletion of oxygen in water, and bioaccumulation of certain toxins in fish. Major water quality concerns at ports include wastewater, the leaking of toxic substances from ships, storm water runoff, and dredging. The presence of polycyclic aromatic hydrocarbons and other priority organic pollutants in the waters of Durrës Bay has been reported recently (Halo *et al.* 2023).

Nowadays, the Durrës Bay faces unique challenges in urban development and water pollution. The surge in tourism and population growth has led to increased pressure on the bay's urban infrastructure. Inadequate waste disposal systems and outdated sewage treatment facilities contribute to elevated levels of pollutants entering the water. The bay's delicate ecosystem faces threats from industrial and port activities, as well as from urban expansion. Addressing these issues requires a holistic approach, integrating modernized infrastructure, stringent environmental regulations, and community engagement to ensure the sustainable development of the area. Recently, the construction of the Yacht Marina was started in Durrës. This project is expected to bring economic growth to the area and a further development of tourism.

### 2.2. Measuring equipment

The HYDROLAB HL7 multiparameter sonde was chosen for seawater measurements. This sophisticated instrument can thrive in demanding environmental conditions for long-term continuous monitoring. It maximizes deployment lifespan, lowers maintenance needs, and provides traceable data for high-quality, reliable monitoring of vital changes in water quality. The Operating Software streamlines data collection and calibration tasks necessary to validate accurate data. The battery life is 90 days, the maximum measuring length is 200 m, and the measuring frequency can arrive at one measurement per second. The sonde helps environmental scientists to correctly log data autonomously and integrate it into real-time telemetry systems. The equipment can be adjusted for static measurements as well as for use on moving vessels, offering increased flexibility in monitoring campaigns.

The HL7 sonde, with a large sensor suite, is able to thrive in demanding environmental conditions for long-term continuous monitoring. Bio-fouling is minimized when equipped with the central cleaning brush, and performance is maximized with an advanced power management system (OTT HydroMet n.d.). The HL7 sonde held the sensors for temperature, conductivity, pH, dissolved oxygen (DO), turbidity, and depth. Other parameters, such as salinity, total dissolved solids (TDS), and oxidation–reduction potential, were calculated through built-in correlations. The data logger connected to the sonde was programmed to acquire data and send them every 15 min to the server.

The HL7 multiparameter sonde with the data logger and power supply system was installed in the Durrës Bay at the coordinates 41°18′31.5″N 19°26′19.8″E (Figure 1).

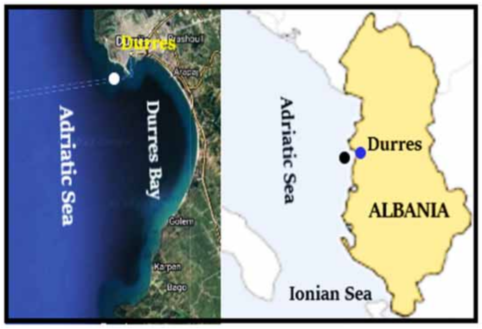


**Figure 1** | HYDROLAB HL7 multiparameter sonde installation site in the Durrës Bay, Albania.

### 2.3. Data curation and analysis

This research is part of the SEAVIEWS Project, which aims to enhance the ability to address environmental vulnerability, fragmentation, and the protection of ecosystem services in the Adriatic Sea. This is enabled by using a network of smart sensors allocated at critical points and supporting the establishment of digital labs to be used as channels for information, data analysis, and research results to be circulated to the general public. In our study, data analysis was carried out through statistical analysis.

Descriptive statistical analysis was used to check the concentration level and variability of the investigated parameters. Pearson's Rho correlation was applied to investigate the associations between parameters ($p < 0.05$) and then factor analysis (FA) was used to clarify the association between parameters and discuss the probable sources of their association. FA groups the investigated parameters into different factors based on their similarity level (Pearson correlations). FA is an important tool for extracting useful information from the investigated data after grouping the variables into separated factors. Time series are used to visualize the distribution of the data during the full monitoring period and to compare the measured data with the recommended values of each parameter.

The measured data for each parameter were transmitted every 15 min to the computer for the entire period under study, December 2021–November 2022. It was observed that in about 10.8% of the total number of measurements ($N = 3{,}772$ out of 35,040 measurements), the sonde did not transmit data for any of the parameters in the study. For some of the parameters, such as TDS, salinity, and turbidity, this number was higher. For this, the correlation between the parameters was studied, and it turned out that between electro-conductivity and TDS, as well as salinity, there was a very strong correlation ($r \approx 1$, $p = 0.000$). Based on it, the linear regression between TDS–electrical conductivity (EC) and salinity–EC was studied.

TDS is an important parameter for the characterization of natural waters for environmental, geochemical, and petrochemical studies. The method of determining TDS through linear correlation with the EC of groundwater, surface water, or marine water systems has found wide use (Rebello *et al.* 2020) due to its advantages over the gravimetric method. It consists in the weighing of the dry residue obtained from evaporating a certain volume of a filtered water sample (APHA/AWWA/WEF 1995).

The relationship between TDS and EC is often described in the literature (Rebello *et al.* 2020, after the review from Walton 1989; Siosemarde *et al.* 2010; Rusydi 2017) by Equation (1) that remains linear over a certain range of water salinity, which is equivalent to TDS.

$$\mathrm{TDS} = k \times \mathrm{EC} \tag{1}$$

where $k$ is a correlation factor and EC is the electrical conductivity. The correlation factor shows different values for different water systems like groundwater, surface water, or marine water systems. It ranges from 0.5 to 0.75 for various water types (after the review from Walton 1989; Siosemarde *et al.* 2010; Rusydi 2017) over a certain range of water salinity (after the review from Rusydi 2017). In general, the EC of an aqueous solution depends on the activity of each specific dissolved ionic component and the average activity of all in the solution, which causes a nonlinear relationship between TDS and EC (Hubert & Wolkersdorfer 2015). The TDS of seawater is composed of inorganic components, mainly sodium and chloride ions, and less calcium, magnesium, sulfate, bicarbonate ions, as well as a few dissolved organic components (Rebello *et al.* 2020, after the review from Siosemarde *et al.* 2010; Rusydi 2017). In this regard, we tried to linearize the TDS–EC relationship by using the TDS and EC data measured during December 2022 and November 2023 and controlled by temperature and salinity. As the data on temperature and salinity showed low variability (25 and 13%, respectively) (Table 2), a good linear relationship between TDS and EC was obtained (Table 1). After that, the missing TDS and salinity values were calculated based on the relevant equations shown in Table 1.

**Table 1** | Regression analysis: TDS (g/L) versus EC (mS/cm) and salinity (PSU) versus EC (mS/cm)

| Regression analysis | Regression equation | Model summary | | |
|---|---|---|---|---|
| TDS (g/L) versus EC (mS/cm) | $\mathrm{TDS} = -0.00391 + 0.6401\ \mathrm{EC}$ | $S$<br>0.0289 | $R^2$<br>99.99% | $R^2$ (adj)<br>99.99% |
| Salinity (PSU) versus EC (mS/cm) | $\mathrm{Salinity} = -2.892 + 0.7133\ \mathrm{EC}$ | $S$<br>0.0980 | $R^2$<br>99.92% | $R^2$ (adj)<br>99.92% |

**Table 2** | Descriptive statistical analysis of the obtained data

| Variable | *N* | *N** | Mean ± SD | CV% | Min | Q1 | Median | Q3 | Max | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DO (mg/l) | 31,252 | 16 | 8.1 ± 0.796 | 10 | 5.7 | 7.6 | 8.1 | 8.6 | 12 | 0.01 | −0.11 |
| TDS (g/l) | 31,263 | 5 | 27 ± 3.2 | 12 | 10.3 | 25 | 27 | 29 | 33 | −0.64 | 0.96 |
| EC (mS/cm) | 31,263 | 5 | 42 ± 4.9 | 12 | 16.2 | 39 | 42 | 46 | 52 | −0.64 | 0.96 |
| Salinity (PSU) | 31,263 | 5 | 27 ± 3.5 | 13 | 9.5 | 25 | 27 | 30 | 34 | −0.55 | 0.65 |
| pH | 31,262 | 6 | 8.8 ± 0.08 | 1 | 8.5 | 8.7 | 8.8 | 8.8 | 9.1 | 0.09 | −0.17 |
| Turbidity (NTU) | 25,805 | 5,463 | 221 ± 400 | 181 | 0 | 26 | 52 | 179 | 2,000 | 2.63 | 6.54 |
| Water Temp (°C) | 31,266 | 2 | 18.7 ± 4.7 | 25 | 10.3 | 14.1 | 19 | 23 | 29 | 0.11 | −1.22 |
| Depth (m) | 31,252 | 16 | 3.0 ± 0.125 | 4 | 2.63 | 2.95 | 3.0 | 3.1 | 3.6 | 0.28 | 055 |

## 3. RESULTS AND DISCUSSION

The common physical–chemical parameters of seawater, such as depth, DO, EC, pH, temperature, TDS, turbidity, salinity, and water temperature, have been continuously measured *in situ* from December 2022 to November 2023. After correcting the missing data, all parameters were analyzed using the descriptive statistics model (Table 2). The significant variations in physical–chemical parameters along these lines are shown in Table 1 and Figure 2.

Table 2 shows that the sensor for turbidity measurement did not function and did not transmit data to the server for a period of 48 days ($N^* = 5{,}463$ measurements). Other sensors functioned normally ($N^* = 2$–16 measurements). All parameters in the study, with the exception of turbidity, were quite stable for the entire period under study, with a very low variation (CV%: 1–25% $\leq$ 25%) and a narrow range of data fluctuation (skewness and kurtosis are close to 0).

The boxplot diagrams revealed a relatively stable situation for pH, depth, and water temperature parameters. It is supported by descriptive statistical parameters, which revealed narrow ranges and symmetric outliers of their respective data on both sides of minimum and maximum values (8.8 ± 0.08 for pH, 3.0 ± 0.125 for depth, and 18.7 ± 4.7 for water temperature). Higher outlier values greater than the median concentration were detected for DO, and EC, TDS, and salinity revealed

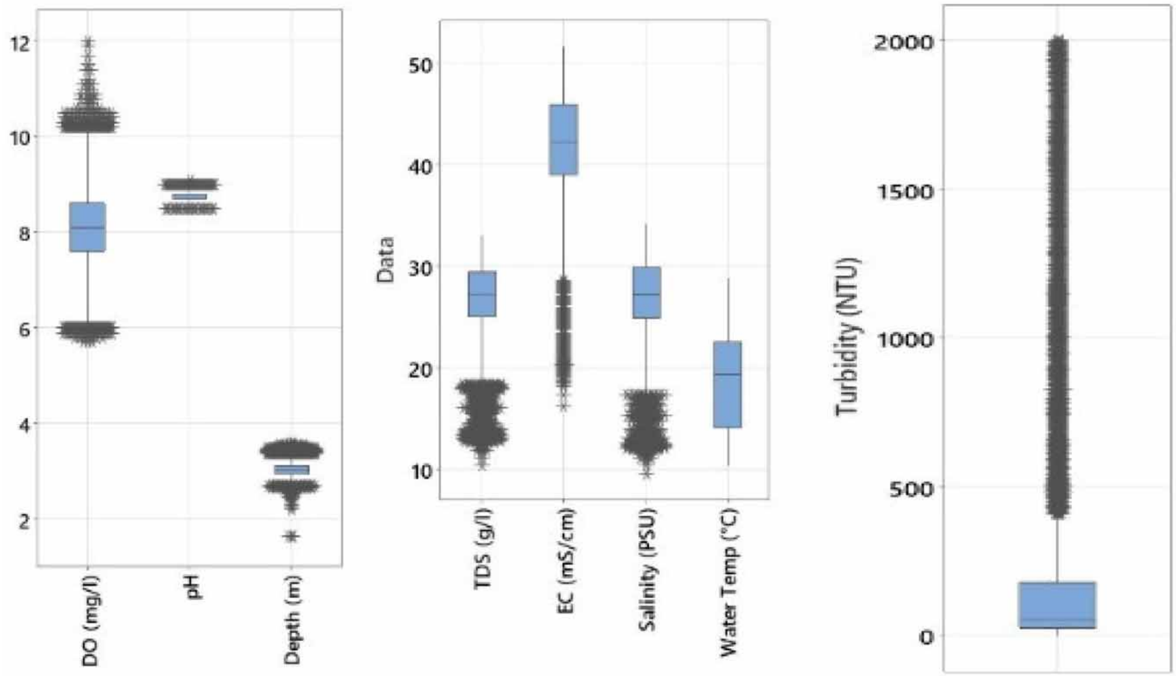


**Figure 2** | The boxplot diagrams of descriptive statistical data.

the data are skewed, leaving a high number of outlier values lower than their respective median values. Turbidity is the sole parameter that shows very high variation (CV% = 181% > 75%). It revealed a high concentration level and a great number of outlier data, higher than the median value, indicating that the data are skewed right.

The time series of the measured data show a temporal trend of the investigated parameters measured for 12 months, from December 2022 to November 2023. A few spikes in data caused by spontaneous factors (6.6% of the total data for the depth values and less than 0.27% of the total data for other parameters) do not affect the values of descriptive statistical data, obtained from 35,040 measurements for all parameters.

### 3.1. Water temperature

Temperature affects water parameters such as solubility and chemical equilibria of oxygen, gases, and other chemicals in water. It has a strong effect on the biodegradation process of organic material in water and sediment, which increases the oxygen demand and affects the DO level. The measured temperature ranged from 10.3 to 29 °C. It revealed a symmetrical distribution of Q1 (14.1 °C) and Q3 (23 °C) around the median temperature value (19 °C) (Table 2). Water temperature showed seasonal variation, with lower values in the winter and higher values in the summer (Figure S1 in the Supplementary Material). The water temperature of the Adriatic Sea during 2019 ranged from 13 °C in February and up to 27 °C in August.

In the northern Adriatic Sea, the surface temperature near the coast ranges from about 5 °C in winter to 27 °C in summer, with a difference greater than 20 °C observed between winter and summer (Russo & Artegiani 1996). The temperature values recorded in the Adriatic Sea at the Durrës site (10.3–29 °C) match with the temperatures recorded in the southern Adriatic Sea, higher than 13.5 °C (Russo & Artegiani 1996). Higher temperatures (10.3–29 °C) were recorded during 2023 at the Durrës site compared with those recorded in the northern Adriatic Sea (5–27 °C). It is affected by the geographical position of Durrës site and the trend of temperature increases due to global climatic changes, with a mean value of 1.27 °C during the 35-year study of the period 1982–2016 (Pastor *et al.* 2018) and about 1 °C in southern Albania since 1970 (Knez *et al.* 2022). Compared with the surface water temperature of Durrës coast published by Gjiknuri (1995), the minimum value increased by 2.6 °C, from 7.7 °C in 1995 to 10.3 °C in 2022, while the maximum value remained the same.

The temperature variation from the northern to the southern Adriatic Sea is about 8 °C greater in winter (Russo & Artegiani 1996; Lipizer *et al.* 2014), which is in the same range as the measured temperature of the Durrës site. The temperature of the Durrës site is lower in winter (10.3 to about 15 °C, Figure S1 in the Supplementary Material) and reaches its maximum level (29 °C) in summer (Figure 3). It is a normal range of temperature for fish growth (8–30 °C) (Alabaster & Lloyd 1980) and indicates the good condition of the water at this site. Temperature variation at the sea surface is important, because it controls the evaporation process and salinity level and contributes to water density and water circulation (Emeis *et al.* 2000).

### 3.2. TDS, salinity, and EC

EC and salinity are both related to the dissolved matter (TDS), the final product of which is the forming of ions of dissolved salts and other compounds, including organic compounds present in water. This makes EC directly related to TDS and salinity, which is used to check the TDS and salinity measurements. Figure 4 clearly shows the similarity between temporal trends and the relationship between TDS, salinity, and EC data.

TDS, salinity, and EC data revealed the same temporal trend over the full monitoring period, indicating a strong relationship between them. The measured TDS, salinity, and EC ranged within a narrow interval (10.3–33 g/L for TDS, 9.5–34 g/L for salinity, and 16.2–52 mS/cm for EC) and revealed a symmetrical distribution around median values (Table 2).

Salinity is an important parameter of seawater quality because it has a strong effect on the marine biota. The South Adriatic Sea shows high salinity (>38.6 PSU) and low variability (Lipizer *et al.* 2014). A similar situation was observed at the Durrës site, with Q1–Q3 recorded from 25 to 30 PSU and a mean value of 27 ± 3.5 PSU. Some fluctuations of lower salinity were observed during the rainy seasons of spring and autumn. A higher salinity change was recorded in the Eastern Mediterranean Sea (Emeis *et al.* 2000).

EC data show a constant situation during the full monitoring period, evaluated by low variability (CV% = 12% < 25%) and low kurtosis ($K = 0.96 < 3$). This indicates a narrow range of EC (mean ± SD = 42 ± 4.9) and a relatively stable water composition. Siosemarde *et al.* (2010) mentioned the presence of many cases of reasonably constant water composition in a given region or study site.

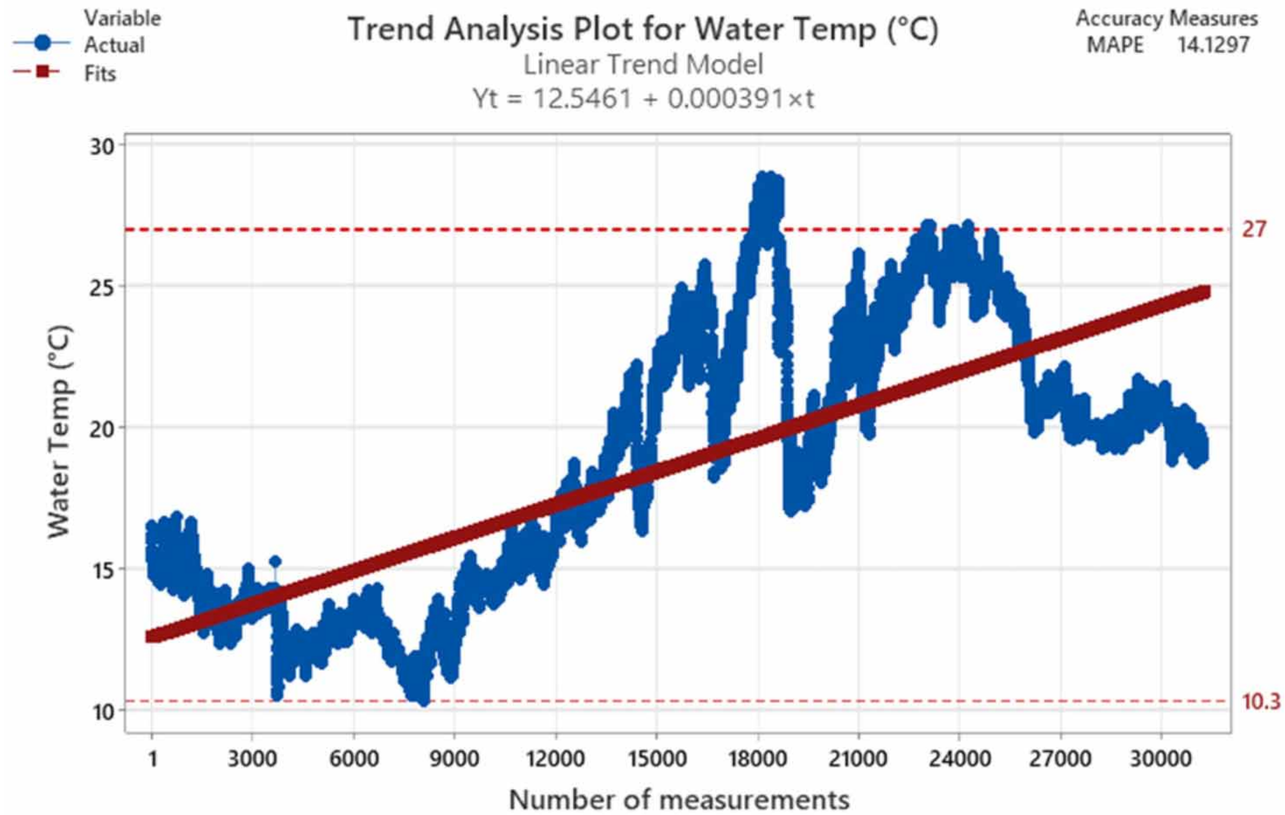


**Figure 3** | The variation of water temperature (in °C) measured in Durrës site from December 2022 to November 2023.

### 3.3. pH

The pH of aquatic ecosystems depends on the chemical and biological activity of the water. In general, pH is relatively stable. The changes in pH values are usually caused by anthropogenic pollution, photosynthesis, or the respiration of algae and bacteria. Most ecosystems are sensitive to changes in pH, and the monitoring of pH has been incorporated into the marine water standards (PHILMINAQ 2008). On the other hand, under the great effect of the carbonate–bicarbonate buffer system in seawater, the pH of the water remains quite stable (Trang *et al.* 2020).

The data presented in Table 2 and Figure 5 confirmed a very stable status of seawater at the monitoring site. The pH values ranged from 8.5 to 9.0, with a mean value of 8.8 ± 0.08 and a median of 8.8, followed by very low variability (CV% = 1%) of pH at the monitoring site during the full monitoring period. The pH of surface seawater was usually quite constant at around 8.2 (Hansen 2002). The median value of pH (8.8) measured at the Durrës site was higher than the pH value (8.2) reported by Hansen (2002), but was similar to the seasonal distribution of median pH in the surface waters of Mariager Fjord, Denmark, reported for a 10-year period (1990–1999). However, higher pH values in marine water may not be considered uncommon, as pH has not been considered an important determinant of pelagic processes, and papers regarding the possible effects of pH on the growth and succession of marine phytoplankton are sparse (Hansen 2002). The pH values of 8.9–9 were found in May 2023. The increase in pH in surface marine waters is caused by biological and physical processes such as inorganic carbon uptake by phytoplankton during photosynthesis, while the release of $CO_2$ through respiration processes is followed by a decrease in pH value (Hansen 2002). The pH increase in May 2023 is not clear. Despite that, the measured pH values are acceptable, as the accepted range of pH suitable for fish growth and supporting aquatic life is from 6 to 9 (PHILMINAQ 2008).

### 3.4. Dissolved oxygen

DO is an important environmental parameter for good surface water quality. It revealed seasonal variation with lower values in winter (December, January, and February), increased in March and April. The measured values reached the maximum

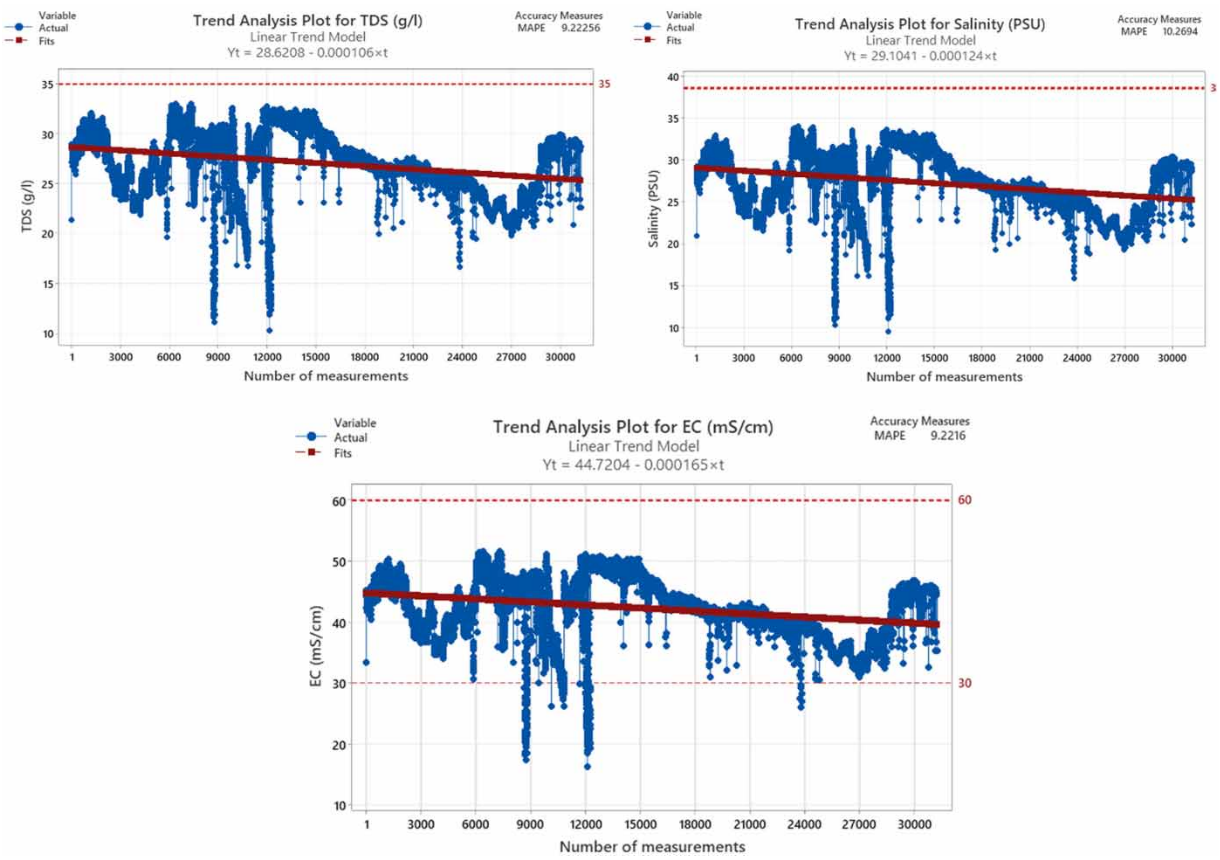


**Figure 4** | Time series of TDS, salinity, and EC data (in mg/L).

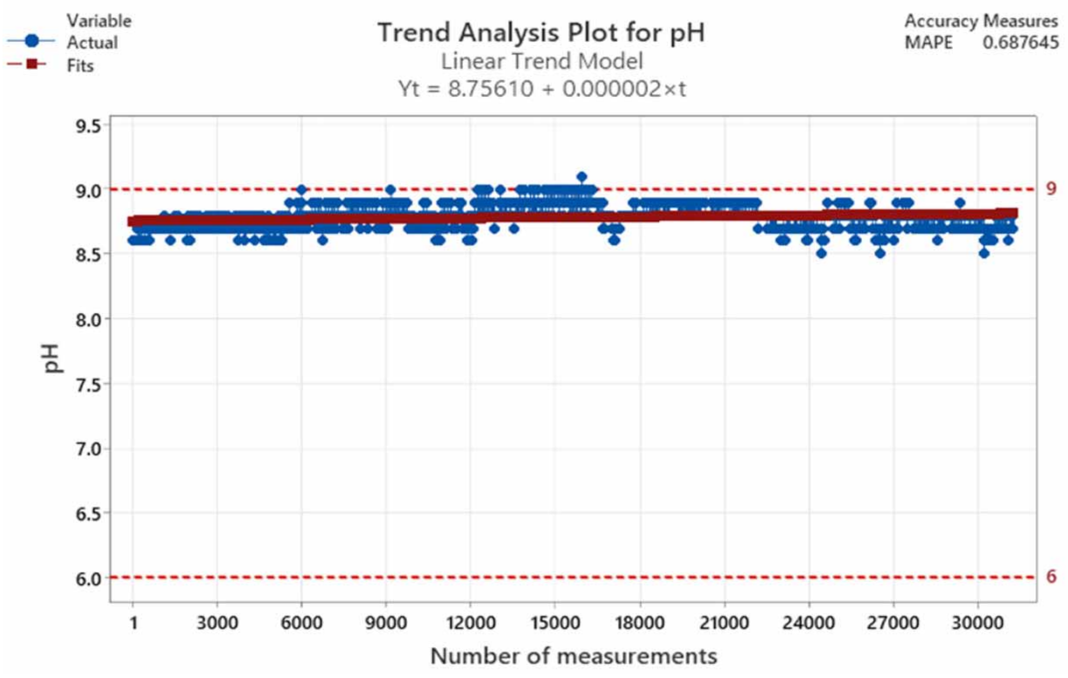


**Figure 5** | Temporal trend of pH measured in the Durrës site during December 2022 to November 2023.

level during May, June, and July; depleted during August; and remained relatively stable during September, October, and November (Figure S1 in the Supplementary Material). The fluctuations in the DO levels in water can be caused by various factors, such as the presence of waves in marine water. It increases the contact between oxygen in air and marine water and consequently the solubility of oxygen in water, temperature, salinity, aquatic vegetation, and the anthropogenic status of the water (Lee *et al.* 2023). DO in the seawater of the Durrës site fluctuates in a narrow range, from 5.7 to 8.6 mg/L, with a mean value of 8.1 ± 0.796 mg/L and a median of 8.1 mg/L. This is followed by very low variability ($CV\% = 10\% < 25\%$) and skewness and kurtosis values close to zero, indicating a stable situation of DO in the seawater of the Durrës site (Figure 6).

Low DO values ($DO > 5.7$ mg/L) could be explained by the effects of various natural and anthropogenic factors. In coastal areas, where the physical processes are generally dynamic and complex, DO concentration depends on multiple factors. Some of them are the hydrological conditions affecting gas solubility, air–water exchange, water vertical stratification, and pelagic and benthic metabolism, where the net balance between oxygen production and consumption processes is a key factor affecting changes in DO concentration in coastal waters (Kralj *et al.* 2019). Water ecosystems can become undersaturated with oxygen when natural processes and/or anthropogenic processes produce enough organic carbon that is aerobically decomposed faster than the rate of oxygen deaeration (Rabalais *et al.* 2010). The Durrës Bay is affected by two Albanian rivers, Ishmi and Erzeni, the most polluted rivers in Albania, which discharge different pollutants in the bay. The positive temperature trend in bottom waters, coupled with the increase in riverine discharges in late spring, limiting vertical mixing and bottom water renewal, may favor events of oxygen depletion in coastal ecosystems (Kralj *et al.* 2019).

Water upwelling is another process affecting DO due to the heterotrophic processes in coastal environments. These processes lower the DO during the degradation of organic matter in the water column or bottom sediments, using DO during the oxidation process of reduced constituents such as sulfide and methane in water (Zhang *et al.* 2010). Besides this, coastal upwelling can bring high concentrations of nutrients and sinking organic particles to surface waters. It can stimulate oxygen production and also bring low DO due to local or large-scale oxygen demand from the microbial decay of sinking organic particles (Zhang *et al.* 2010). These values are within an acceptable range for aquatic life, as the optimal DO values are higher than 5 mg/L (Zhang *et al.* 2020). Similar DO values (mean value of 8.7 mg/L) were registered at the Vlora Bay in

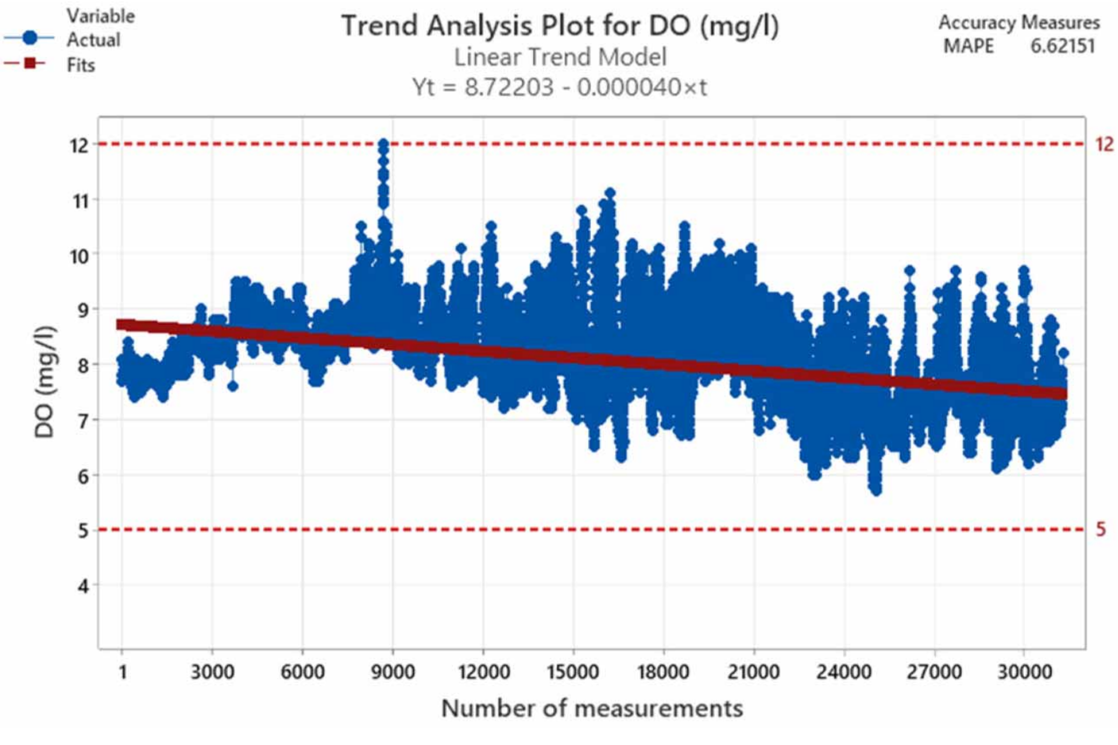


**Figure 6** | Temporal trend of DO (mg/L) measured in the Durrës site during December 2022 to November 2023.

May 2014 measured at 0.5 m deep (Kane *et al.* 2015) at 14 sampling sites positioned 100 m far from the coast. The mean DO value of 8.6 mg/L was also registered in the Durrës Bay (Figure S1 and Table S1 in the Supplementary Material).

### 3.5. Seawater depth

The sonde is installed 100 m away from the coast, at a depth of about 3 m. The values measured during the full course of the monitoring period show high stability in the measurement, with very similar values of mean and median (3.0 m) and a fluctuation range of 2.63–3.6 m. Of the measured values given by the range of the first quartile (Q1) and the third quartile (Q3), 99% fluctuate in a very narrow range, from 2.95 to 3.1 m. The temporal trend of the depth measured at the Durrës site from December 2022 to November 2023 (Figure 7) shows negligible spikes and outliers, which did not affect the calculated descriptive statistical data or the accuracy of the measurement of depth.

### 3.6. Turbidity

High variability was observed in the turbidity data recorded at the Durrës site from December 2022 to November 2023. It is the only parameter recorded in Durrës with a very large measured range (0–2,000 NTU), with big differences between the median value (52 NTU) and the mean value (221 ± 400 NTU). The high values of skewness and kurtosis (2.6 and 6.5, respectively) indicate a high variation (CV% = 181%) in turbidity data. From the historical data reported by Russo & Artegiani (1996), a surface general circulation exists along the Albanian–Croatian coast with cyclonic gyres during the summer and autumn seasons. Lipizer *et al.* (2014) described a cyclonic circulation pattern along the eastern coast, with several re-circulation cells flowing northward. The Durrës site is positioned on the eastern coast of the Adriatic Sea and is affected by the cyclonic gyres of the Albanian–Croatian coast. High turbidity values were observed in the summer and autumn (Figure 8) in the same period of cyclonic gyres described by various authors (Brana & Krajcar 1995; Russo & Artegiani 1996), confirming the natural processes affecting the turbidity values of the Durrës site. Estuarine circulation is highly relevant for the transport of fine sediments and sedimentation (Ferrarin *et al.* 2019), which stimulates the increase in the turbulence in coastal water.

### 3.7. Time series analysis

The data of this study were measured from a single site, transmitted to the server at 15-min time intervals, and found to be relatively stable (CV% ≤ 25%) for all parameters except turbidity. Under such conditions, time series were used to visualize the distribution of the data during the full monitoring period and to compare the measured data with the recommended

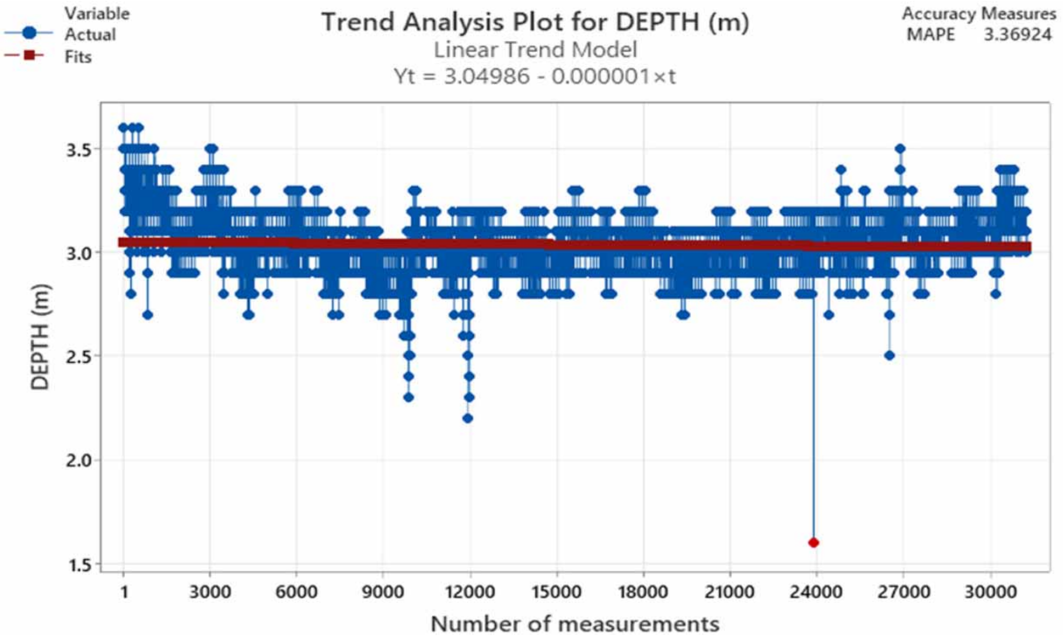


**Figure 7** | Temporal trend of the depth measured in the Durrës site during December 2022 to November 2023.

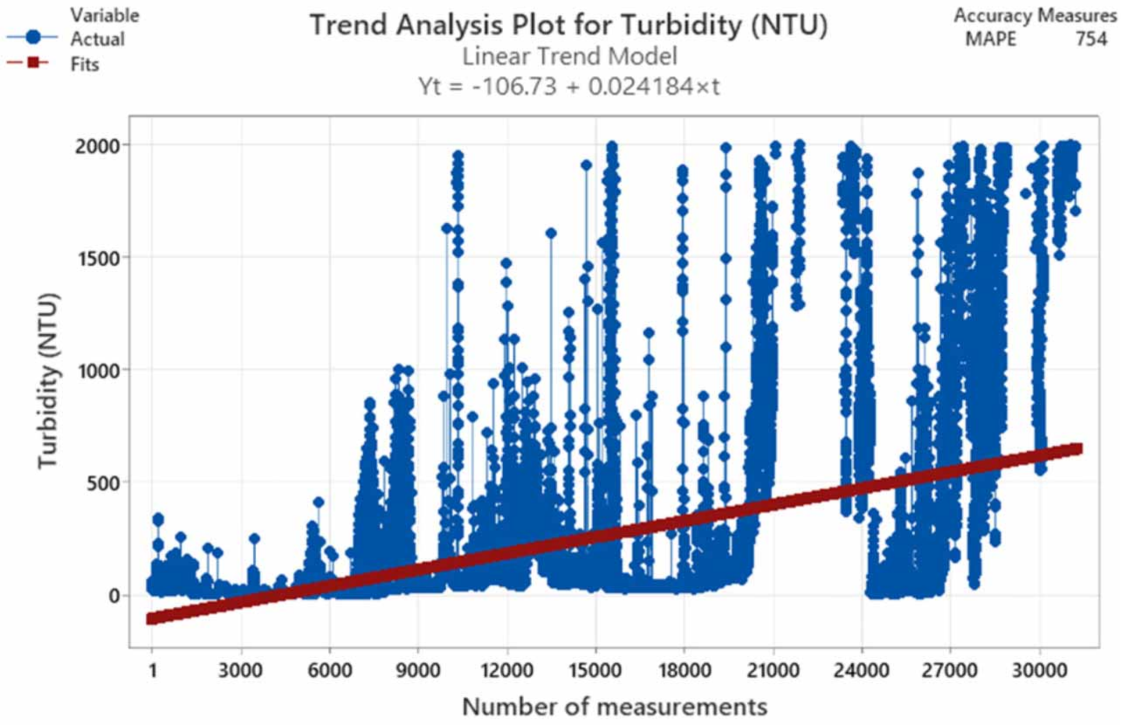


**Figure 8** | Temporal trend of turbidity (NTU) measured in the Durrës site from December 2022 to November 2023.

values of each parameter. The time domain analysis is also performed by investigating the stability of the dataset for each parameter studied by the linear trend model.

The mean absolute percent error (MAPE), which expresses the accuracy as a percentage of the error, is used to compare the fits of different time series models (in our case the linear model) with the measured data. The measured data close to zero greatly inflates to very high MAPE values, because it is calculated as the ratio of the absolute error to the actual data. In this case, it is better to use the MAPE data in combination with the respective CV% values (Table 3).

The MAPE (%) data of all parameters, except turbidity, are smaller than 14% and followed by small variation ($CV\% \leq 25\%$). It means the data of DO, pH, EC, TDS, salinity, depth, and water temperature are stable. It is confirmed by small slopes of the linear equations model ($b = 0.000001$–$0.00004$ for the depth, pH, and DO; $b = 0.00011$–$0.00017$ for TDS, salinity, and EC; and $b = 0.00039$ for water temperature). Higher slopes, CV%, and MAPE values indicate higher effects of seasonal conditions or other factors.

### 3.8. Multivariate analysis

The measured physical–chemical data were analyzed by Pearson's correlation analysis (Table 4). The correlation matrix data indicate the level of similarity between particular physical–chemical parameters. At least five similar pairs of parameters were found, characterized by a correlation coefficient $r > 0.4$ and $p = 0$. Very strong positive correlations were found between the pairs of EC–TDS, EC–salinity, and TDS–salinity data (Table 4), followed by a moderate and significant negative correlation ($r > 0.4$, $p = 0.000$) between DO and water temperature, and a weak and significant correlation between pH and DO ($r = 0.317$, $p = 0.000$) (Table 4).

Natural waters are complex systems characterized by various ionic ratios of specific ions and the average activity of all ions present in water, which cause a nonlinear relationship between TDS and EC in water systems (Hubert & Wolkersdorfer 2015). The investigated parameters were continuously measured at the same sampling site, which exhibits similar conditions in the measured parameters, and much higher contents of Na and Cl ions than other characteristic ions of the seawater. It establishes stable ionic strength and ionic ratios, which are favorable parameters for establishing a linear relationship between

**Table 3** | Accuracy data of trend analysis linear model

| Parameters | CV% | MAPE (%) | Linear equation models |
|---|---|---|---|
| DO | 10 | 6.6 | $DO = 8.72 + 0.00004t$ |
| EC | 12 | 9.2 | $EC = 44.7 - 0.000165t$ |
| pH | 12 | 0.7 | $pH = 8.76 + 0.000002t$ |
| Salinity | 13 | 10 | $Salinity = 29.1 - 0.000124t$ |
| Seawater depth | 4 | 3.4 | $Depth = 3.05 + 0.000001t$ |
| TDS | 12 | 9.2 | $TDS = 26.6 - 0.000106t$ |
| Turbidity | 181 | 754 | Linear model not available |
| Water temperature | 25 | 14 | $Water\ Temp = 12.5 + 0.00039t$ |

**Table 4** | Pearson correlation analysis of DO (mg/l), TDS (g/l), EC (mS/cm), salinity (PSU), pH, turbidity (NTU), water temp (°C), depth (m) (Number of rows used: 25,801–31,263)

| Variables | DO | TDS | EC | Salinity | pH | Turbidity | Water Temp |
|---|---|---|---|---|---|---|---|
| TDS | 0.068 | | | | | | |
| EC | 0.068 | 1.000* | | | | | |
| Salinity | 0.078 | 1.000* | 1.000* | | | | |
| pH | 0.317* | 0.216 | 0.216 | 0.211 | | | |
| Turbidity | −0.206 | −0.126 | −0.126 | −0.131 | 0.041 | | |
| Water Temp | − 0.418* | −0.206 | −0.206 | −0.228 | 0.268 | 0.243 | |
| Depth | −0.152 | −0.027 | −0.027 | −0.027 | −0.280 | 0.034 | −0.010 |

*$p = 0.000$.

EC and TDS. Under such conditions, very strong and significant correlations ($r = 1$, $p = 0.000$) were found between the pairs EC–TDS and EC–salinity.

FA is performed to better explain the associations between the measured parameters. The results of FA are shown in Table 5.

Three main factors were extracted from factor loads (Table 4). Factor 1 is compiled by very high loads of EC, TDS, and salinity, all derived from the same factor in seawater – the content of the dissolved ions. Factor 2 is compiled by a high negative load of water temperature and a positive load of DO, which indicate a reverse relationship between temperature and DO. This is a normal phenomenon suggesting that temperature changes contribute to the surface DO distribution, such as increasing solubility in cold seasons and degassing in warm seasons, which likely represents natural components or climate processes (Lee *et al.* 2023). The association of the turbidity in this factor with a moderate negative load is not clear. Factor 3 is compiled by a high negative load of pH and a positive load of depth, as well as a moderate negative load of DO (Table 4). The pH and DO change in the same sense, indicating the DO content is higher in clean water than in acidic conditions. A similar phenomenon was investigated by Lee *et al.* (2023). Another finding from Factor 3 is related to the inverse relationship of pH and DO with depth, indicating that pH and DO are lower at higher depths and higher in surface.

## 4. CONCLUSIONS

In this study, the seawater quality from the Durrës site, Albania, was assessed using an automatic measuring sonde for the measurement of the physical and chemical parameters. The obtained data for all parameters, except turbidity, were within the recommended values for the survival of aquatic life.

**Table 5** | Sorted rotated factor loadings and communalities (Varimax rotation)

| Variable | Factor 1 | Factor 2 | Factor 3 | Communality |
|---|---|---|---|---|
| EC (mS/cm) | 0.993 | 0.000 | 0.000 | 0.998 |
| TDS (g/l) | 0.993 | 0.000 | 0.000 | 0.998 |
| Salinity (PSU) | 0.992 | 0.000 | 0.000 | 0.998 |
| Water Temp (°C) | 0.000 | −0.827 | 0.000 | 0.767 |
| DO (mg/l) | 0.000 | 0.698 | −0.479 | 0.718 |
| Turbidity (NTU) | 0.000 | −0.597 | 0.000 | 0.365 |
| pH | 0.000 | 0.000 | −0.841 | 0.792 |
| Depth (m) | 0.000 | 0.000 | 0.682 | 0.474 |
| Variance | 3.026 | 1.600 | 1.483 | 6.109 |
| % Var | 0.378 | 0.200 | 0.185 | 0.764 |

Low variability ($CV\% < 25\%$) on the measured parameters, except turbidity, indicates a stable status in the water quality from the Durrës site. Time series revealed small seasonal variations on all parameters, except turbidity.

The measured data confirmed the linear relationship between EC and TDS, which enables the calculation of TDS based on the conversion factor from the equation of their linear relationship. Since the measurements were carried out under a low variation of the parameters measured at the same monitoring site, it has favored a fairly high linear regression between EC and TDS ($r = 1$), which provided a correct calculation of TDS values.

TDS, salinity, and EC data revealed the same temporal trend over the full monitoring period, indicating a strong relationship between them. Salinity is an important parameter of seawater quality, because it has a strong effect on the marine biota. The Durrës site revealed a stable situation characterized by a very close Q1–Q3 range, which was recorded from 25 to 30 PSU with a mean value of 27 ± 3.5 PSU. Some fluctuations of lower salinity were observed during the rainy seasons of spring and autumn.

The high negative load of water temperature and the positive load of DO in Factor 1 revealed a reverse relationship between them. This indicates that the solubility of DO decreased with the increase in temperature, which is a normal phenomenon in water. The association of the turbidity in this factor with a moderate negative load is not clear. The pH and DO change in the same sense, indicating that the DO content is higher in clean water than in acidic water conditions. pH and DO show inverse relationships with depth, indicating that pH and DO are lower at higher depths.

The small variations of full data and monthly data, smaller than those of early data, indicate the effectiveness of monthly or seasonal monitoring programs. Nonetheless, the sporadic peaks observed at outlier points indicate the need for conducting repeated *in situ* measurements until stable outcomes are achieved. While the obtained data for physical–chemical parameters in this study align with the recommended values, it is important to prioritize the maintenance and enhancement of water quality in the Durrës Bay. This can be done through regular monitoring of marine waters and by including other chemical parameters in future studies.

This study is very important for understanding the current state of marine water quality in the Durrës Bay. It addresses the gaps in existing data on the physical–chemical parameters in the area and provides an essential baseline for tracking changes over time and assessing the impact of human activities on the marine environment. Sharing the results of this study internationally can foster collaboration and knowledge exchange, for a more comprehensive understanding of the Adriatic Sea's water quality and implementation of regional environmental management strategies.

Decision-making bodies, including environmental agencies and policymakers, can leverage these research findings to enhance systematic monitoring programs for real-time data and prompt responses to emerging issues. These entities can develop evidence-based policies, enforce strict regulations on industrial and municipal discharges to mitigate pollution, advocate for sustainable coastal development, implement erosion control measures, establish comprehensive waste management programs in coastal communities to prevent marine pollution, and conduct educational campaigns to increase awareness of individual impacts on marine water quality. These actions are essential to mitigate human-induced stress on the ecosystem, safeguard critical habitats, and contribute to the overall preservation of the Durrës Bay's aquatic environment.

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## AUTHOR CONTRIBUTIONS

EM contributed to the conceptualization, methodology, formal analysis, and writing and revising the original draft. JT contributed to formal analysis and investigation. PL contributed to the conceptualization, data analysis, and writing and revising the original draft. SD contributed to the methodology and formal analysis. FQ, AN, and BM contributed to formal analysis. All authors have read the draft of the manuscript and approved it.

## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

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