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Monitoring Water Quality in Ballona Lagoon, Los Angeles, California: Nitrate Level Fluctuation in Low and High Tide Condition

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Abstract

The coastal wetland, Ballona Lagoon in Southern California has experienced degradation and size reduction due to urbanization. This study analyzes nitrate concentrations in the lagoon to identify contamination sources and assess its impact. The study includes determining nitrate levels during high and low tides during wet and dry seasons, establishing concentration gradients, and examining the relationship between salinity and nitrate concentrations. The nitrate concentrations were found to be higher in locations closer to the head of the lagoon, particularly in urbanized areas, suggesting land-based sources during the dry season's high tide (S2: 2.37 mg/l; S3: 3.85 mg/l; S4: 3.91 mg/l). Findings highlight the importance of managing nitrate contamination near urban areas. Monitoring nitrate levels over time are crucial for sustainability efforts. This research emphasizes the need for long-term monitoring and conservation strategies to mitigate nitrate contamination in Ballona Lagoon.

Keywords

Ballona Lagoon, Urbanization, Nitrate Contamination, Nitrification

1. Introduction

Coastal aquatic environments are highly susceptible to nutrient loading, specifically an increased influx of terrigenous nitrogen (N), due to the escalating anthropogenic activities worldwide [1] [2] [3]. The population growth and urban development in coastal areas, particularly in Southern California, have exerted significant pressure on coastal ecosystems. Between 1960 and 1990, the population in coastal areas of the United States increased from 80 million to 112 million people, with Southern California experiencing one of the highest population changes [4]. This influx of people was accompanied by extensive urban development, with Los Angeles, Orange, and San Diego counties ranking among the top ten in the nation for construction activities. The increased urban development in Southern California coastal watersheds, similar to other coastal areas, led to alterations in natural drainage systems, expansion of impervious areas, and changes in watershed dynamics. Consequently, these modified watersheds became sources of anthropogenic contaminants carried by urban runoff. This contamination, along with other sources, has impaired water quality in many Southern California coastal systems [5]. In urban watersheds such as Ballona Creek (upstream of the Ballona Lagoon), the presence of pollutants in stormwater runoff and downstream bodies of water has led to the listing of these water bodies as impaired under Section 303(d) of the Clean Water Act. To address this issue, total maximum daily load requirements have been imposed to reduce the load of urban-associated contaminants such as metals, bacteria, and organic pollutants [6]. As a result, the Ballona Lagoon, a coastal wetland located in Southern California, has experienced a significant decrease in size and a degradation of its natural habitat as a result of urbanization. Over the past 18,000 years, the expansive Ballona Lagoon system spanned more than 2200 acres [7]. However, today it exists as a relatively small area, measuring just 16 acres [7].

The degradation of water quality within the lagoon can be attributed to urban runoff and the inadequate treatment of wastewater. Urbanization has led to the replacement of natural vegetation with impermeable surfaces, preventing contaminants like nitrate from being absorbed or entering the soil during storm events [8]. In our current research, we are focusing on analyzing the nitrate concentrations in the lagoon to identify the various sources of nitrate contamination. These sources may include atmospheric deposition, sewage, groundwater, as well as dispersal processes such as denitrification and nitrification [9].

The Ballona Creek watershed and lagoon in the greater Los Angeles, California area provide an optimum environment for conducting a pollution source identification study. Therefore, there is a need for this investigation in Ballona Lagoon to ensure its long-term sustainability. Additionally, this study is the first one to measure nitrate levels during high and low tides in both wet and dry seasons. By monitoring nitrate levels over time and identifying patterns in nitrate concentration gradients and their relationship with salinity, we can establish a baseline for long-term monitoring and sustainability efforts.

The main objectives of this study are to determine nitrate levels in urbanized areas during high and low tides, establish the nitrate concentration gradient in the lagoon under different tidal conditions, identify patterns of increasing or decreasing nitrate levels, and examine the relationship between salinity and nitrate concentrations in both the dry and wet seasons.

The findings of this study hold significant implications as they enable the identification of nitrate contamination sources within the urbanized regions of

Ballona Lagoon. The data obtained can provide valuable insights, leading to two key conclusions: firstly, nitrate contamination stems from local street runoff; and secondly, it originates from inherent biogeochemical processes occurring within the lagoon water, such as nitrification. These conclusions contribute to a deeper understanding of the factors contributing to nitrate contamination, aiding in the development of targeted strategies for mitigation and restoration efforts in urbanized areas surrounding the lagoon. Overall, conducting investigations on nitrate levels and contamination sources in the Ballona Lagoon project is essential for environmental protection, human health considerations, effective urban runoff management, ecosystem restoration, and long-term sustainability of the lagoon and its surrounding areas. To that extent, swimmers, surfers, and other people exposed to beach waters contaminated by pathogenic microorganisms have a greater risk of illness [10]. Thus, the consequences of poor water quality are significant.

2. Materials and Methods

Study Area

Ballona Lagoon is located in Los Angeles, California at coordinates 33.9711226˚N, −118.4592449˚W. It lies adjacent to the renowned Venice Beach on its western side, while Marina Del Rey borders it to the east, and Playa Del Rey lies to the south. Towards the southeast, you'll find the Ballona Wetlands Ecological Reserve (Figure 1).

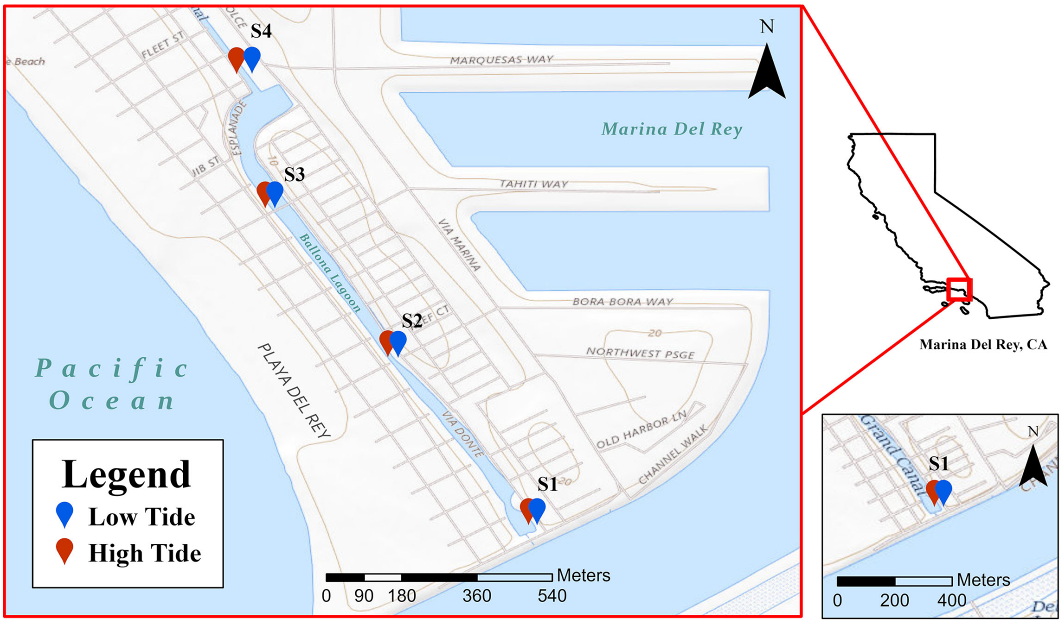

Figure 1. This map shows the locations of the water samples collected (Left). The red pins represent samples in high-tide conditions, and the blue pins represent samples taken during low-tide conditions. The ocean water enters and exits from the inlet (Red arrow; Hide tide) and outlet (Blue arrow; Low tide) of the lagoon at the entrance of the Marina Del Rey harbor where S1 is located (Bottom Right). Modifies after USGS National Map, GCS WGS 1984.

The region enjoys a Mediterranean climate characterized by dry summers and wet winters. Typically, the wet season spans from November to April, while the dry season encompasses the months from May to October. To provide a snapshot of precipitation patterns, between October 1, 2019, and March 18, 2020, the average recorded precipitation in this area amounted to 2.54 cm [11]. These measurements were collected from the vicinity of Los Angeles International Airport, located approximately 3 km south of Ballona Lagoon [12].

The environmental condition of Ballona Lagoon features a combination of brackish and freshwater, resulting from the interplay between the inlet and outlet and the surrounding habitats. Consequently, the lagoon's salinity levels fluctuate in response to tidal conditions, such as high and low tides [13]. The watershed is approximately 80% urbanized, and there are no permitted waste water or consistent industrial discharges to Ballona Creek (with the exception of discharges associated with construction, cleanup, and dewatering activities) [14].

We sampled four locations along the lagoon during high tide (HT) and low tide (LT), as well as the dry and wet seasons, respectively. The selection of sampling sites primarily considered their proximity to the urbanized area. We initiated the sampling process from the lagoon's mouth and progressed towards its head. By focusing on these specific locations, we were able to analyze the nitrate concentration gradient under various tidal conditions using laboratory results. To ensure precise sampling timing during the lowest and highest tidal cycles, we referred to online tide tables and selected the Spring tide condition. Additionally, we conducted in situ tests to measure temperature, dissolved oxygen (DO), pH, and salinity in the lagoon water. To obtain these readings, we utilized specialized equipment, including a dissolved oxygen meter (YSI, 550A) and dual pH and Salinometer instruments (Acumet, AP71 and Hanna, HI98319, respectively). For sample collection and parameter evaluations, we utilized 125ml bottles and conducted the procedures in situ. To ensure the accuracy of measurements and testing, we implemented blank samples and duplicates. This rigorous approach was maintained throughout both the wet and dry seasons, encompassing high and low tide periods within the lagoon. To ensure the quality assurance of the analysis regarding the presence and concentration of nitrate, we promptly transferred the collected water samples in an ice chest on the same day to the esteemed American Environmental Testing Laboratory. They performed an ion chromatography test (Method: SM-4110) on both sample sets, enabling us to identify variations in nitrate levels among the samples.

3. Results

Table 1 contains data related to water quality parameters measured during the dry and wet seasons. The table is divided into two sections: one for the dry season and another for the wet season. Each season has two columns representing two different sites: HT (High Tide) and LT (Low Tide). The parameters measured include Salinity (in ‰), pH, Dissolved Oxygen (DO) (in ppm), and Temperature (in ˚C). **Table 1** offers additional information, including mean, standard deviation (STD), minimum, and maximum values for each parameter in both seasons and at both sites. It should be noted that the table contains missing data (--), indicating that measurements for those specific parameters and seasons were not taken or recorded.

During the dry season, the salinity levels exhibit a narrow range, fluctuating between 32.7‰ and 33.8‰ at the HT site, and between 32.4‰ and 33.4‰ at the LT site, indicating a relatively stable salinity profile.

Throughout the dry season, the pH values demonstrate a moderate variability, ranging from 6.96 to 7.37 at the HT site and from 7.04 to 7.84 at the LT site, suggesting a slightly acidic to neutral pH range prevailing in the lagoon waters. Regrettably, no data regarding dissolved oxygen levels (DO) is available for the dry season, impeding our assessment of the oxygenation conditions during this period. The dry season witnesses a discernible temperature pattern, with temperatures ranging from 20.1˚C to 25.4˚C at the HT site and from 20.3˚C to 23.1˚C at the LT site (**Table 1**), highlighting the presence of a relatively mild and consistent thermal regime in the lagoon ecosystem.

Table 1. This table shows the parameters of the samples collected during the wet and dry seasons in HT and LT conditions. The dry season data was collected May and June 2019, and the wet season data is from February 2020. The dry season salinity values were collected July 2020. Certain samples could not be collected due to instrument limitations. (--) not sampled.

Samples	Dry Season							
	HT				LT			
	Salinity ‰	pH	DO (ppm)	Temp. ˚C	Salinity ‰	pH	DO ppm	Temp. ˚C
S1	32.7	6.96	--	20.1	33.1	7.76	--	20.3
S2	33.8	7.26	--	22.4	32.5	7.84	--	21.6
S3	33.7	7.1	--	24.4	32.4	7.04	--	23.1
S4	33.5	7.37	--	25.4	33.4	7.71	--	22.6
Mean	33.43	7.17	--	23.1	32.85	7.59	--	21.9
ST.D.	0.43	0.16	--	2.03	0.42	0.32	--	1.07
Min	32.7	6.96	--	20.1	32.4	7.04	--	20.3
Max	33.8	7.37	--	25.4	33.4	7.84	--	23.1
	Wet Season							
S1	--	7.31	9.44	14.5	--	7.89	8.23	17.3
S2	--	7.32	8.2	14	--	7.43	9.76	17.6
S3	--	7.48	8.88	14.3	--	7.74	11.6	17.7
S4	--	7.53	9.23	14.5	--	7.93	11.9	18
Mean	--	7.41	8.94	14.3	--	7.75	10.4	17.65
ST.D.	--	0.1	0.47	0.21	--	0.2	1.48	0.25
Min	--	7.31	8.2	14	--	7.43	8.23	17.3
Max	--	7.53	9.44	14.5	--	7.93	11.9	18

Unfortunately, no data regarding salinity levels is available for the wet season, preventing us from assessing the variations in salinity during this period. Throughout the wet season, the pH values showcase a relatively narrow range, spanning from 7.31 to 7.53 at the HT site and from 7.43 to 7.93 at the LT site, suggesting a slightly acidic to near-neutral pH range prevalent in the lagoon waters. The dissolved oxygen levels observed during the wet season present a noteworthy range, varying from 8.2 ppm to 9.44 ppm at the HT site and from 8.23 ppm to 11.9 ppm at the LT site. These measurements indicate a generally well-oxygenated environment in the lagoon during this season. The wet season is characterized by distinct temperature patterns, with temperatures ranging from 14˚C to 14.5˚C at the HT site and from 17.3˚C to 18˚C at the LT site. These values signify a comparatively cooler thermal regime prevailing within the lagoon ecosystem during this season.

Throughout the wet season, the correlation between all parameters is weak except temperature (Temp. ˚C) and dissolved oxygen (DO, ppm). The weak correlations include pH vs. DO (R^2 = 0.0673 for HT) and (R^2 = 0.0185 for LT). On the other hand, the correlation between Temp. vs. DO shows strong positive correlation both in HT (R^2 = 0.9751) and LT (R^2 = 0.8607) (Figure 2).

The correlation analysis for the dry season shows a weak correlation between Salinity (‰) and pH (R^2 = 0.455), temperature (˚C) and pH (R^2 = 0.548), and Salinity (‰) and temperature (˚C) (R^2 = 0.4552) (Figure 2). This clearly indicates that higher temperature recorded corresponds to higher salinity values in the dry season for HT condition, where a salinity and temperature gradient occurs in the lagoon. The salinity values increase toward the head of Ballona lagoon (Figure 3).

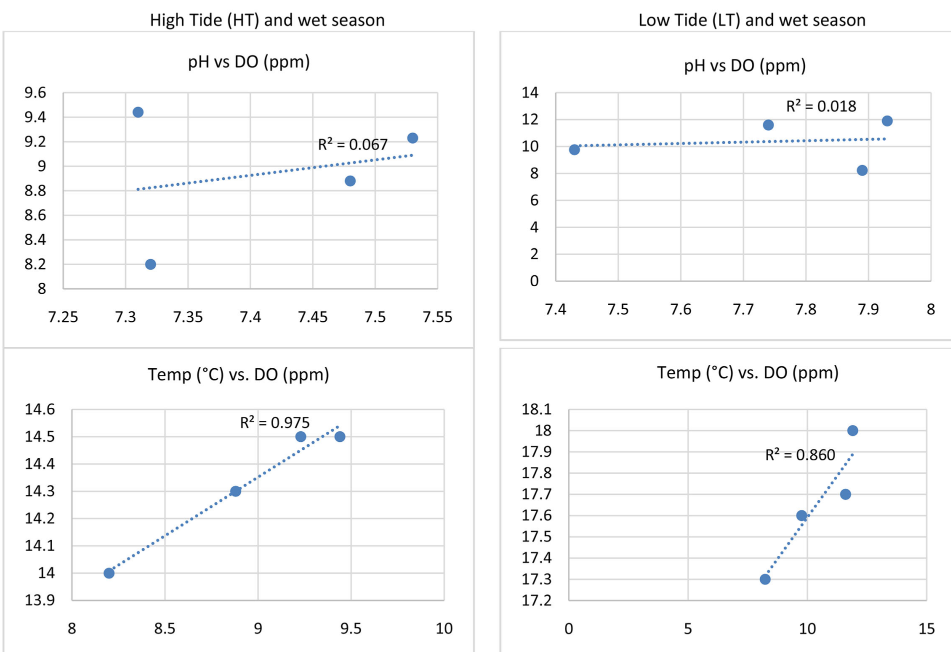

Figure 2. These graphs show correlations of various parameters in wet season in low (LT) and high tide (HT) conditions.

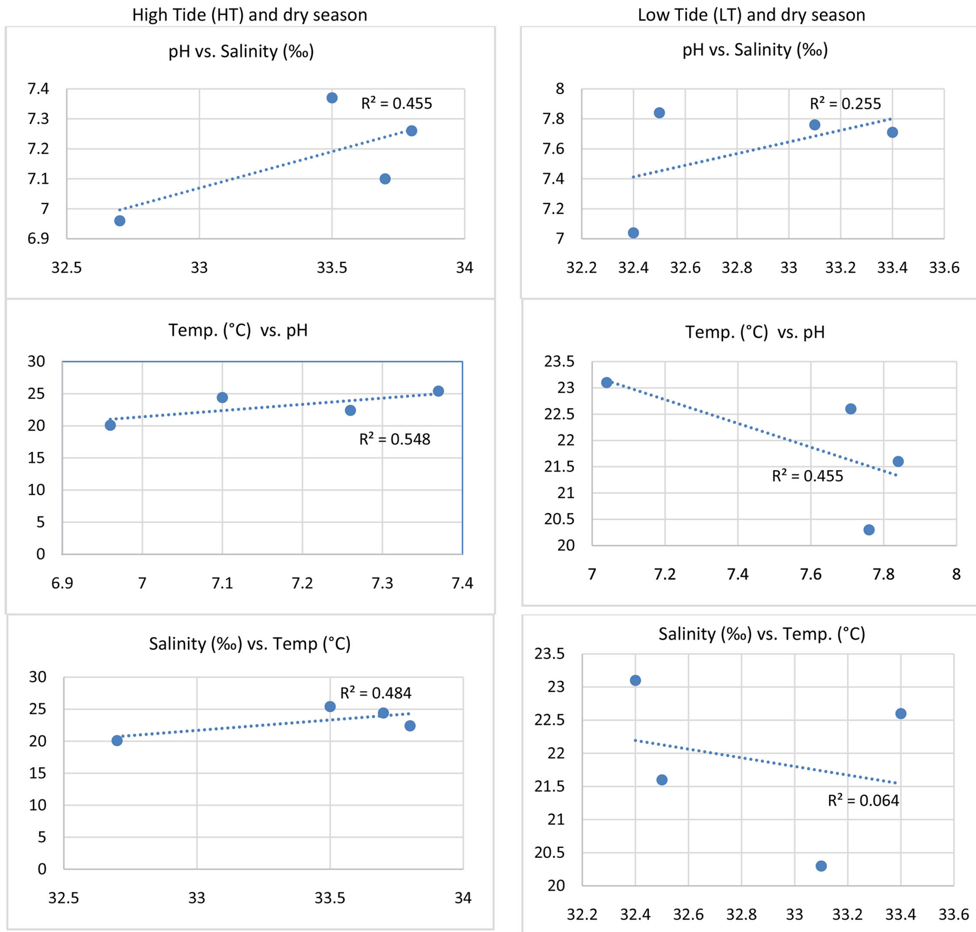

Figure 3. These graphs show correlations of various parameters in dry season in low (LT) and high tide (HT) conditions.

Furthermore, in the wet season-low tide (LT) conditions, nitrate concentrations were observed at S3 (2.55 mg/l) and S4 (1.31 mg/l) near the head of the lagoon. Notably, a strong sewage odor was detected at S4, while evidence of human waste was found under the bridge at S3. During the wet season-high tide (HT) conditions, S2 exhibited a higher nitrate concentration (3.63 mg/l), coinciding with abundant vegetation and bird activity. Moving to the dry season-low tide, our sample set identified the highest nitrate value at S3 (2.33 mg/l), a location in close proximity to a bridge and surrounded by vegetation (**Figure 4**).

In the dry season's low tide conditions, there was a weak correlation (R^2 = 0.471) between salinity and nitrate values. In the dry season-high tide, elevated nitrate concentrations were found at S3 (3.85 mg/l, 2.37 mg/l) and S4 (3.91 mg/l), which are closer to the head of the lagoon and encompass the majority of the urbanized area. A weak positive correlation (R^2 = 0.1703) was observed between salinity and nitrate during high tide periods.

4. Discussion

Water quality encompasses various parameters that influence the health balance

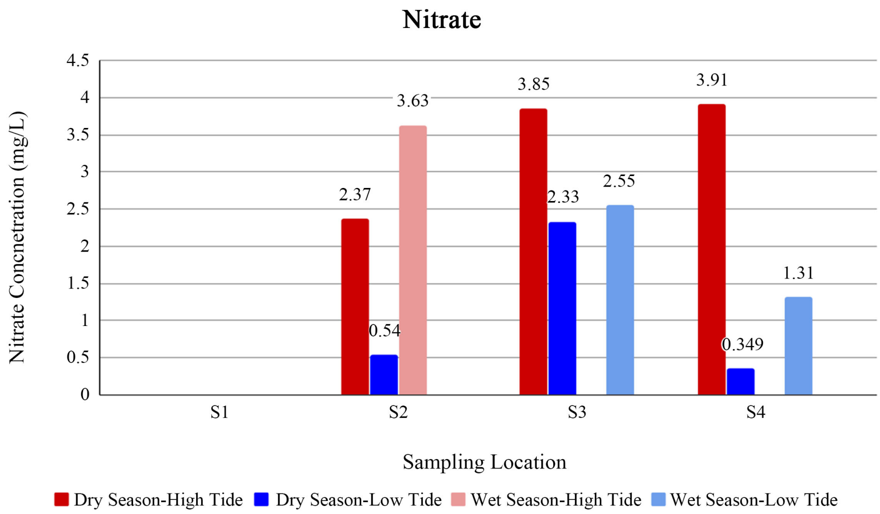

Figure 4. The figure shows the four stops where the nitrate concentrations were collected during HT and LT conditions of the wet and dry season during 2019 and 2020. The maximum contaminant limit (MCL) that is acceptable in California's drinking water (r (according to the EPA, 2002) [15] is 10 mg/l. This bar graph shows that the samples are within the MCL that is acceptable for drinking water MCL.

of a watershed. In our study of the Ballona Lagoon, we focused on parameters such as dissolved oxygen (DO), pH, nitrate, and salinity. DO and pH are essential in determining nutrient solubility and biological availability, thereby impacting organisms in the water and indicating environmental contaminants [16]. During the wet season-HT, the pH tended to be slightly alkaline, whereas during the LT, the pH leaned towards neutrality. Furthermore, the solubility of oxygen in LT condition in the lagoon's water is inversely or very weakly correlated with temperature and salinity. Thus, we believe this effect may be reflected in the variability of oxygen levels (DO).

In addition to the pH and DO, salinity values play a crucial role in identifying the source of nitrates, whether from the adjacent sea or land. The salinity gradient in Ballona Lagoon water can help identify the possible source of nitrates. In Ballona Lagoon, where ocean water mixes with freshwater sources, the salinity level can indicate whether the nitrates come from the adjacent sea or from land-based runoff. Thus, higher salinity levels suggest a greater influence of seawater, while lower salinity levels indicate a larger contribution from land-based sources. Evaluating the results of this study, there is a salinity and temperature gradient with lowest values near the mouth and higher values near the head of the lagoon. The gradient intensifies in Spring tide condition. Green *et al.* (2019) [17] have observed similar pattern in their study. An increase in nutrient concentrations (such as nitrate and phosphate) with salinity suggests an oceanic source, while a decrease indicates a land-based source [17]. When comparing dry season-HT nitrate concentrations with salinity, nitrate concentrations increased from S3 (3.85 mg/l) to S4 (3.91 mg/l), whereas salinity values slightly decreased from S2 (33.8 mg/l) to S4 (33.5 mg/l). Nitrate concentration increased towards the head of the lagoon, while salinity values increased towards the mouth (Figure 5). Dilution of nitrate levels occurs at the mouth due to the mixing of seawater and freshwater [17].

Based on these findings, the source of nitrate during the dry season-HT appears to be from the land. Potential sources for nitrate concentrations in these locations could be anthropogenic, such as street runoff and septic system runoff.

Overall, the relationship between ocean salinity and nitrate concentration is complex and can vary depending on local environmental conditions. Monitoring salinity levels alongside nitrate concentrations can provide valuable insights into the sources and dynamics of nitrates in water systems.

We believe, both natural and anthropogenic sources of ammonia can lead to nitrate contamination in urbanized areas. Although nitrate contamination can occur naturally, it is often enriched to contaminant levels through human [18]. For example, improper domestic waste disposal can introduce ammonia into a system, which is a significant contributor to nitrate contamination, particularly through septic system leakage in urbanized areas. Septic tanks are commonly installed in lagoon areas and near beaches [19]. Therefore, we cannot dismiss the possibility of contaminants entering the lagoon through wastewater percolation in the soil, resulting in residual waste accumulation. The presence of nitrate in the lagoon illustrates the impact of nonpoint sources on its health. Tidal functions and the rate of nitrate flux are believed to affect the residence time of nitrate [20]. The nitrate residence time depends significantly on the nitrate concentration in the lagoon water, with higher concentrations resulting in longer residence times.

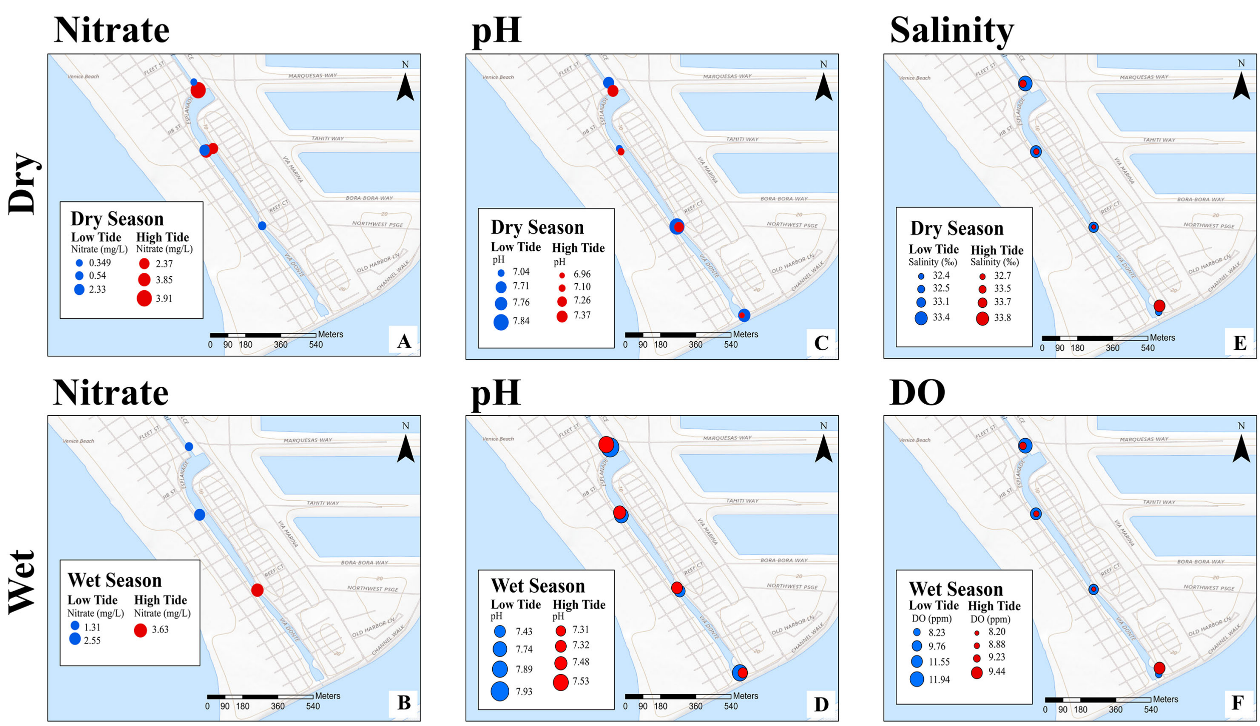

Figure 5. (A-B) Nitrate concentration (C-D) pH (E) Salinity and (F) Dissolved Oxygen (DO) values. This figure illustrates various parameters with blue (low tide) and red circles (high tide) conditions.

Seasonal nitrate dynamics in hydrologic systems are another factor contributing to nitrate contamination. Typically, nitrate enters a system in its organic form and undergoes nitrification and denitrification processes before being released as N-gas. However, climate change has led to hydrologic extremes, altering this dynamic and promoting recycling dominance, thus sustaining nitrate pollution within the system [21]. For instance, in the wet season-HT, S2 exhibited a higher nitrate concentration where there was more vegetation in the water, suggesting nitrate recycling at that location. Consequently, nitrate is cycled within the lagoon, leading to ammonia accumulation and increased nitrification [22]. Although the observed nitrate levels in the lagoon are not high enough to cause algal blooms, they can become problematic if left unaddressed.

Salinity can affect chemical reactions in water. It can influence the solubility and availability of various compounds, including nitrates [23]. Changes in salinity may impact the rates of chemical reactions involving nitrates, leading to variations in nitrate concentrations. In similar hydrodynamic conditions in the Persian Gulf, the water quality status of Sharjah lagoons was assessed by Cavalcante, *et al.* (2021) [23] using specific water quality properties such as chlorophyll and nutrients. The measurements were obtained during both spring and neap tide periods in January 2020. The correlation analysis between nutrients and salinity in the Persian Gulf lagoons revealed that in Al-Khan lagoon, there was a correlation between internal mixing and nutrient levels, particularly for nitrite during spring tide and phosphate during neap tide conditions. However, in Khalid lagoon, no significant correlation was found between nutrients and salinity, suggesting that other factors might be influencing nutrient loads [23].

Cavalcante *et al.* (2021) [23] noted a significant rise in dissolved oxygen (DO) levels, increasing from 8.1 mg/l (S3) to 10.7 mg/l (S4) during neap tide. This increase is likely due to the improved solubility of oxygen resulting from a decrease in temperature and salinity. The authors suggest that the introduction of fresh water through a fountain contributes to this decrease and further enhances water agitation in the end sector of Khalid lagoon. Overall, based on nutrient levels, specifically phosphate, and the presence of eutrophication conditions, the water quality in the lagoons poses a risk to aquatic life.

Our study recognizes that the available data might not capture all processes, as nutrient levels can change rapidly over short time intervals. Therefore, additional observations are necessary to gain a better understanding of the current state of water quality in Ballona Lagoon. Further investigation of the wet season values and conducting isotopic analysis for nitrogen isotopes are necessary to pinpoint sources, whether anthropogenic (runoff) or from the ocean.

5. Conclusion

Nitrification, the process of converting ammonia into nitrate, is a prevalent issue in heavily urbanized areas. In our study of Ballona Lagoon, we observed a clear trend of increasing nitrate levels as the samples approached areas with higher urbanization. This trend is likely a result of urbanization, with ammonia being introduced into the lagoon as a source of inorganic nitrate. Nitrification can lead to ecological problems, including extensive algal blooms and phytoplankton die-offs, which can result in eutrophication of the lagoon. Eutrophic conditions pose potential hazards to the local wildlife and the residents living in close proximity to the lagoon. As we move forward, it is crucial to monitor and address nitrate contamination in water bodies near urbanized areas. By continuously assessing nitrate levels and implementing appropriate management strategies, this project can work towards maintaining and improving the ecological health and water quality of Ballona Lagoon. To identify the precise sources of nitrate and determine residence time and flux rate, analysis of the isotope signatures of nitrate is necessary.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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