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Original Research Article

Assessment of Water Quality of El Oulfa Wetland (Morocco) Using the Water Quality Index and the Trophic State Index

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ABSTRACT

Water quality degradation is one of the most pressing environmental challenges in reservoirs around the world, making the trophic status assessment essential for restoration and sustainable use. Urban ponds, such as El Oulfa wetland in Morocco, face unique pressures due to urbanisation, climate variability, and nutrient loading, making their study critical for understanding and mitigating anthropogenic impacts on aquatic ecosystems. This study aimed to evaluate the water quality of El Oulfa Pond by calculating two critical indices: the Water Quality Index and the Trophic State Index. Water samples were collected from July 2021 to July 2023 at three sampling stations. Twelve physico-chemical parameters, including temperature, pH, electrical conductivity, dissolved oxygen, Secchi disk depth, total suspended solids, total phosphorus, soluble reactive phosphorus, ammonium, nitrates, sulfates, and chlorophyll-a, were measured using standard methods. The Trophic State Index results show the pond is eutrophic, mainly, with nutrient levels varying over time and between sites. Station S3 had a peak Trophic State Index of 83.49 in April 2024. These findings underscore the critical need for targeted interventions to address nutrient pollution and provide a framework for the sustainable management of urban aquatic ecosystems.

KEYWORDS

Oulfa Pond, Morocco, Carlson's Trophic State Index, Water Quality Index, Urban Pond, Eutrophication.

INTRODUCTION

Water is an indispensable resource essential to sustaining life, biodiversity, and ecosystem health [1]. It offers vital provisioning services, including irrigation, domestic water supply, energy generation, and transportation. Additionally, it contributes valuable goods and

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economically significant services to society, such as supplying drinking water [2], ensuring food production, supporting recreational activities [3], sustaining fishery resources, and providing numerous other benefits [4]. Furthermore, the chemical and physical characteristics of water affect the composition, abundance, and diversity of aquatic organisms [3] and are crucial for sustaining the overall productivity and ecological health of these ecosystems [5].

However, water scarcity and quality have been impacted dramatically due to population growth [6], industrialisation and climate variabilities [7], leading to severe water pollution and scarcity worldwide [8]. Poor water quality can negatively impact aquatic habitats, diminish biodiversity, and disrupt the natural processes of ecosystems, leading to far-reaching consequences for food security and overall biodiversity [7]. Climate change further exacerbates these challenges by intensifying the vulnerability of natural and human systems at various scales, with far-reaching consequences [9]. Rising global temperatures disrupt precipitation patterns and accelerate the timing of spring snowmelt [10], contributing to shifts in the hydrological cycle. These changes have profound effects on aquatic ecosystems, amplifying existing water quality and scarcity issues [11].

Eutrophication, resulting from the over-enrichment of water bodies with nutrients [12], poses a significant threat to aquatic ecosystems [13]. Eutrophication refers to a state in aquatic environments [14] characterised by elevated concentrations of nutrients, particularly nitrogen and phosphorus, leading to algal blooms and subsequently deteriorating water quality within these ecosystems [15]. Anthropogenic activities have hastened eutrophication by influencing the cycles of nutrients, especially those of nitrogen and phosphorus [13]. These nutrients are derived from sources like agricultural runoff, urban drainage, industrial discharges, and household wastewater. In contrast, the mix of land uses within a catchment significantly influences the extent of nutrient enrichment in water resources [16]. Phosphorus has been recognised as the most critical limiting nutrient for phytoplankton growth [14], and excessive phosphorus input has led to eutrophication and harmful algal blooms in aquatic systems [17]. The decline in water quality heightens risks to both ecosystems and human health, while also diminishing water-related ecosystem goods and services [4]. Evaluating and monitoring water quality conditions is a vital first step in implementing effective water resource management strategies [18]. Reliable assessment tools, such as the Water Quality Index and Trophic State Index, are crucial for effective water quality monitoring and management.

The Water Quality Index (*WQI*) serves as a powerful tool for synthesising and communicating information about water quality to both experts and the general public [19]. It is also beneficial for water management authorities in maintaining the health of surface waters [20]. By addressing usage criteria, the negative impact of environmental pollution becomes tangible. It is a unit-less number that combines information from manifold analytical data into a sole aggregate through a method that portrays the situation of water quality well for the public and experts [20].

To conduct all-inclusive water quality valuation for lakes besides the water quality indices approach, implementing the trophic state index approach to identify the productivity of the lake is mandatory. The Carlson trophic status index (*TSI*) has long been established to evaluate the trophic state of many reservoirs and lakes and is determined using the procedures explained by Carlson in 1977 [21]. *TSI* has been a commonly used approach, and separately estimated from total nitrogen concentration, Secchi depth (SD), Chlorophyll-a (Chl-a) and total phosphorus concentration (TP) [22].

El Oulfa Pond is one of the few urban lakes in Morocco and is considered a site of biological and ecological interest in terms of scientific, tourist, and educational value. Formerly known as «Schneider Pond», the pond is fed by groundwater sources and rainwater, and is rich in flora and fauna that should be preserved and enhanced. It is also a suitable habitat for rare migratory birds that visit the region at certain times of year, such as *Apus apus* and *Ardea cinerea* [23]. The richness of the pond runs a risk of deterioration due to human activities (household waste, wastewater drained into the pond, solid waste, construction debris, etc.). Due to resulting eutrophication, the water in the pond is turning green.

This natural body of water will be converted into an urban ecological park with modern infrastructure and recreational areas. Hence, there is a need to determine its quality and trophic level. This study has, therefore, tried to elucidate the use of *WQI* and *TSI* water quality indices to categorise the water quality and identify the trophic state of El Oulfa pond.

MATERIALS AND METHODS

El Oulfa pond, located in the vibrant city of Casablanca, Morocco, spans an area of 7 ha and receives water from both groundwater sources and stormwater runoff [24]. This region is characterised by a semi-arid climate, significantly influenced by oceanic conditions, with an average annual rainfall of approximately 400 mm and a mean temperature typically around 25°C. In recent decades, urban expansion near the pond (Figure 1) has led to the discharge of wastewater into the water body, significantly accelerating its degradation.

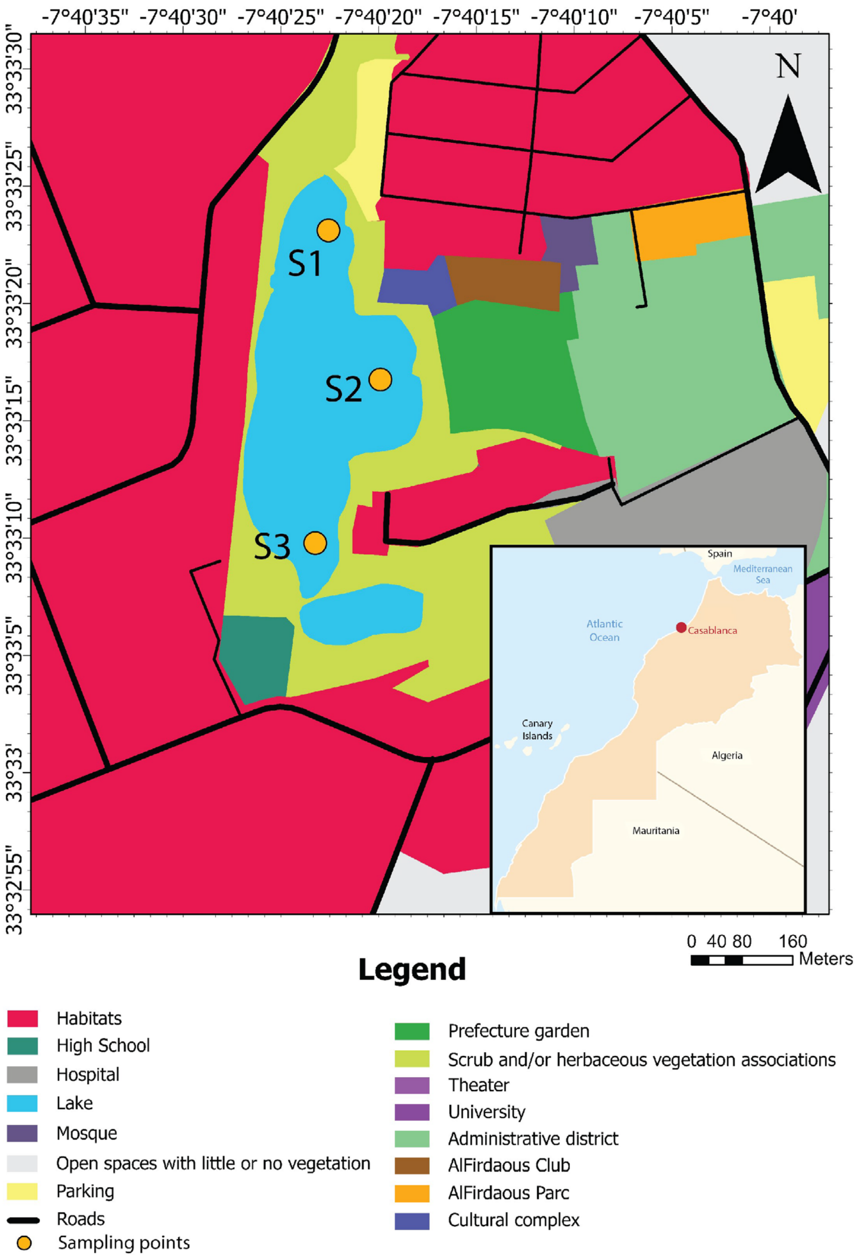

Figure 1. LULC map of the study area and sampling points [25]

Sampling and analysis

This study was conducted from July 2023 to July 2024. The water samples were collected from the surface layer of the pond (<0.5 m) at three different sampling locations: S1 (upstream), S2 (deepest point) and S3 (downstream) as shown in **Figure 1**.

One-litre water samples were collected using bottles that were thoroughly cleaned and rinsed. The samples were stored at 4 °C and transported to the laboratory for analysis on the same day. The selected water quality parameters included Temperature (T), pH (Potential of Hydrogen), EC (Electrical Conductivity), Dissolved Oxygen (DO), Secchi Disk Depth (SDD), Total Suspended Solids (TSS), Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP), Ammonium (NH_4), Nitrates (NO_3), Sulphates (SO_4) and Chlorophyll-a (Chl-a). Temperature, pH, EC and DO were measured on site using a Multi-parameter analyser. A 30-cm metal disk was used to measure the SDD. The analytical procedures for TSS, SRP, TP, NH_4, NO_3, SO_4 and Chl-a were performed according to standard methods [26].

Water Quality Index

In this study, the *WQI* was used to assess the impact of both natural and anthropogenic factors on various key parameters of the surface water chemistry in El Oulfa Pond. This index was calculated using the weighted arithmetic index method, as described by [27]. This approach involves calculating a numerical value known as the relative weight (*Wi*), which is assigned to each physicochemical parameter, based on eq. (1):

$$Wi = k/Si \tag{1}$$

Here, *k* represents the constant of proportionality, which can also be determined using eq. (2):

$$k = 1/\sum_{i=1}^{n} (\frac{1}{Si}) \tag{2}$$

Where *n* denotes the number of parameters, and *Si* – the maximum value of each parameter's standard Moroccan threshold of surface water quality [28], expressed in mg/L for BOD5, in µg/L for Chlorophyll-a, etc.

Next, a quality rating scale *Qi* is determined for each parameter by dividing the concentration by the standard for that parameter and multiplying the result by 100, as illustrated in eq. (3):

$$Qi = \left(\frac{Ci}{Si}\right) \times 100 \tag{3}$$

Where *Ci* denotes the concentration of each parameter in mg/L.

Finally, the overall *WQI* is computed using eq. eq. (4):

$$WQI = \frac{\sum_{i=1}^{n} Qi \times Wi}{\sum_{i=1}^{n} Wi} \tag{4}$$

Trophic State Index

The trophic state index of Carlson [21] was determined based on the values of water transparency measured by the Secchi disc (TSI_{SD}) and the values of surface concentrations of Chl-a ($TSI_{Chl\text{-}a}$) and total phosphorus (TSI_{TP}), according to eq. (5), eq. (6) and eq. (7):

$$TSI_{\mathrm{TP}} = 14.42 \times \ln \mathrm{TP} + 4.15 \tag{5}$$

$$TSI_{\mathrm{Chl-a}} = 9.81 \times \ln(\mathrm{Chl-a}) + 30.6 \tag{6}$$

$$TSI_{\mathrm{SD}} = 60 - 14.41 \times \ln \mathrm{SD} \tag{7}$$

Where SD denotes Secchi disk depth [m], TP – total phosphate [μg/L], and Chl-a – Chlorophyll-a [μg/L].

The overall index (*TSI*) is calculated by taking the average of the values TSI_{SD}, $TSI_{\mathrm{Chl\text{-}a}}$ and TSI_{TP}, according to eq. (8):

$$TSI = (TSI_{\mathrm{SD}} + TSI_{\mathrm{Chl-a}} + TSI_{\mathrm{TP}})/3 \tag{8}$$

RESULTS

Results of the *WQI* and *TSI* assessment for the surface water of El Oulfa Pond showed interesting variations in water quality, highlighting the impact of urban runoff and wastewater discharge on the ecosystem. The analysis revealed critical insights into the physicochemical parameters, indicating levels of nutrients and contaminants that affect the overall health of the pond.

Water Quality Index

The *WQI* is a numerical index that integrates various water quality parameters into a single value. It classifies water as illustrated in 2 into five categories: excellent ($WQI < 25$), good ($25 \leq WQI \leq 50$), poor ($50 < WQI \leq 75$), inferior ($75 < WQI \leq 100$), and non-potable ($WQI > 100$) [29]. This classification offers a simplified yet comprehensive overview of the water's suitability for various uses.

As shown in Figure 2, the pond water was generally of non-potable quality. The mean *WQI* values for stations S1, S2, and S3 were 1984, 2026, and 1928, respectively. Station S3 exhibited the highest variability with a standard deviation of 549, compared to 475 for S1 and 367 for S2, indicating significant fluctuations in water quality (Table 1).

Table 1. Min, Max, Mean and Standard Deviation of the WQI values of each station

Station	S1	S2	S3
Min	1155	1430	1375
Max	2762	2864	3756
Mean	1984	2026	1928
StDev	475	367	549

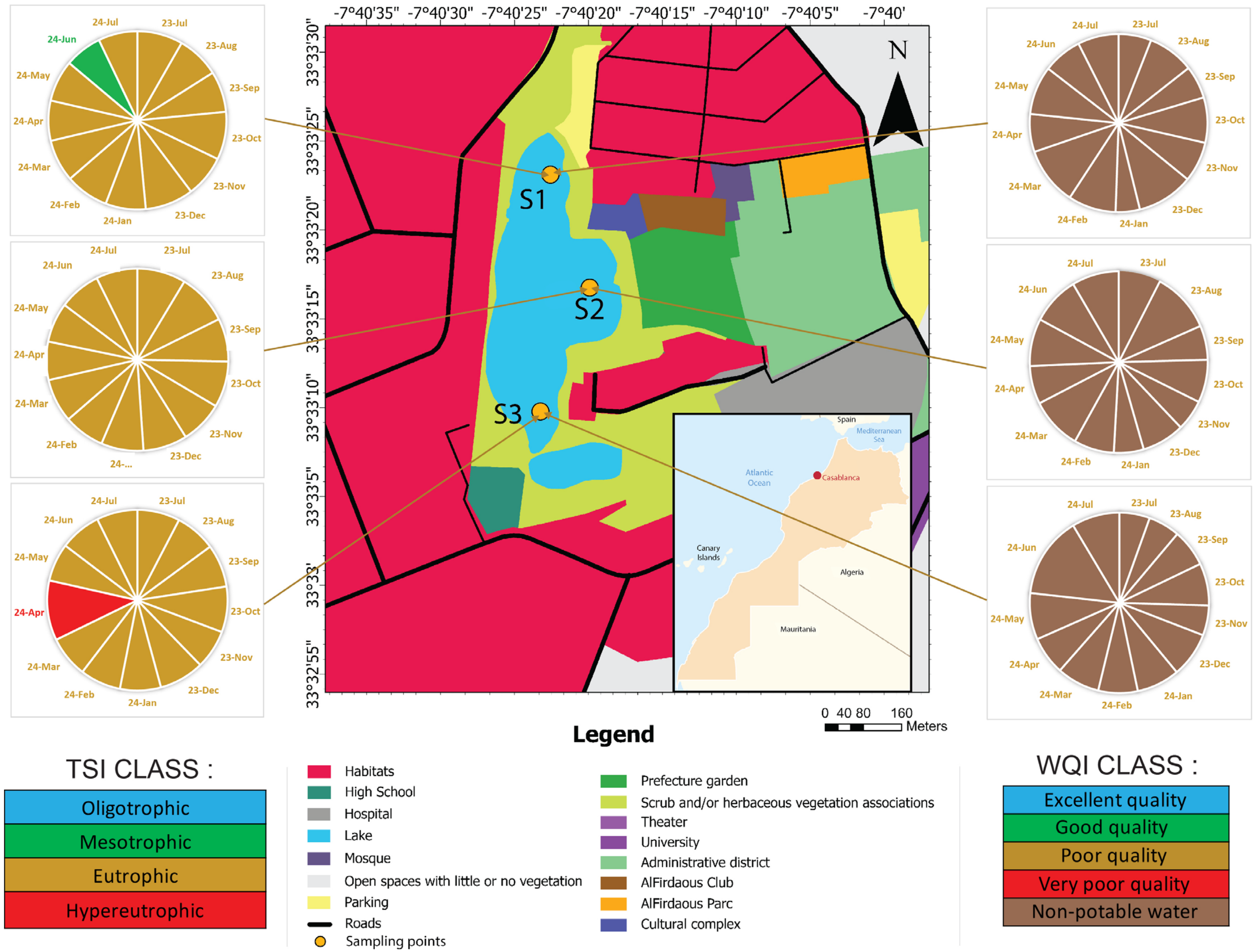

Figure 2. Comparative map of WQI and TSI on the three different stations during the 13 months; the pie chart's content for each slice represents a WQI and TSIcolour category

Temporal analysis (**Figure 3**) revealed key trends. In July 2023, *WQI* values ranged from 1412.62 to 2013.34, indicating moderate levels of water quality. From September to January, *WQI* values stabilised across all stations, ranging between 1500 and 2000, suggesting more uniform water conditions. In December 2023, a notable spike was observed at S1 (*WQI* = 2691.69).

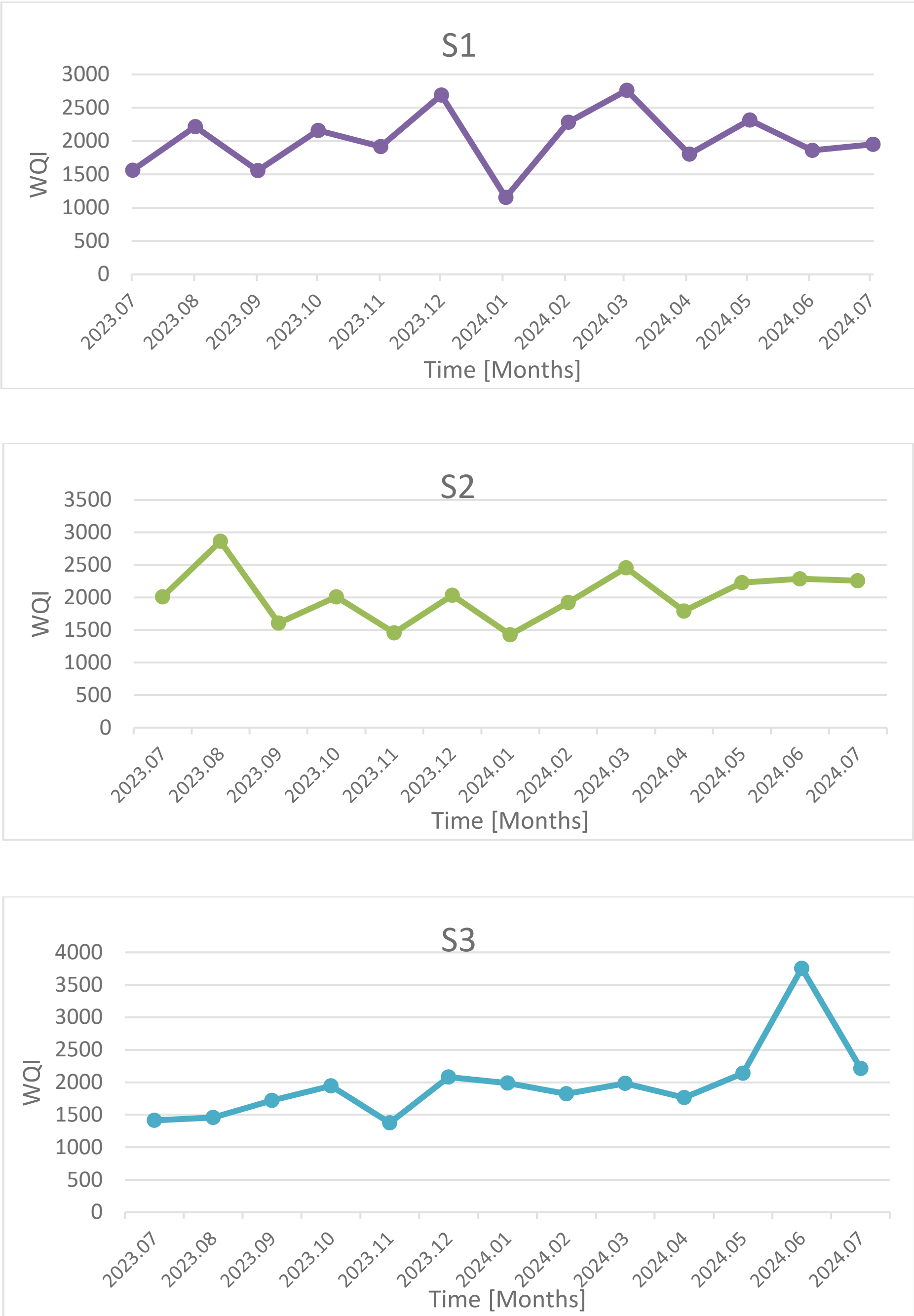

Figure 3. Temporal variation of the WQI in S1 (a), S2 (b), and S3 (c)

In March 2024, S1 recorded its highest *WQI* value (2761.67), while the most extreme value in the entire dataset occurred in June 2024 at S3, reaching 3755.52. Throughout the study period, S3 appeared as the most variable station, while S1 and S2 showed more consistent trends. Clear seasonal patterns were evident, with higher *WQI* values in warmer months (June, July, August) and stabilisation during colder periods (September to February).

Table 2 shows the results of the *WQI* assessment in both summer and winter seasons. During summer, *WQI* values ranged from 1859.69 (S1) to 3755.52 (S3), indicating severe water quality deterioration. Winter values, although somewhat lower (1155.17 to 1987.6), remained within the non-potable category. Across both seasons, all stations exceeded drinking water safety thresholds. S3 consistently exhibited the poorest water quality, while S1 recorded relatively better values.

Table 2. Results of the WQI assessment for the surface water of El Oulfa Pond in summer and winter seasons

Station	Longitude	Latitude	Summer		Winter	
			WQI	Type of water	*WQI*	Type of water
S1	33,556,431	–7,672,734	1859.687	Non-potable	1155.167	Non-potable
S2	33,554,592	–7,672,107	2286.709	Non-potable	1429.622	Non-potable
S3	33,553,181	–7,673,114	3755.519	Non-potable	1987.68	Non-potable

Trophic State Index

The traditional *TSI* criteria, based on TP, Chl-a, and SDD, were applied to assess eutrophication in the selected reservoirs. The typical *TSI* ranges are 30 to 40 for oligotrophic conditions, 40 to 50 for mesotrophic conditions, 50 to 70 for eutrophic conditions, and greater than 70 for hypereutrophic conditions.

Table 3 shows the descriptive statistics of the *TSI* values, revealing some interesting patterns in the nutrient levels at each sampling point. From these data, it is clear that all three sampling points generally fell within the eutrophic category throughout most of the year. However, the variability in nutrient levels was particularly pronounced at S3, suggesting a more unstable trophic state there.

Table 3. The minimum, maximum, mean, and standard deviation (StDev) values of the *TSI* for each sampling point

Sampling Point	Mean	Min	Max	StDev
S1	55.26	49.00	63.58	4.23
S2	58.33	51.48	68.34	4.66
S3	59.79	52.86	83.49	8.87

At S1, *TSI* values ranged from a low of 49.00 in June 2024 to a high of 63.58 in December 2023. The average *TSI* of 55.26 indicates that this site mainly remained eutrophic, with the occasional dip towards mesotrophic conditions, notably in June 2024. The relatively low standard deviation of 4.23 suggests that the nutrient levels were relatively stable at this point.

Table 4. Carlson Trophic State Index in S1, S2 and S3

S1	23-Jul	23-Aug	23-Sep	23-Oct	23-Nov	23-Dec	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul
$TSI_{\text{Chl-a}}$	76.02	73.26	53.32	76.12	63.31	80.03	53.32	76.12	76.65	70.99	78.93	59.19	62.30
TSI_{SD}	89.40	85.96	87.34	86.41	84.71	85.53	84.71	68.61	67.36	60.00	67.36	63.22	67.36
TSI_{TP}	14.37	9.49	20.63	25.94	16.65	25.18	20.63	25.94	22.19	27.27	17.33	24.61	24.95
S2	23-Jul	23-Aug	23-Sep	23-Oct	23-Nov	23-Dec	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul
$TSI_{\text{Chl-a}}$	88.31	79.48	66.75	68.22	68.28	71.75	66.75	68.22	77.32	68.76	74.40	74.65	76.65
TSI_{SD}	100.54	106.38	86.41	88.33	83.56	84.71	83.56	66.77	66.66	58.63	66.21	67.36	66.21
TSI_{TP}	7.28	19.16	20.44	29.20	20.58	21.58	20.44	29.20	31.65	27.05	19.38	25.91	24.09
S3	23-Jul	23-Aug	23-Sep	23-Oct	23-Nov	23-Dec	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul
$TSI_{\text{Chl-a}}$	81.51	74.55	62.35	74.63	57.80	81.33	62.35	74.63	78.01	66.42	75.13	79.59	81.45
TSI_{SD}	87.34	84.71	90.55	89.40	83.19	83.93	83.19	69.29	67.12	57.37	66.66	68.61	66.89
TSI_{TP}	9.44	10.67	25.66	26.53	22.23	22.78	25.66	26.53	27.05	126.66	16.80	23.72	22.47

In contrast, S2 exhibited *TSI* values ranging from 51.48 (April 2024) to 68.34 (August 2023), with an average of 58.33 and a StDev of 4.66. This point consistently showed elevated nutrient levels, especially during the late summer months. The slight increase in variability compared to S1 hints at localised factors that may influence nutrient dynamics, leading to occasional spikes in *TSI*, as shown in **Figure 4**, such as the fact that S2 is the deepest sampling point.

Sampling point S3 stood out with a mean *TSI* of 59.79, showcasing the highest variability among all sites. The *TSI* ranged from 52.86 in May 2024 to a concerning 83.49 in April 2024, indicating hypereutrophic conditions. The high standard deviation of 8.87 further emphasises the instability at this site.

Table 4 and **Figure 4** show *TSI* values across all points, revealing distinct seasonal trends. Notably, nutrient concentrations peaked in August 2023 (S2: 68.34), December 2023 (S1: 63.58), and April 2024 (S3: 83.49). Interestingly, the warmer month of June 2024 saw a significant decrease in *TSI* values, particularly at S1, which reached mesotrophic status. Significant spatial variability was also observed. S3 recorded the highest *TSI* in April 2024, while S1 showed more stable nutrient levels, gradually decreasing towards the end of the study period. S2 experienced moderate fluctuations but consistently maintained eutrophic conditions.

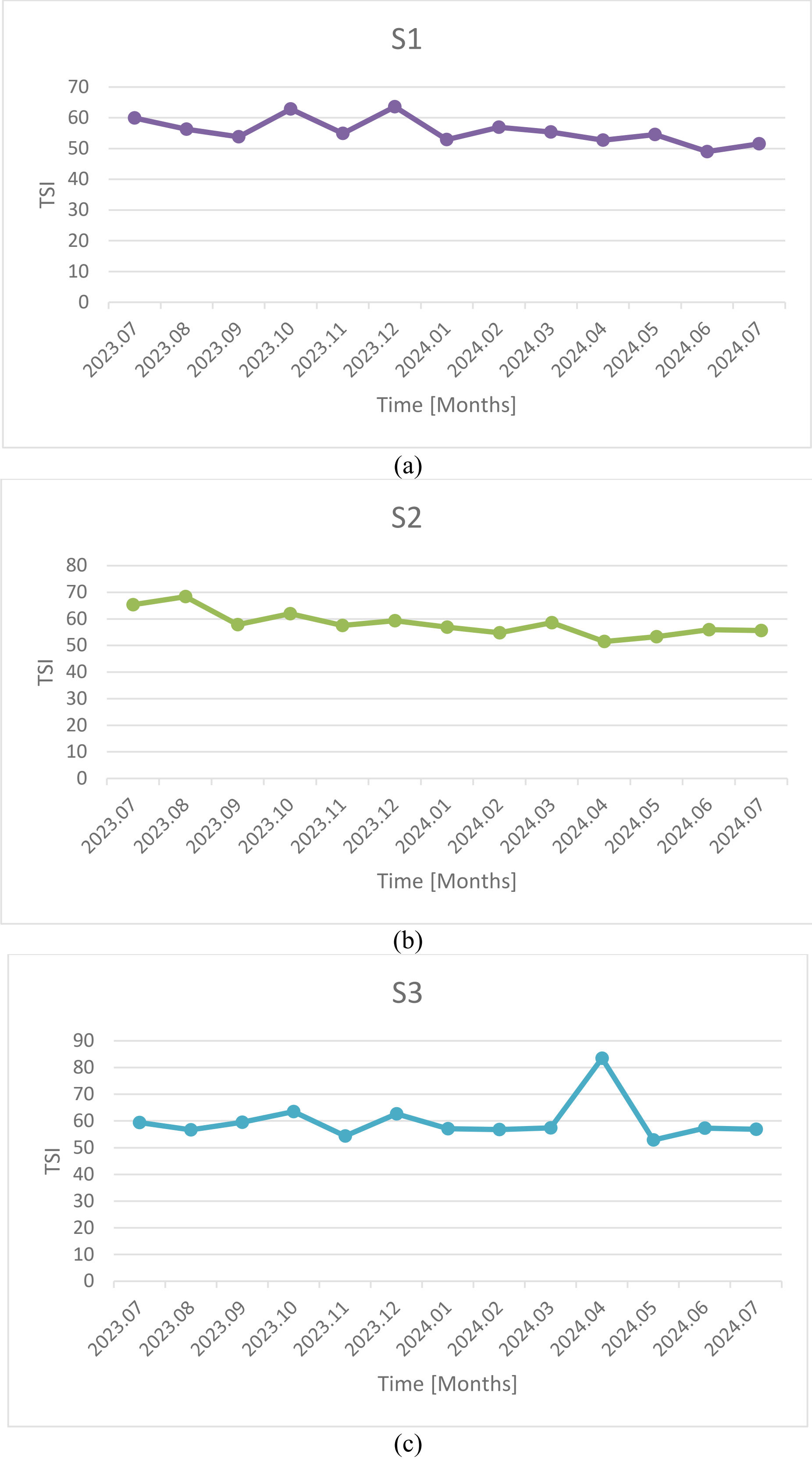

Figure 4. Temporal variation of the TSI in S1 (a), S2 (b), and S3 (c)

DISCUSSION

The assessment of water quality using both the Water Quality Index (*WQI*) and the Trophic State Index (*TSI*) has provided a comprehensive overview of the ecological status of El Oulfa Pond. While the *WQI* highlighted critical degradation and seasonal fluctuations in overall water quality, the *TSI* revealed persistent eutrophic conditions with significant spatial variability. Together, these indices reflect the combined impact of nutrient loading, urban runoff, and hydrological dynamics.

Water Quality Index

The higher variability observed at S3 may reflect localised nutrient loading or specific environmental pressures disproportionately affecting this site [27]. Notably, urban discharges have been recorded in this area, further contributing to fluctuations in water quality. The sharp increase in *WQI* values at S2 during summer 2023 likely suggests an influx of pollutants or nutrients, potentially from anthropogenic sources such as wastewater discharges from urban stormwater outlets [30]. It aligns with existing literature that highlights enhanced nutrient loading during the summer due to increased rainfall and urban runoff [31].

The stabilisation of *WQI* values from September to January may be attributed to more stable hydrological conditions and reduced biological activity during colder months [32]. However, the spike observed in December 2023 at S1 could indicate a localised pollution event or internal nutrient cycling, potentially driven by organic matter degradation or redox dynamics within the pond [33].

The peak at S1 in March 2024 likely corresponds to the onset of spring, when runoff intensifies, introducing new nutrient inputs [34]. The extremely high value recorded at S3 in June 2024 (3755.52) may point to a major pollution incident or nutrient surge, potentially associated with heavy rainfall events or unmanaged discharges [30]. The seasonal trends observed support the findings of Cloern [35], who noted that warmer months promote evaporation, pollutant concentration, and heightened biological activity, while cooler months favour dilution and natural flushing [36]. The spikes recorded in August 2023 at S2 and in June 2024 at S3 likely result from intense stormwater runoff, which is a well-known contributor to nutrient enrichment in aquatic environments [37].

Overall, water quality dynamics in El Oulfa Pond are strongly influenced by both seasonal variations (temperature, precipitation) and site-specific nutrient sources, which play a crucial role in shaping the overall water conditions. This influence is reflected in the *WQI* results, which indicate that all three monitoring stations consistently fall within the non-potable water classification throughout the year, as illustrated in **Figure 2**. The combination of external environmental factors and localised nutrient inputs significantly impacts the pond's ecological balance.

Trophic State Index

The pronounced *TSI* variability at S3, especially the 83.49 value in April 2024, suggests significant nutrient overload, likely exacerbated by localised inflows or runoff [38]. Rain during this period might have washed polluted water from an upstream area, where there is a known pollution source, into the lower basin. This runoff could have picked up contaminants along the way, contributing to the problem.

The brief drop at S1 in June 2024, when it reached mesotrophic status, could indicate improved water quality, possibly due to increased nutrient uptake by aquatic plants or enhanced water exchange. Nevertheless, throughout the year, *TSI* values remained predominantly in the eutrophic range, emphasising the pond's vulnerability to high nutrient levels.

Spatial trends were equally telling. S1's relatively low variability and stable average suggest a site less affected by short-term nutrient inputs. However, the peak in December 2023 could reflect seasonal factors, such as increased productivity or internal nutrient cycling [39]. Meanwhile, S2, the deepest site, showed slightly greater variability and a clear peak in August 2023, consistent with seasonal nutrient loading [40]. This observation may be linked to stratification effects or delayed mixing at depth [41]. S3, by contrast, presented the most unstable trophic state, with wide fluctuations and the highest standard deviation. The hypereutrophic peak in April 2024 was particularly alarming and suggests hotspots of nutrient input, potentially from direct runoff or nearby pollution sources [42]. Even the minimum value at S3 in May still reflected eutrophic conditions, confirming that the site is consistently under stress. These results indicate that all sampling points generally remained within the eutrophic range throughout the year [43], with occasional excursions into mesotrophic or hypereutrophic conditions as shown in Figure 2.

Overall, seasonal dynamics played a key role, with peak nutrient levels aligning with months of heightened biological productivity (e.g., August, April, and December). The temporary improvement observed in June might be due to plant uptake or water turnover. Still, the persistent eutrophic status confirms the ongoing challenge of nutrient enrichment in El Oulfa Pond.

CONCLUSION

The results indicate that El Oulfa Pond is predominantly eutrophic, with notable seasonal and spatial variations in nutrient levels. Station S3 stands out as a nutrient hotspot, evidenced by a peak *TSI* value of 83.49 in April 2024, highlighting the urgency to address nutrient overload. This situation contrasts with Station S1, which shows progress toward mesotrophic conditions and greater stability, likely due to improved water circulation during warmer months.

To mitigate eutrophication, particularly at S3, targeted measures such as installing retention basins and natural filtration systems can help reduce phosphorus and nitrogen runoff. Monitoring nutrient cycling in the sediment and conducting intensified follow-ups during heavy rainfall seasons are essential to pinpoint pollution sources. Additionally, maintaining proactive water level management at S1 can encourage hydrological exchanges.

Water Quality Index (*WQI*) data further reveal seasonal and site-specific changes, with notable increases in *WQI* values at S2 and S3 during the summer months (June to August) due to nutrient runoff and heightened biological activity. In contrast, the colder months (September to February) exhibit more stable *WQI* values, indicating reduced nutrient inflows. Persistent pollution throughout the year underscores the need for a dual approach that tackles both seasonal and localised water quality issues.

In response, strategies should focus on reducing summer stormwater runoff, improving sediment nutrient management, and enhancing water circulation. Community outreach programs aimed at curbing domestic and agricultural nutrient discharges could also play a key role in improving the pond's overall water quality.

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NOMENCLATURE

Symbols

Ci	The concentration of each parameter in mg/L
k	constant of proportionality
n	number of parameters
Qi	Quality rating scale for each parameter
Si	Maximum value of each parameter's standard Moroccan thresholds of surface water quality
Wi	relative weight

Abbreviations

Chl-a	Chlorophyll-a
DO	Dissolved Oxygen
EC	Electrical Conductivity
LULC	Land Use / Land Cover
NH_4	Ammonium
NO_3	Nitrates
pH	Potential of Hydrogen
SDD	Secchi Disk Depth
SO_4	Sulphates
SRP	Soluble Reactive Phosphorus
StDev	Standard deviation
T	Temperature
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
WQI	Water Quality Index

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