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RESEARCH ARTICLE

SUBSURFACE DYNAMICS OF PHYSICOCHEMICAL PARAMETERS IN THE PASUR RIVER ESTUARY, BANGLADESH: A BASELINE ASSESSMENT

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ABSTRACT

The investigation aimed to record the vertical distribution of some key physicochemical parameters in the Pasur River estuary across five sampling stations using a CTD. Each sampling zone demonstrated varying depth according to the local bathymetric feature. Data were collected at one-meter intervals, ranging from 6 to 22 vertical layers, according to the stations. Pressure exhibited a consistent linear increase with depth, as expected in aquatic environments. Temperature profiles showed overall stability around 29°C, with minor variations at greater depths in some stations. Turbidity generally demonstrated an increasing trend with depth, though sporadic deviations were observed. Conductivity values remained predominantly stable across depths at all stations (nearly 1 S/m) with marginal deviations, reflecting a relatively homogeneous ionic composition corresponding to salinity, which ranged from 4.47 to 5.65 PSU. pH levels exhibited marginal but steady increases (within approximately 0.1 units) along the vertical profiles, suggesting a well-buffered system. These baseline findings provide critical insights into the estuarine dynamics of the Pasur River and contribute valuable reference data for future studies on environmental monitoring, biogeochemical cycling, and ecosystem modelling.

KEYWORDS

CTD (Conductivity, Temperature, Depth) Sundarbans, Physicochemical parameters, Vertical distribution

1. INTRODUCTION

Estuaries are the interface between the fluvial and the marine ecosystem (Nanjappa et al., 2023). They have significance from both the economic and ecological perspectives (Shefat et al., 2020). Occupying less than 10% of the ocean surface, they have a crucial role in global and marine biogeochemical cycling, including the carbon cycle, nitrogen cycle, and nutrient cycles (Shefat et al., 2020). Additionally, the fresh and marine water inflow brings higher nutrient levels to both the water surface and the water column in the estuary (Nanjappa et al., 2023). These ecosystems are characterized by the drastic dynamic interaction of physicochemical and biological parameters. These parameters fluctuate notably in the vertical layers of the water columns and are influenced by tidal actions, water inflows, and anthropogenic activities (van der Most and Marchand, 2011). These interactions are a general phenomenon; however, they provide insights about the water chemistry, the catchment area's geology, weathering processes, precipitation, and anthropogenic activities (Giridharan et al., 2010; Haddout et al., 2016).

Thorough knowledge of the physicochemical parameters of an estuarine system is essential to unravel the scope and utilization of these processes and hence to assess their ecological functionality. For example, temperature, salinity, dissolved oxygen (DO), pH, and nutrient levels notably influence the occurrence, diversity, and distribution of aquatic macro- and microbiota. Temperature is a crucial factor for regulating metabolic rates and stratification patterns; osmoregulation is a function of water salinity; DO is critical for aerobic respiration; and pH impacts biochemical processes (Clarke, 2006; Lin-lin et al., 2011; Wang et al., 2023). The most interesting issue about these parameters is they are not static; they demonstrate variations both temporally and spatially, particularly along the vertical axis of the water column. Such a vertical heterogeneous profile has profound implications for the ecology and the biogeochemical cycles (Gao et al., 2016).

Vertical profiling of physicochemical parameters has been investigated worldwide. In the Gulf of Montijo, Panama, a quasi-homogeneous water column with minimal stratification was found; it's attributed to the warm tropical climate and mixing processes (García et al., 2023). In temperate estuaries, including Chesapeake Bay, USA, and the Celtic Sea, Europe, on the other hand, seasonal variations lead to severe thermal stratification during warmer months. A trend of gradual increase in vertical salinity profile was found in the Gulf of Montijo (García et al., 2023; Kundu et al., 2024; Testa et al., 2018). Another study analyzed pH levels in the top ~10 meters of deep-ocean sediments in the South China Sea (Shao et al., 2023). A study in the Maldives region of the Indian Ocean observed an oxygen-deficient and well-developed thermocline layer between 300 and 1250 meters of water column (Ramamirtham, 1968). On the other hand, categorized vertical profiles of suspended sediment levels into three types influenced by density stratification and mixing conditions in the turbidity maximum zone of the Changjiang Estuary, China (Li et al., 2019).

Studies are limited on the vertical distribution of environmental parameters in Bangladesh. Investigations mostly focus on the surface water qualities. A study conducted in the Pasur-Sibsha river estuary found an inconsistent stratification pattern of dissolved oxygen (DO) ranging from 6.0 to 8.6 mg/L. Water samples were collected from 0.60 m depth. Temperature and phytoplankton density showed significant correlations with DO, while pH and salinity did not exhibit significant associations (Rouf et al., 2022). Another study in the Sundarbans found an acceptable status of DO; however, there was a critical range of BOD and COD values for fifteen water samples collected from discrete water layers (Rahaman et al., 2014) . Despite the importance of physicochemical parameters and their vertical distribution, previous studies have focused on surface water

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analyses (Miah et al., 2015). These investigations are informative; however, they lack the critical subsurface dynamics.

This lack restricts our ability to generate a proper model for estuarine dynamics. Additionally, it limits our prediction of proper ecological responses with respect to environmental change and implementation of proper management policies. High-resolution data on the vertical distribution are crucial for understanding the dynamics of coastal and estuarine ecosystems. To bridge the gap, the present study employs conductivity-temperature-depth (CTD) measurements to obtain a comprehensive vertical profile of key physicochemical parameters. By systematically collecting data across multiple vertical layers, this study aims to provide baseline data to support future research, monitoring, and management efforts in the estuary and similar systems. The findings of this research will contribute to a more deepened understanding of estuarine dynamics in Bangladesh, facilitating informed decision-making for conservation and sustainable resource utilization.

2. Materials and Methods

2.1 Study Area

The current study was conducted during August 2024 in the Pashur River Estuary, located in the southwestern region of Bangladesh. It exemplifies complex estuarine dynamics, supporting the Sundarbans mangrove ecosystem (Figure 1). The Pasur River and the Sibsa River joined together to form an estuary at the Akram Point, and eventually, it falls into the Bay of Bengal. The river receives freshwater from the Padma River through the Rupsha-Modhumoti-Gorai River System and falls into the Bay of Bengal through the Sundarbans mangrove ecosystem. This unique positioning makes the estuary a vital source of ecological and economic resources, supporting diverse aquatic life and human livelihood (Shefat et al., 2020). The Pasur River holds a high fish biodiversity: 95 finfish species across 14 orders, 45 families, and 77 genera are reported in the river (Dhiman et al., 2015). Economic activities, including transportation, agriculture, and tourism, are also supported by the Pasur River estuary. Millions of people in the southwestern coastal region of Bangladesh are dependent on this estuary for their livelihood. Vital fishery resources and commercial fishing activities are provided by the estuary (Hasan et al., 2022). This estuarine system plays a crucial role in supporting regional biodiversity as well. Understanding its environmental parameters is essential for the sustainable management and conservation efforts of this region.

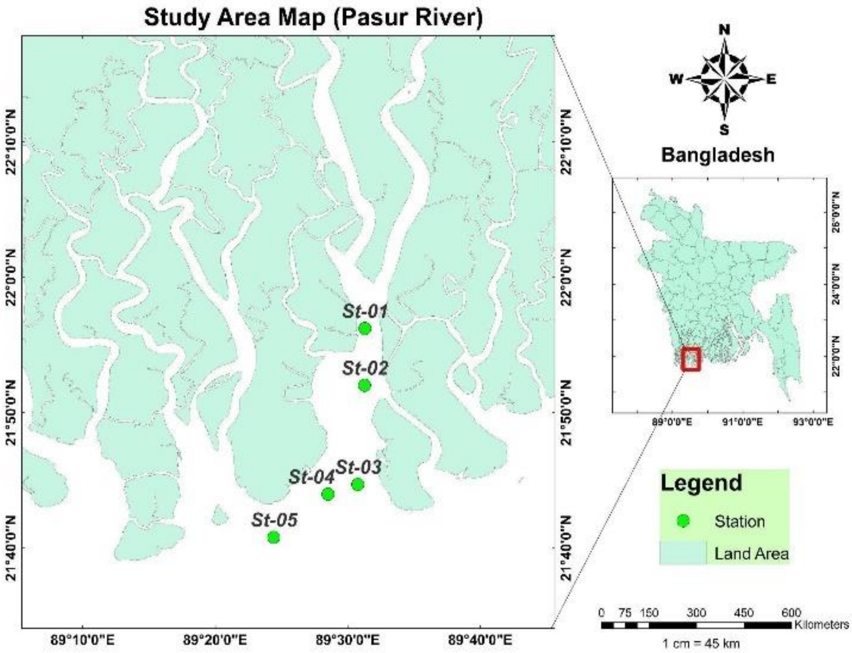

Figure 1: Distribution of sampling stations in the Pasur River channel

2.2 Sampling and Data Collection

For simplicity, the whole study area was divided into 5 sampling stations (Figure 1). A calibrated multiparameter probe CTD (Seabird Electronics, SBE 19 Plus) was employed for collecting water samples from the surface to various vertical layer depths according to the local bathymetry (Horja et al., 2016). The system was configured with multi-modular sensors for the measurement of various water quality parameters, including pressure, temperature, turbidity, conductivity, and pH, while depth and salinity were derived from pressure and conductivity, respectively. An external protective cage coupled with titanium was a part of the CTD for protection. A ship crane was used to deploy the instrument. The built-in microcomputer recorded the data and stored it in the internal memory of the CTD. The calibration coefficients and program settings were maintained in that nonvolatile memory. Sea-Bird's "SeaSave" and "SBEDataProcessing" were the accompanying software that were used for retrieving data afterward.

2.3 Data Extraction

The extraction process of the Sea-Bird CTD instrument underwent systematic execution to achieve accurate results. CTD raw data files, downloaded as ". hex", were retrieved through a USB interface connection to a computer. Subsequently, Sea-Bird's SBE Data Processing software, part of the SeaSoft package, was installed and configured to recognize the raw data and configuration files. This package contained modules including Data Conversion, Filtering, Align CTD, Loop Edit, Bin Average, and ASCII Out. The Data Conversion module transformed raw data into ". cnv" files that used text-based data processing. Here, an appropriate configuration file was introduced to the software, and the input data file was processed for the measured parameters (depth, pressure, temperature, turbidity, conductivity, salinity, and pH). In this process, a ". cnv" file was generated with both a metadata header and a columnar data format.

The subsequent modules enabled the completion of further refinements on the process. Noise was eliminated through low-pass filtering, and the Align CTD module established time-based alignments. The Loop Edit module eliminated all data scans moving slower than 0.1 m/s. Afterwards the data received an average process using 0.25-meter bins to produce smooth profiles through the Bin Average module. Finally, user-friendly ASCII files were created through the ASCII Out module, which was then converted into Excel files through Python.

3. Results and Discussions

Vertical distributions of physicochemical parameters of the Pasur River estuary are provided in the tables (1-5). The whole study area was divided into five data collection zones for simplicity. Different stations had different depths due to the river bathymetry. Vertical distribution of physicochemical parameters was recorded with respect to the depths of the sampling stations

Distribution of environmental parameters was recorded up to six vertical layers in the first station (Table 1). However, pressure (dbar) demonstrated a positive linear trend (1.01 to 6.03 dbar) with depth. Interestingly, temperature remained almost constant (29°C) with a negligible decreasing trend downwards. Moreover, turbidity (NTU) had an increasing trend that broke in specific layers. The zone demonstrated nearly stable conductivity (S/m) values around 1.00 S/m across depths. Salinity was almost stable within the vertical layers too. pH Weakly increased with depth (6.92 to 6.99).

Table 1: Vertical profiling of physicochemical parameters at the first sampling zone

Depth	Pressure	Temperature	Turbidity	Conductivity	Salinity	pH
1	1.01	29.28	265.55	0.99	5.04	6.92
2	2.01	29.27	271.04	0.99	5.04	6.94
3	3.01	29.26	262.35	0.99	5.04	6.95
4	4.02	29.09	271.77	1.01	5.25	6.97
5	5.03	29.08	310.29	0.99	5.15	6.98
6	6.03	29.17	347.05	0.99	5.04	6.99

Parameters up to the 14th depth layer have been recorded in the second station (Table 2). However, pressure (dbar) demonstrated anticipated linear increasing trends as the previous station, ranging from 1.01 to 13.08. Interestingly, temperature remained stable and demonstrated the same value as the previous station except for the last layer (29.15). Moreover, turbidity (NTU) had a steady increment with respect to depth. Conductivity remained nearly stable with values around 1.08 to 1.09. Salinity and pH were stable, showing value ranges of nearly 6.8-6.9 and 5.6 PSU, respectively.

Table 2: Vertical profiling of physicochemical parameters at the second sampling zone

Depth	Pressure	Temperature	Turbidity	Conductivity	Salinity	pH
1	1.01	29.22	165.81	1.08	5.61	6.81
2	2.01	29.22	168.19	1.08	5.61	6.82
3	3.01	29.22	169.74	1.08	5.61	6.84
4	4.02	29.22	168.74	1.09	5.62	6.85
5	5.03	29.22	169.45	1.09	5.62	6.86
6	6.03	29.23	173.67	1.09	5.63	6.87
7	7.04	29.23	172.48	1.09	5.63	6.88
8	8.05	29.23	175.68	1.09	5.64	6.89
9	9.05	29.23	181.41	1.09	5.64	6.90
10	10.06	29.22	186.26	1.09	5.64	6.91
11	11.06	29.22	248.03	1.09	5.64	6.91
12	12.07	29.20	444.96	1.09	5.65	6.92
13	13.08	29.15	564.60	1.09	5.65	6.92

Third stations facilitated the collection of data across eight distinct layers (Table 3). Pressure demonstrated mirroring the stability observed at the previous stations, with values fluctuating between 1.01 and 8.05. Temperature had the same stable feature analogous to previous values across the layers; however, in the last two layers, temperature fell by one unit. However, turbidity (NTU) exhibited a heterogeneous pattern. Conductivity at this zone remained consistent across the depths, mirroring the stability observed at the previous stations. Salinity demonstrated a stable value; however, pH increased with depth at a very ignorable rate (6.89 to 6.98).

Table 3: Vertical profiling of physicochemical parameters at the third sampling zone

Depth	Pressure	Temperature	Turbidity	Conductivity	Salinity	pH
1	1.01	29.07	303.82	1.02	5.28	6.89
2	2.01	29.07	315.15	1.02	5.28	6.91
3	3.01	29.07	310.72	1.02	5.28	6.93
4	4.02	29.06	306.86	1.02	5.28	6.94
5	5.03	29.06	308.40	1.02	5.28	6.95
6	6.03	29.05	313.36	1.02	5.28	6.96
7	7.04	28.32	315.60	1.02	5.31	6.97
8	8.05	28.59	304.12	1.02	5.31	6.98

Eleven layers of vertical data were recorded in the fourth zone (Table 4). Pressure (dbar) demonstrated similar linear trends; however, temperature was stable but increased suddenly at the lowest vertical layer (29.53°C). However, turbidity (NTU) had a general increasing pattern; however, some of the layers broke the trend. Conductivity was stable across the depths (0.88 S/m), maintaining the trend; however, it increased very marginally at the last three layers. Salinity remained constant (4.47 psu) to the fifth layer, afterwards demonstrating a negligible increase, resulting in 4.82 PSU in the last layer. pH also demonstrated a marginal increasing trend.

Table 4: Vertical profiling of physicochemical parameters at the fourth sampling zone

Depth	Pressure	Temperature	Turbidity	Conductivity	Salinity	pH
1	1.01	29.13	210.76	0.88	4.43	6.72
2	2.01	29.16	211.87	0.88	4.47	6.88
3	3.01	29.15	221.03	0.88	4.47	6.90
4	4.02	29.15	218.56	0.88	4.47	6.92

Table 4 (Cont.): Vertical profiling of physicochemical parameters at the fourth sampling zone						
5	5.03	29.15	220.50	0.88	4.47	6.93
6	6.03	29.16	228.68	0.88	4.47	6.93
7	7.04	29.16	238.05	0.88	4.48	6.94
8	8.05	29.17	250.48	0.88	4.50	6.94
9	9.05	29.18	241.50	0.89	4.53	6.95
10	10.06	29.24	241.04	0.91	4.65	6.96
11	11.06	29.53	234.38	0.95	4.81	7.02

The final station provided data with respect to depth pertaining to 22 layers (Table 5). This is the zone with the deepest bathymetry across the study. Pressure (dbar) demonstrated the expected linear progression with depth; temperature was stable (nearly 29.5°C) with a negligible increasing trend. However, turbidity (NTU) demonstrated an incremental pattern, though sporadic deviations disrupted this trend within specific layers. Conductivity remained predominantly stable across the depths; however, in some of the layers, the value increased marginally, which is unprecedented in the previous zones. Both salinity and pH demonstrated a modest but consistent inclination with increasing depth.

Table 5: Vertical profiling of physicochemical parameters at the fifth sampling zone

Depth	Pressure	Temperature	Turbidity	Conductivity	Salinity	pH
1	1.01	29.50	233.61	0.95	4.86	6.67
2	2.01	29.51	229.30	1.09	5.58	6.79
3	3.01	29.51	227.07	1.07	5.48	6.85
4	4.02	29.51	225.31	1.07	5.48	6.85
5	5.03	29.51	225.81	1.07	5.48	6.86
6	6.03	29.51	222.82	1.07	5.48	6.86
7	7.04	29.51	222.97	1.07	5.48	6.86
8	8.05	29.51	222.70	1.07	5.48	6.87
9	9.05	29.51	227.60	1.07	5.48	6.87
10	10.06	29.51	231.28	1.07	5.48	6.88
11	11.06	29.51	232.63	1.07	5.48	6.89
12	12.07	29.52	232.01	1.07	5.48	6.89
13	13.08	29.52	237.62	1.07	5.48	6.9
14	14.08	29.53	244.11	1.07	5.48	6.90
15	15.09	29.53	281.97	1.07	5.48	6.90
16	16.10	29.53	323.48	1.07	5.48	6.91
17	17.10	29.54	369.58	1.08	5.55	6.91
18	18.11	29.54	415.93	1.08	5.56	6.91
19	19.12	29.54	440.77	1.08	5.57	6.91
20	20.12	29.55	446.15	1.08	5.57	6.91
21	21.13	29.55	459.53	1.08	5.57	6.92
22	22.139	29.55	463.96	1.08	5.57	6.92

The vertical distribution of physicochemical parameters in the Pasur River estuary contributes to the understanding of the complex dynamic interaction among the physical, chemical, and biological entities of estuarine systems. This baseline data can contribute to the current environmental monitoring and serve as a basis for future studies.

The linear increase of pressure with respect to depth (Figure 2) is a universal oceanographic principle. Even in estuarine environments, which are relatively shallow compared to the deep ocean, the pressure gradient is significant enough to be a defining vertical characteristic. This makes pressure a dominant environmental factor in any aquatic system. According to the study, pressure-driven density gradients can influence water column stratification and mixing, which in turn affects the vertical distribution of nutrients and can play a role in limiting the vertical transport of nutrients from deeper layers (Merino-Ibarra et al., 2021; Zhu et al. (2021). Besides, linear progression of pressure creates distinct vertical zones in the water column. Marine organisms inhabiting different depths have evolved specific physiological and morphological adaptations to cope with these varying pressure regimes. For instance, deep-sea organisms possess unique enzymes and cellular structures that function optimally under high pressure (Ohmae et al., 2013). Marine organisms' behavior is also affected by pressure, especially migratory species or larval stages that may experience different pressure conditions during their development or daily movements (Pradillon and Gaill, 2007). The substantial pressure difference between the surface and deeper layers (e.g., a 6 dbar difference in the first station and a 21 dbar difference in the last) represents a considerable environmental gradient that organisms must tolerate or avoid.

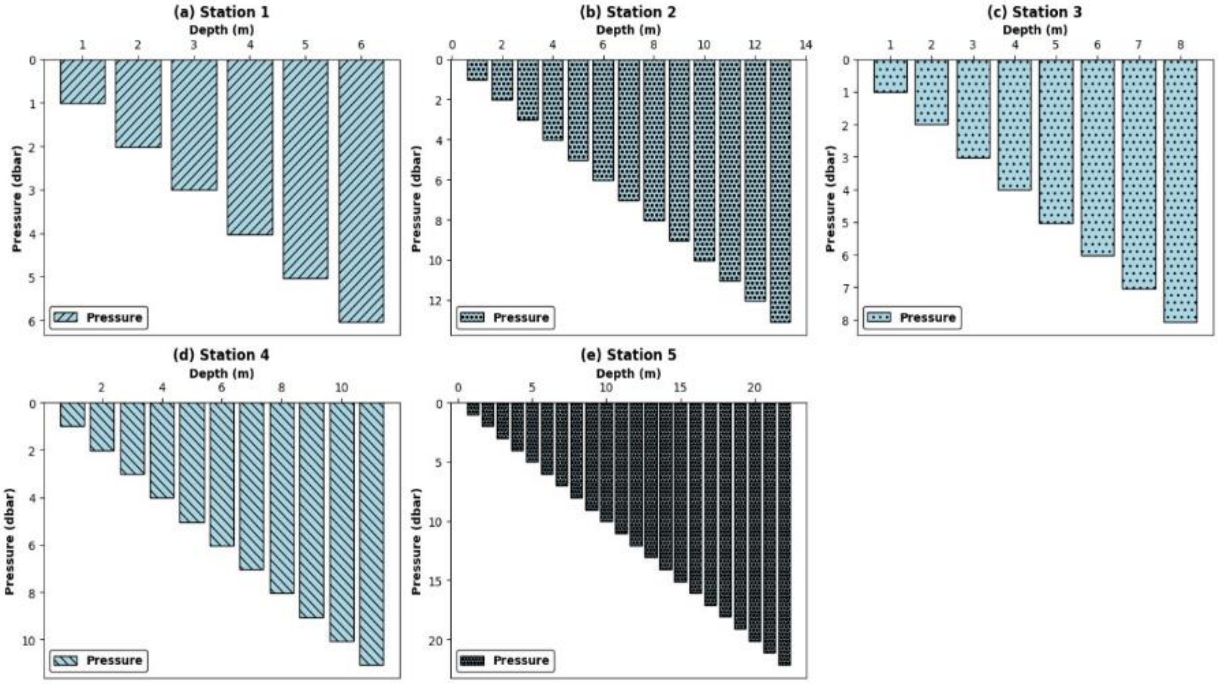

Figure 2: Vertical distribution of Pressure in Pasur River Estuary

Temperature demonstrated a remarkable vertical uniformity (Figure 3), which was seen before (Rouf et al., 2022). The results from this study also showed the same pattern, which is primarily a consequence of heavy rainfall in monsoon followed by a rigorous mixing of river water. This type of temperature profile is favorable for a homogenous microbial distribution in the estuarine waterbodies where organisms that can tolerate the temperature range will increase in abundance and others will decline (Hervé et al., 2025).

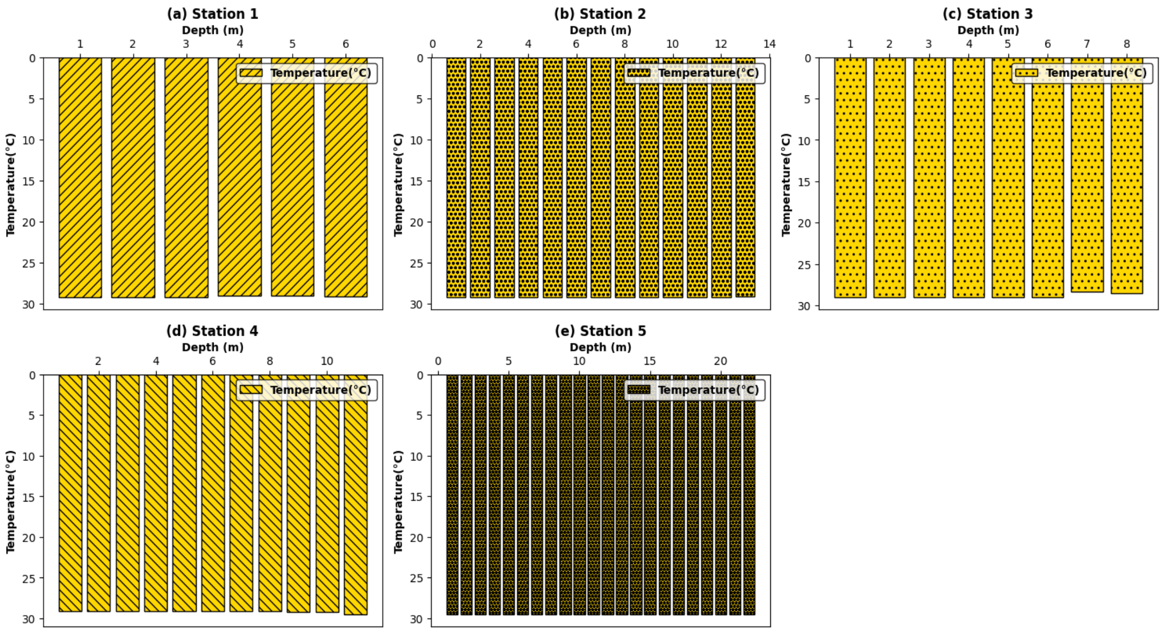

Figure 3: Vertical distribution of Temperature in Pasur River Estuary

Turbidity is the measurement of water transparency. Across most stations, turbidity generally exhibited an increasing trend with depth (Figure 4). However, it was not always consistent; for example, Station 1 showed a break in the increasing trend in specific layers, while Station 3 displayed a heterogeneous pattern. This indicates a more complex distribution of suspended particles with depth coupled with the influence of local factors in particle distribution (e.g., sediment resuspension, riverine input, biological activity) that differs across the study area. The increase in turbidity (reduction of transparency) reflects the particle settlement, while heterogeneous behavior might have resulted from the resuspension of sediments due to tidal currents, especially during spring tides, lateral advection of turbid waters, or localized sources of particulate matter. According to the study, heavy precipitation can result in massive erosion and sediment input during the monsoon, which can increase the turbidity compared to other seasons (Hasan et al., 2022). Consequently, it blocks more light from penetrating, limiting photosynthesis for benthic algae (Rouf et al., 2022). However, layers with lower turbidity are supposed to be characterized by photosynthetic microorganisms, including phytoplankton, phototrophic bacteria, and biofilm (Bengtsson et al., 2018; Piwosz et al., 2020). Additionally, mixotrophic organisms, including *Arcobacter sp.,* can be hypothesized to inhabit columns of fluctuating turbidity (Li et al., 2024). The changing turbidity can influence the heterotrophic bacterial colonization (Eiler, 2006). Moreover, chemoautotrophic bacteria are expected to dominate columns with higher turbidity (Chung et al., 2025). Besides, high turbidity can reduce visibility for predators and filter feeders while also affecting the availability of suitable substrate (Ortega et al., 2020).

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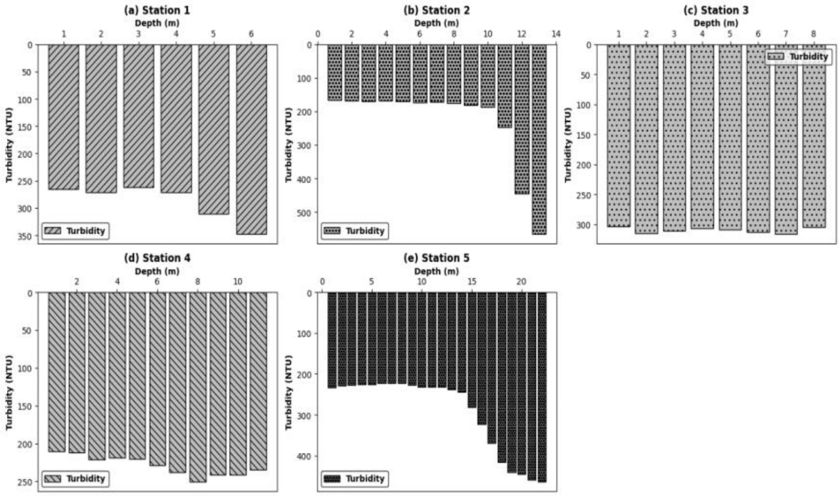

Figure 4: Vertical distribution of Turbidity in Pasur River Estuary

In the Pasur River, the conductivity (Figure 5) and salinity (Figure 6) showed consistent values within certain columns during the investigation. While salinity and conductivity are indirect measures of each other. The nature of the vertically uniform distribution of these parameters coincides for the same region during monsoon with (Rouf et al., 2022). Heavy rainfall during monsoon induces a very strong mixing in the water column, resulting in near uniformity in these parameters (Hasan et al., 2022). This uniformity and mixing can affect microorganism distributions. For instance, such conditions are favorable for cyanophyte plankton; however, diatom density might decline in such a state. Moreover, the bacterial population, especially those consisting of *Vibrio spp.*, was reported to increase in such homogeneous water columns (Hervé et al., 2025).

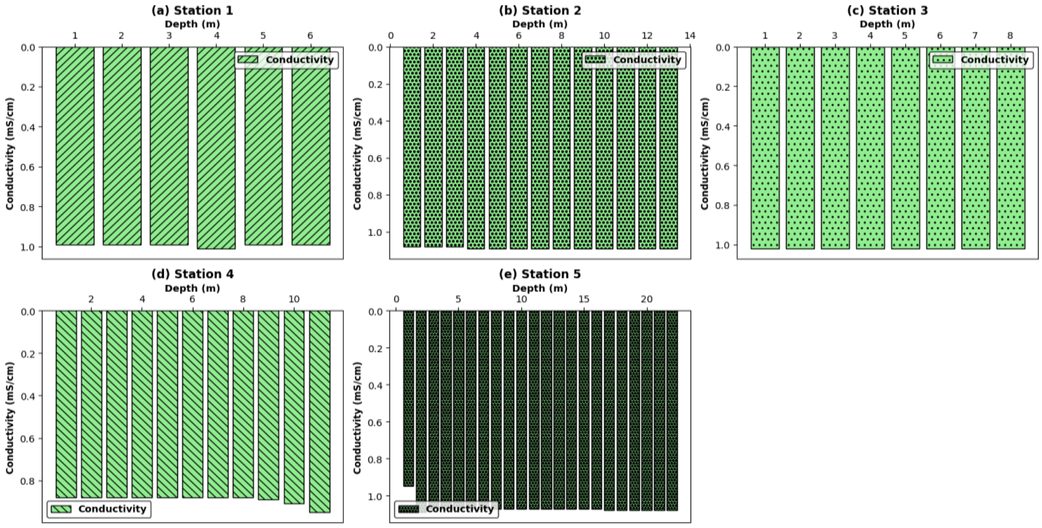

Figure 5: Vertical distribution of Conductivity in Pasur River Estuary

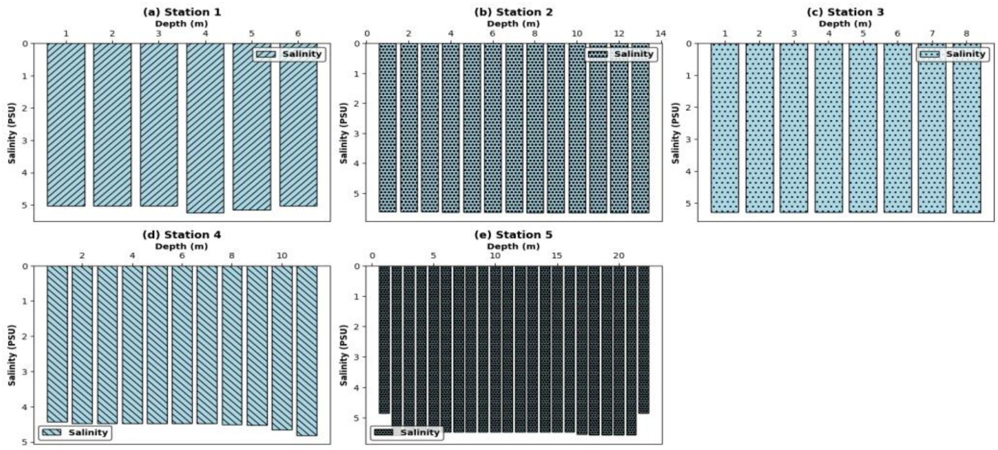

Figure 6: Vertical distribution of Salinity in Pasur River Estuary

pH values of the vertical layers across all five zones (Figure 7) were circumneutral (ranging from approximately 6.8 to 7.0). The overall lower pH values compared to ocean water (typically around 8.1) are characteristic of estuarine environments that tend to have lower pH and alkalinity (Howland et al., 2000). This marginal vertical gradient of pH with respect to depth indicates a buffered system that emanates from the concentration of CO_3^{2-} and HCO_3^{-}. This indicates the occurrence of relatively uniform biogeochemical processes throughout the water column in each zone. Moreover, it further suggests a supportive environment for microbial communities, especially bacteria, in these conditions across different depths of the water columns (Das et al., 2022). pH plays a crucial role in both microbial nitrification and denitrification processes. Traditionally, efficient nitrification has been reported at a pH ranging from 6.5 to 8.5 (Zhou et al., 2023). The vertical distribution pH range is conducive to both processes. Moreover, the range is within the preferred pH for the survivability of fish (6.5–9.0) (Yusoff et al., 2024).

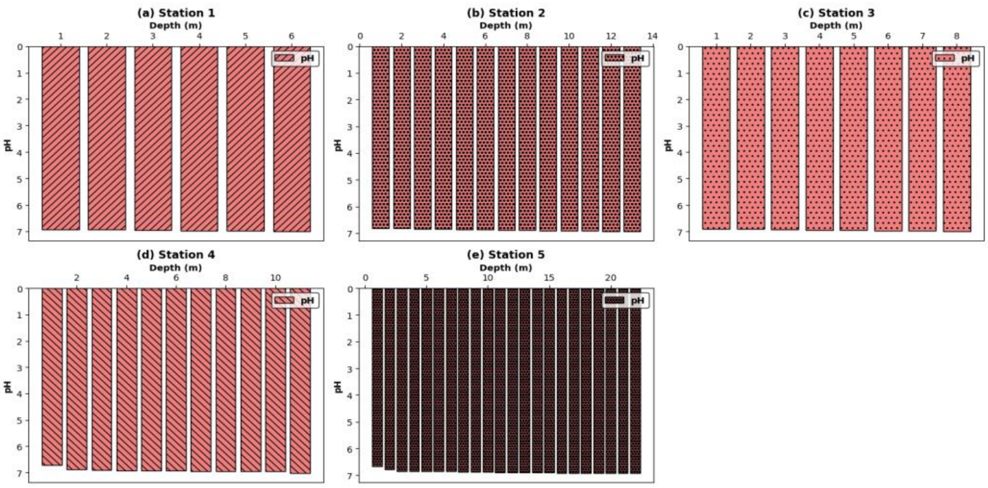

Figure 7: Vertical distribution of pH in Pasur River Estuary

4. Conclusion

The current investigation in the Pasur River estuary revealed the vertical distribution of the oceanographic parameters in spatial scale. The study recorded six key environmental parameters. Among these, only pressure demonstrated a linear progression with respect to depth, while turbidity demonstrated an overall increasing trend downwards with sporadic deviations in some stations. Temperature, conductivity, and salinity exhibited nearly stable values across the depths in various sampling zones. pH showed a poorly developed gradient downwards. Regarding vertical behavior, the parameters demonstrated a well-mixed property across the bathymetry. Studies across greater regions coupled with seasonal variation are recommended for future research in this aspect that is lacking in the current research. These baseline findings will provide critical insights into the estuarine dynamics of the Pasur River and will contribute valuable reference data for environmental monitoring, biogeochemical cycling, and ecosystem modeling.

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