Spatial and Tidal Structuring of Physicochemical Conditions Along a Tropical Estuarine Gradient: Evidence from the Bolgoda Estuary, Sri Lanka

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Estuaries are dynamic transitional systems in which physicochemical conditions are shaped by tidal exchange, freshwater inflow, and local environmental pressures. This study examined the spatial and tidal structuring of salinity, dissolved oxygen, pH, and water temperature along the Bolgoda Estuary, Sri Lanka. Sampling was conducted between December 2025 and February 2026 across five stations distributed from the estuary mouth to the landward reach under both low- and high-tide conditions, yielding 136 observations. Core physicochemical variables were measured in situ together with short-term meteorological conditions. Linear mixed-effects models, with station and tide as fixed effects and sampling date as a random effect, were used alongside descriptive summaries, longitudinal profile plots, and principal component analysis (PCA). Salinity showed the clearest estuarine gradient, with higher values near the estuary mouth and lower values inland, and differed significantly among stations ($F = 17.72$, $p < 0.001$) and between tidal states ($F = 10.68$, $p = 0.001$). Dissolved oxygen also varied significantly with station ($F = 10.61$, $p < 0.001$) and tide ($F = 11.31$, $p = 0.001$), although its spatial pattern was not strictly monotonic, suggesting localized oxygen demand or mixing effects. pH differed significantly among stations ($F = 8.73$, $p < 0.001$) and showed a significant association with sky condition ($F = 4.59$, $p = 0.013$), whereas water temperature showed no significant spatial or tidal structuring, likely reflecting relatively uniform thermal conditions during the short dry-season sampling window. PCA showed that the first two axes explained 66.2% of total variance, with salinity, pH, and DO contributing most strongly. Physicochemical variation was therefore better represented as a continuous estuarine gradient than as sharply discrete zones. Regional comparison indicated that pH and salinity fell within reported Sri Lankan estuarine ranges, whereas minimum DO was lower than regional values, suggesting localized oxygen-stress risk and the need for continued water-quality monitoring and pollution-source assessment.

Keywords: *Estuary, Physicochemical variability, Salinity gradient, Tidal influence, Bolgoda Estuary, Sri Lanka*