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SEASONAL DYNAMICS OF ACTIVATED SLUDGE QUALITY IN A MUNICIPAL WASTEWATER TREATMENT PLANT: AN INTEGRATED PHYSICOCHEMICAL AND MICROBIOLOGICAL ASSESSMENT

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Introduction

Activated sludge performance is influenced by environmental and operational factors such as temperature, dissolved oxygen (DO), organic matter concentration and biomass concentration. Seasonal variations may affect microbial activity, floc structure and settling properties, with consequences for wastewater treatment efficiency. Although routine monitoring is mainly physicochemical, microscopic examination can provide complementary information on biomass condition and early process disturbances.

This study investigated temporal variations in activated sludge characteristics during a one-year monitoring campaign at a municipal wastewater treatment plant (WWTP) by combining physicochemical measurements with microscopic observations. Particular attention was given to associations between COD-Cr concentration, biomass characteristics and biological indicators, and to identifying periods of concurrent physicochemical and microbiological disturbance.

Materials and methods

Influent and treated-effluent wastewater samples and mixed liquor from the aeration basin were investigated from December 2024 to December 2025. The monthly sampling design comprised influent/effluent sampling in weeks 1 and 3 and activated-sludge sampling in week 2. Thirteen activated-sludge samples were analyzed; influent/effluent samples were available for 11 sampling events in week 1 and 7 sampling events in week 3. COD-Cr was determined in influent and treated-effluent samples, whereas temperature, dissolved oxygen (DO), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and settled sludge volume were evaluated in mixed liquor. Complete monthly DO records for January-November 2025 were used with temperature and MLVSS for Figure 1. Microscopy focused on *Vorticella sp*., *Epistylis sp*., rotifers, nematodes and filamentous bacteria. Statistical analysis in R used Pearson correlations; the MLVSS/MLSS ratio was additionally evaluated.

Results and conclusions

The monitoring campaign revealed temporal variations in activated sludge characteristics. Temperature showed a moderate negative relationship with DO ($r = -0.594$; $p = 0.054$), while DO was negatively associated with COD-Cr concentration ($r = -0.552$; $p = 0.078$); neither relationship reached statistical significance. COD-Cr concentration correlated positively with MLSS ($r = 0.729$; $p = 0.011$) and MLVSS ($r = 0.932$; $p < 0.001$). Because MLVSS is a fraction of MLSS, the MLVSS/MLSS ratio was also evaluated: mean 0.68, range 0.61-0.90, and 0.70 in February (MLSS = 8.00 g/L; MLVSS = 5.60 g/L), close to the monitoring-period mean. February DO was 2.14 mg/L and was interpreted together with settling and microscopic evidence, rather than as an indicator of process instability by itself. In available February samples, influent COD-Cr was 273.7 mg O_2/L and treated-effluent COD-Cr was <30 mg O_2/L, corresponding to >89% removal.

Microscopic observations were consistent with settling data. During January–February, settled sludge volume increased from approximately 210 cm^3/dm^3 in December 2024 to approximately 600 cm^3/dm^3, concurrently with dispersed flocs, increased supernatant turbidity and abundant filamentous bacteria. These concurrent changes indicate a temporary disturbance in sludge structure and settling behavior. Attached ciliates (*Vorticella sp., Epistylis sp.*), rotifers and nematodes were also used to evaluate sludge condition.

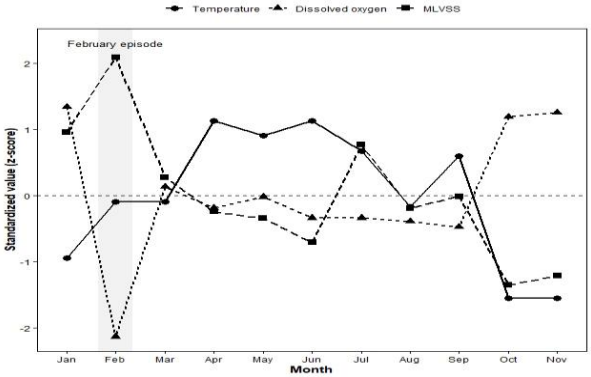


Figure 1 - Seasonal dynamics of standardized (z-score) temperature, dissolved oxygen (DO) and MLVSS (January–November 2025). The shaded area indicates the February episode, interpreted using absolute physicochemical values, settling behavior and microscopic observations.

Activated sludge quality showed temporal variability. Thus, the observed changes in biomass structure and settling behavior were not accompanied by an evident deterioration in COD-Cr removal in the available February samples. Integrating physicochemical, settling and microscopic indicators can support the detection and interpretation of temporary WWTP process disturbances.

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