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MODELING THE KINETICS OF POLLUTION REDUCTION IN RIVERS FOR EVALUATING WASTEWATER TREATMENT PLANT EFFICIENCY

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ABSTRACT: *This study investigates the application of pollution reduction kinetics in rivers as a basis for evaluating and optimizing the efficiency of wastewater treatment plants. Traditional assessment methods primarily rely on effluent quality standards, often neglecting the natural self-purification capacity of receiving water bodies. In this research, the kinetics of organic pollutant degradation—particularly Biochemical Oxygen Demand (BOD)—are modeled using first-order reaction equations, alongside the oxygen balance described by the Streeter–Phelps model.*

Key hydrological and environmental parameters, including flow velocity, temperature, and reaeration rates, are incorporated into the modeling framework to simulate pollutant transformation along the river course. The results demonstrate that accounting for natural attenuation processes can significantly improve the accuracy of treatment efficiency evaluation and support more cost-effective and environmentally sustainable design strategies.

The findings highlight that integrating river self-purification capacity into engineering assessments allows for optimized treatment levels while maintaining ecological safety. This approach contributes to the development of adaptive and resource-efficient wastewater management systems, particularly in regions with limited infrastructure and high environmental sensitivity.

Keywords: *River self-purification, pollution kinetics, wastewater treatment, BOD decay, environmental modeling, water quality.*

INTRODUCTION

The increasing pressure on water resources due to rapid urbanization, industrial development, and population growth has intensified the need for effective wastewater management. Rivers, which serve as primary recipients of treated and untreated effluents, play a crucial role in maintaining ecological balance and water quality. Within the framework of Environmental Engineering and Hydrology, significant attention has been given to understanding how natural processes contribute to the restoration of polluted water bodies. One of the key characteristics of river systems is their inherent ability to reduce pollution through self-purification mechanisms. These processes include dilution, sedimentation, biochemical oxidation, and reaeration, all of which contribute to the gradual decrease in contaminant concentrations. However, conventional approaches to evaluating wastewater treatment plant performance often focus solely on effluent standards, without adequately considering the assimilative capacity of the receiving river.

This limitation can lead to inefficient design and operation of treatment facilities. Overestimation of treatment requirements may result in unnecessary economic costs, while underestimation can cause environmental degradation, particularly in terms of dissolved oxygen depletion and aquatic ecosystem stress. Therefore, there is a growing need to integrate river self-purification dynamics into the assessment framework of wastewater treatment efficiency. Modeling the kinetics of pollution reduction provides a scientific basis for such integration. By describing the rate at which pollutants degrade or transform in a river system, kinetic models enable engineers and researchers to predict downstream water quality under varying conditions. In particular, first-order decay models for organic pollutants and oxygen balance models, such as the classical Streeter–Phelps formulation, offer valuable tools for analyzing the interaction between pollutant loads and natural recovery processes.

The objective of this study is to develop and apply a modeling approach that incorporates pollution reduction kinetics into the evaluation of wastewater treatment plant efficiency. By linking treatment performance with riverine processes, the research aims to provide a more comprehensive and environmentally sound methodology for water quality management.

METHODS

Study Approach - This study employs a combined analytical and modeling approach to evaluate wastewater treatment plant efficiency by incorporating river self-purification processes. The methodology integrates principles from Environmental Engineering and Hydrology, focusing on the interaction between treated effluent and natural river dynamics.

Data Collection - The following input data were collected or assumed for modeling purposes:

- **Hydraulic parameters:** river flow rate, velocity, depth, and cross-sectional area
- **Water quality indicators:** Biochemical Oxygen Demand (BOD), dissolved oxygen (DO), temperature
- **Pollution characteristics:** initial pollutant concentration at the discharge point
- **Environmental factors:** reaeration rate, river slope, and atmospheric conditions

Field measurements or literature-based values were used depending on data availability.

Modeling of Pollution Reduction Kinetics - The degradation of organic pollutants in the river was modeled using a **first-order kinetic equation**, which assumes that the rate of pollutant reduction is proportional to its concentration:

$$L_t = L_0 \cdot e^{-kt}$$

Where:

- L_t — pollutant concentration at time ttt (mg/L)
- L_0 — initial concentration (mg/L)
- k — decay coefficient (day^{-1}), dependent on temperature and flow conditions

- t — travel time of water (days)

The travel time was calculated based on river velocity and distance:

$$t = \frac{x}{v}$$

Where:

- x — distance downstream (m)
- v — flow velocity (m/s)

Oxygen Balance Modeling - To assess ecological impact, the dissolved oxygen regime was analyzed using the **Streeter–Phelps model**, which accounts for the balance between oxygen consumption (deoxygenation) and oxygen replenishment (reaeration). This model allows estimation of the critical oxygen deficit and its location downstream.

Evaluation of Treatment Plant Efficiency - The efficiency of the wastewater treatment plant was evaluated using the following criteria:

- **Pollutant removal efficiency:**

$$\eta = \frac{L_{in} - L_{out}}{L_{in}} \times 100\%$$

- **Compliance with environmental standards** at the discharge point
- **Impact on downstream water quality**, particularly dissolved oxygen levels
- **Assimilative capacity of the river**, determined through modeling results

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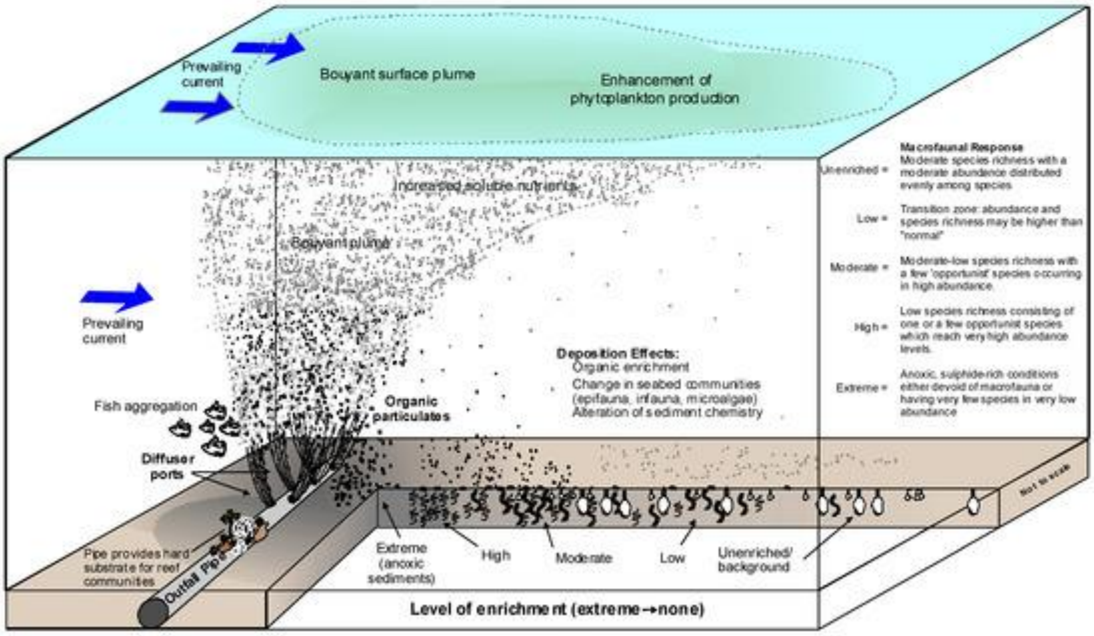

Figure 1. Schematic Representation of River Self-Purification and Pollutant Dispersion

Model Implementation and Analysis - The calculations were performed using analytical methods and simplified numerical simulations. Different scenarios were analyzed, including:

- Variation in treatment efficiency levels
- Seasonal changes in temperature and flow conditions
- Different pollutant loading rates

The results were compared to identify optimal treatment levels that ensure environmental safety while minimizing operational costs.

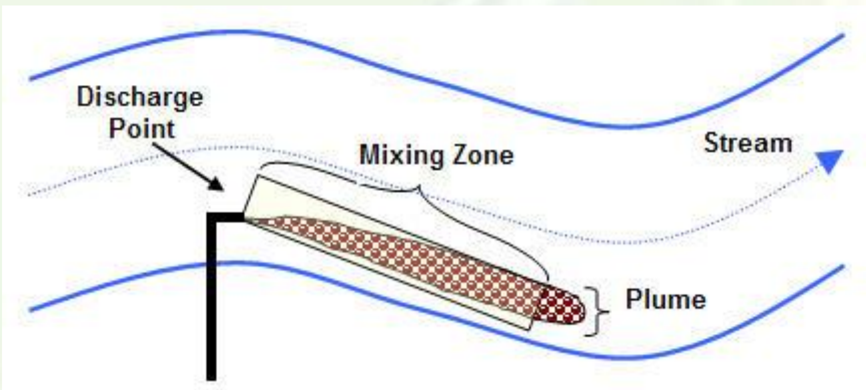

Figure 2. Schematic Representation of River Self-Purification and Pollutant Dispersion

Limitations - The model assumes steady flow conditions and uniform mixing, which may not fully represent complex natural systems. Despite these limitations, the approach provides a practical framework for integrating natural purification processes into wastewater treatment assessment.

RESULTS AND DISCUSSION

The application of pollution reduction kinetics and oxygen balance modeling provided comprehensive insights into the interaction between treated wastewater and river self-purification processes. The results demonstrate the importance of integrating natural attenuation mechanisms into the evaluation of wastewater treatment plant efficiency.Pollutant Reduction Along the River - The simulation results based on first-order kinetics indicate that the concentration of organic pollutants decreases exponentially with distance downstream from the discharge point. The rate of reduction is primarily influenced by the decay coefficient (kkk), which depends on temperature and flow conditions.

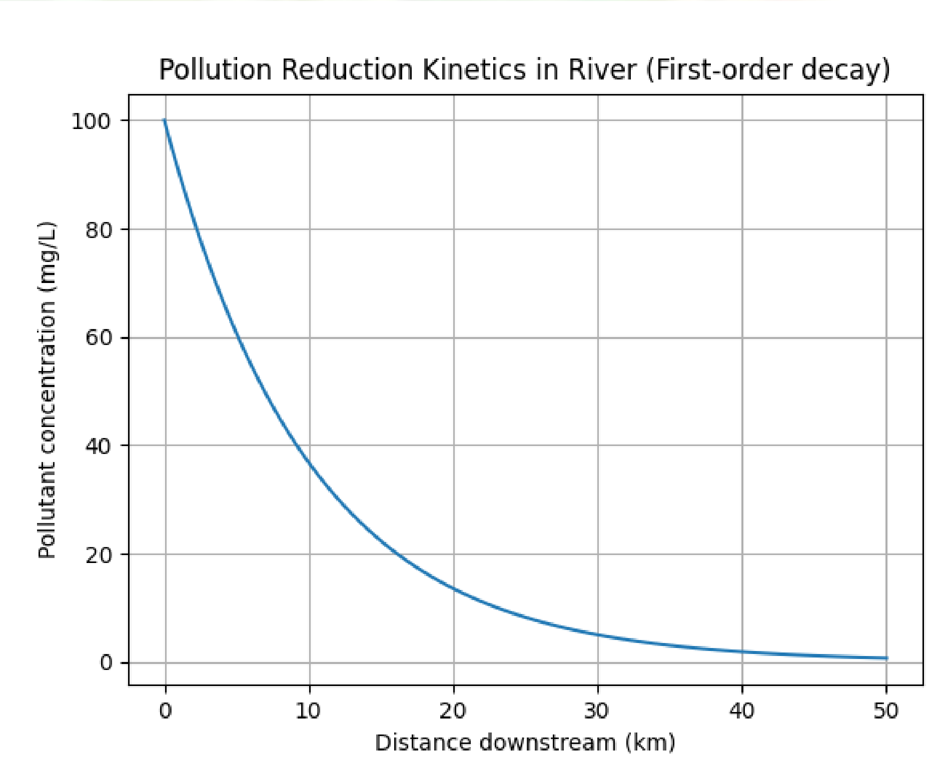

Figure 3. Exponential Decay of Pollutant Concentration Along the River

Higher values of kkk, typically observed at elevated temperatures, resulted in faster degradation of pollutants. Conversely, lower temperatures slowed down biochemical processes, extending the distance required for significant pollutant reduction.

Additionally, river velocity played a dual role:

- Increased velocity reduced travel time, limiting reaction time for degradation
- However, it enhanced dilution and dispersion of pollutants
- Dissolved Oxygen Dynamics - The application of the Streeter–Phelps model revealed the formation of a critical oxygen deficit zone downstream of the wastewater discharge point. This zone represents the location where dissolved oxygen (DO) reaches its minimum value due to intense biochemical oxidation of organic matter.

The results showed that:

- Higher initial pollutant concentrations led to deeper oxygen deficits
- Increased reaeration rates (krk_rkr) helped restore oxygen levels more rapidly
- The location of the critical point shifted further downstream under lower flow velocities

In well-aerated rivers, oxygen recovery occurred relatively quickly, minimizing ecological risks. However, in slow-flowing or highly polluted conditions, prolonged oxygen depletion was observed, posing a threat to aquatic life.

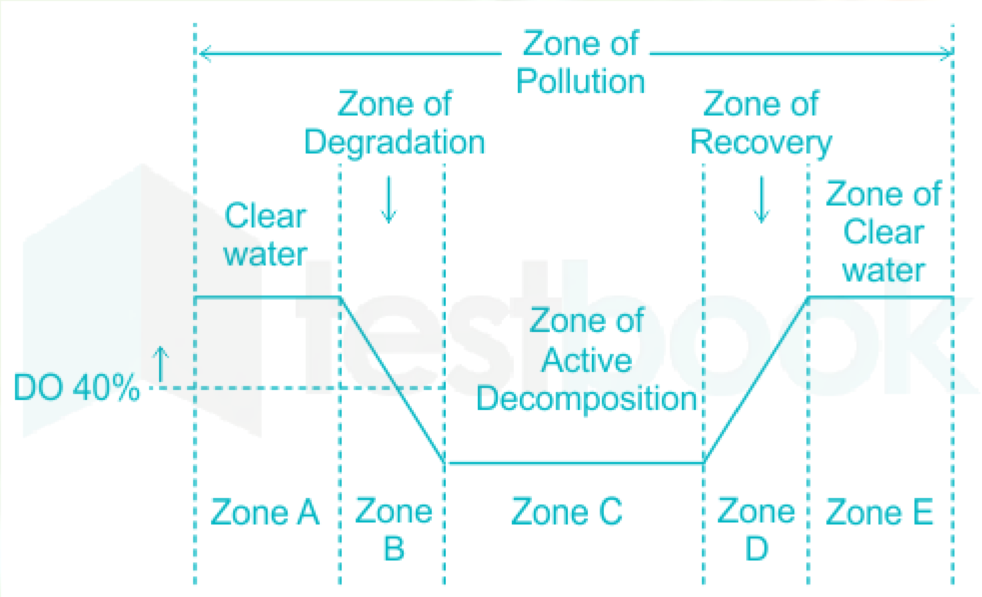

Figure 4. Stages of Pollutant Reduction and Oxygen Recovery in a River

Evaluation of Treatment Plant Efficiency - The integration of river self-purification into the assessment framework revealed that treatment plant efficiency can be evaluated more realistically when downstream processes are considered.

Key findings include:

- In rivers with strong self-purification capacity, moderate treatment levels were sufficient to meet environmental standards
- Over-treatment did not significantly improve downstream water quality, indicating potential for cost reduction
- In rivers with limited assimilative capacity, higher treatment efficiency was necessary to prevent ecological degradation
- Sensitivity Analysis - A sensitivity analysis was conducted to determine the influence of key parameters on model outcomes. The results indicate that:
- The decay coefficient (kkk) and reaeration rate (krk_rkr) are the most sensitive parameters
- Small changes in temperature significantly affect reaction kinetics
- Flow velocity strongly influences both pollutant transport and oxygen dynamics

These findings highlight the need for accurate parameter estimation in practical applications.

Practical Implications - The results suggest that incorporating pollution kinetics into wastewater management strategies can lead to:

- More efficient design of treatment plants
- Reduced operational and energy costs
- Improved alignment with environmental sustainability goals
- Better prediction of ecological impacts in receiving water bodies

CONCLUSION

This study demonstrates that modeling the kinetics of pollution reduction in rivers provides a scientifically robust and practically relevant approach for evaluating wastewater treatment plant efficiency. By incorporating natural self-purification processes into the assessment framework, a more comprehensive understanding of pollutant behavior in receiving water bodies is achieved. The results confirm that first-order decay kinetics and oxygen balance models effectively describe the transformation and attenuation of organic pollutants in river systems. Key factors such as flow velocity, temperature, and reaeration rates significantly influence both pollutant reduction and dissolved oxygen dynamics. These parameters must therefore be carefully considered in engineering analyses.

Importantly, the findings reveal that the efficiency of wastewater treatment plants cannot be accurately assessed based solely on effluent quality at the discharge point. Instead, the assimilative capacity of the river and downstream water quality conditions should be included in the evaluation process. This integrated approach allows for the optimization of treatment levels, ensuring environmental protection while avoiding unnecessary operational costs. In conclusion, the integration of river self-purification kinetics into wastewater treatment design and assessment contributes to more sustainable and cost-effective water management strategies. Future research should focus on the development of advanced numerical models, real-time monitoring systems, and region-specific parameter calibration to enhance the reliability and applicability of this approach.

REFERENCES

1. Metcalf & Eddy (2014). Wastewater Engineering: Treatment and Resource Recovery. 5th ed. New York: McGraw-Hill Education.
2. Stephen C. Chapra (2008). Surface Water-Quality Modeling. Long Grove, IL: Waveland Press.
3. H. W. Streeter & E. B. Phelps (1925). A Study of the Pollution and Natural Purification of the Ohio River. U.S. Public Health Service Bulletin.
4. George Tchobanoglous, Burton, F.L., & Stensel, H.D. (2014). Wastewater Engineering: Treatment and Resource Recovery. McGraw-Hill Education.
5. World Health Organization (2017). Guidelines for Drinking-water Quality. Geneva: WHO Press.

6. United States Environmental Protection Agency (2012). Water Quality Standards Handbook. Washington, DC.

7. Mark M. Clark (2015). Transport Modeling for Environmental Engineers and Scientists. Wiley.

8. Larry W. Mays (2010). Water Resources Engineering. 2nd ed. Wiley.

9. International Water Association (2018). Water Quality and Treatment: A Handbook on Drinking Water.

10. C. N. Sawyer, McCarty, P.L., & Parkin, G.F. (2003). Chemistry for Environmental Engineering and Science. McGraw-Hill.

11. О воде и водопользовании - Закон Республики Узбекистан. Постановление Верховного Совета Республики Узбекистан № 837- XII от 06.05.1993 г. (в ред. № 568-II от 12.12.2003 г.)

12. Quvondiqov, Q. (2021). Обоснование проведения реконструкции Бектемириских канализационных очистных сооружений г. Чирчика с целью повышения эффективности их работы. *Scienceweb academic papers collection*.

13. Ibadullayev, A., Teshabayeva, E., Kakharov, B., & Nigmatova, D. (2021). Composite elastomeric materials filled with modified mineral fillers. In *E3S Web of Conferences* (Vol. 264, p. 05006). EDP Sciences.https://doi.org/10.1051/e3sconf/202126405006

14. Quvondiqov, Q. (2023). On the Issue of Efficiency in the Transportation of Oil Products by Main Pipeline. *International Journal of Trend in Scientific Research and Development (IJTSRD)*.

15. Quvondiqov, Q. (2021). Suv ta'minoti, oqova suv, gidravlika va suv resurslarini muhofaza qilish sohalarida yangi yutuqlar. *X МЕЖДУНАРОДНАЯ НАУЧНО-ПРАКТИЧЕСКАЯ КОНФЕРЕНСИЯ*.

16. Quvondiqov, Q. (2022). Gidrotransport tizimlaridagi adgeziyani dispers sistemalarni modifikaцyalash orqali kamaytirish. *Scienceweb academic papers collection*.