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RIVER WATER POLLUTION AND ITS IMPACT ON THE HYDROLOGICAL SYSTEM (ARTICLE REVIEW)

BY

***Tarteel faisal Ghaze Kanbar**

College of Medicine. Al- Muthanna University, Iraq

Abstract:

River water pollution represents a critical environmental challenge that severely degrades freshwater ecosystems and disrupts the integrity of the broader hydrological system. This study provides a comprehensive overview of the sources of river contamination—encompassing agricultural runoff, industrial effluents, untreated municipal wastewater, and urban stormwater—and evaluates their systemic impacts on water quality parameters and hydrological processes. The influx of excess nutrients (nitrogen and phosphorus), organic matter, toxic heavy metals, and emerging micro-pollutants elevates Biological Oxygen Demand ,reduces Dissolved Oxygen , triggers eutrophication, and alters natural chemical balances. Beyond direct water quality degradation, river pollution impacts surface water–groundwater interactions, contamination of underlying aquifers via bank filtration, and the modification of evapotranspiration patterns through altered vegetation dynamics. Furthermore, polluted river networks compromise global water security, elevate municipal treatment costs, and diminish ecosystem resilience against climate-induced hydrological extremes. Addressing these challenges requires integrated watershed management, stringent point and non-point source controls, advanced wastewater treatment infrastructure, and continuous, data-driven water quality monitoring to safeguard both aquatic health and sustainable freshwater resources.

Keywords: River Pollution, Water Quality, Hydrological System, Eutrophication, Heavy Metals, Surface–Groundwater Interaction, Watershed Management.

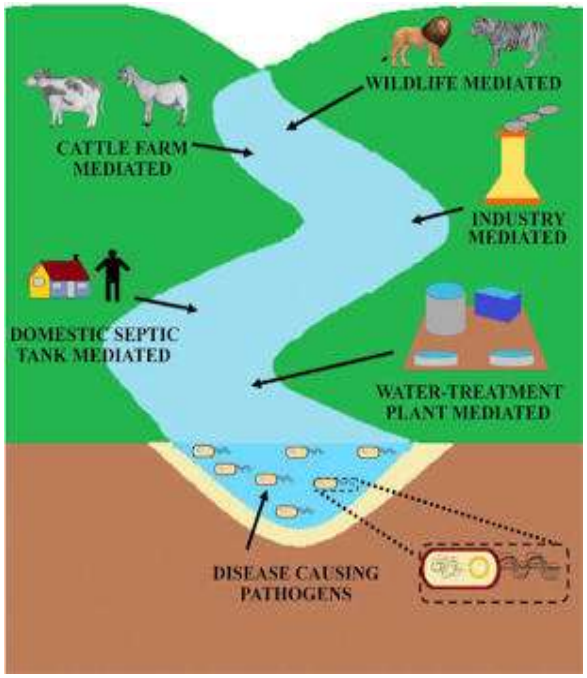
Introduction

Rivers are fundamental components of the hydrological cycle and provide water for domestic, agricultural, industrial, and ecological purposes. Pollution has become a major challenge globally. Previous studies have documented the effects of industrial effluents, agricultural runoff, sewage discharge, and urbanization on river systems. Research consistently demonstrates declining water quality and ecological degradation. (1)

Sources of River Water Pollution

Major pollution sources include industrial waste, agricultural chemicals, domestic sewage, mining activities, and solid waste disposal. Each source contributes differently to contamination.

River water pollution originates from various human activities and natural processes. In hydrology and environmental engineering, pollutants are categorized by how they enter the waterbody (point vs. non-point sources) and their specific origin/sector (agricultural, industrial, municipal, and natural).(2)



Sector-Specific Sources of Contaminants

A. Agricultural Sources

Agriculture is often the largest global contributor to diffuse surface water degradation:

- Excess Nutrients (Nitrogen & Phosphorus): Over-application of synthetic fertilizers and animal manure leads to nutrient leaching into streams, causing widespread eutrophication, harmful algal blooms (HABs), and hypoxia (depleted dissolved oxygen).
- Pesticides & Herbicides: Chemical compounds run off into rivers, exerting toxic effects on aquatic macroinvertebrates and fish communities.
- Sedimentation (Soil Erosion): Poor tillage practices lead to topsoil erosion. Suspended solids increase turbidity, block light penetration for photosynthesis, and smother benthic habitats.
- Pathogens: Fecal coliforms (e.g., *E. coli*) and enteric pathogens enter waterbodies via livestock grazing near riverbanks or uncontained manure lagoons.(3,4)

B. Municipal & Domestic Wastewater

- Raw or Inadequately Treated Sewage: Discharges introduce high biological oxygen demand (BOD), chemical oxygen demand (COD), and microbial pathogens (viruses, bacteria, parasites).
- Emerging Contaminants (CECs): Pharmaceuticals, personal care products, microplastics, and artificial sweeteners pass through conventional wastewater treatment plants (WWTPs) unremediated.
- Household Detergents: Phosphates in cleaning agents elevate nutrient loads in receiving rivers.(5-7)

C. Industrial Discharges

- Heavy Metals: Facilities such as electroplating, tanning, chemical synthesis, and metallurgy can release toxic heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), and arsenic (As).
- Organic Solvents & Synthetic Chemicals: Petrochemicals, polycyclic aromatic

hydrocarbons (PAHs), and persistent organic pollutants (POPs) accumulate in riverbed sediments.

- Thermal Pollution: Discharges of heated cooling water from power stations reduce the solubility of dissolved oxygen (DO) in water and induce thermal stress in aquatic biota.(8)

D. Urban Runoff & Infrastructure

- Stormwater Impurities: Rain falling on impervious surfaces (roads, roofs, parking lots) carries accumulated heavy metals, automotive fluids, rubber particles, and de-icing salts directly into storm drains and adjacent rivers.
- Combined Sewer Overflows (CSOs): In older municipal systems during heavy rain, combined stormwater and sanitary sewage exceed plant capacity and discharge directly into rivers untreated.

E. Mining & Resource Extraction

- Acid Mine Drainage (AMD): Oxidation of exposed iron sulfide minerals (pyrite, FeS_2) produces sulfuric acid, drastically lowering river pH and solubilizing toxic metals into the stream network.
- Tailings Infiltration: Leaching from mine tailings ponds releases heavy metals, cyanides, or processing reagents.(9-11)

Hydrological System

At its core, a hydrological system refers to the pathway and mechanisms by which water moves through the Earth-atmosphere continuum. It functions as a closed mass-balance system—meaning the total volume of water on Earth remains virtually constant over geological time scales, though its distribution, phase, and quality shift continuously.(12)

The system is driven by two primary forces:

Solar Energy: Acts as the thermal engine, providing the latent heat required to evaporate liquid water from oceans, lakes, and vegetation.

Gravity: Pulls condensed atmospheric moisture back to the Earth as precipitation and drives surface runoff, subsurface infiltration, and river flow toward sea level.

The hydrological cycle involves evaporation, condensation, precipitation, infiltration, groundwater recharge, runoff, and streamflow. Rivers connect these processes. establishes the fundamental framework of how water moves, changes states, and is stored across our planet. At its core, the hydrological system is a closed planetary loop driven by solar energy and gravity. It represents the continuous circulation of water among the atmosphere, oceans, land surface, and biosphere. (13-16)

Impacts on Water Quality

Pollution alters pH, dissolved oxygen, nutrient concentrations, turbidity, conductivity, and microbial loads. These changes reduce water suitability for human and ecological use.

Water quality impacts describe how physical, chemical, and biological contaminants alter the baseline state of a waterbody, rendering it unsafe for human consumption, agricultural use, or ecological support.(17)

1. Physical Impacts

- **Turbidity & Suspended Solids:** High concentrations of eroded topsoil, clay, and suspended particulate matter block sunlight penetration. This reduces submerged aquatic vegetation photosynthesis and smothers benthic habitats.
- **Thermal Pollution:** Heated industrial effluent or power plant cooling discharges reduce gas solubility—directly lowering **Dissolved Oxygen (**DO**)** levels—while accelerating the metabolic rate and stress of aquatic organisms.
- **Electrical Conductivity (EC) & Salinization:** Agricultural runoff carrying dissolved salts elevates Total Dissolved

Solids (TDS), shifting osmotic balances and rendering water unsuitable for crops or drinking without energy-intensive desalination.(18)

2. Chemical Impacts

Parameter / Indicator	Impact Mechanism	Primary Source
Nutrient Loading (N**&**P**)**	Triggers **eutrophication** and toxic cyanobacteria (blue-green algae) blooms, causing severe hypoxia/anoxia as algae die and decompose.	Synthetic fertilizers, livestock waste, municipal sewage
Dissolved Oxygen (DO**) Depletion**	High **Biological Oxygen Demand (**BOD**)** and **Chemical Oxygen Demand (**COD**)** strip dissolved oxygen, creating "dead zones" where fish cannot survive.	Untreated organic wastewater, food processing effluent
Heavy Metal Accumulation	Toxic elements (Pb, Cd, Cr, Hg, As) alter pH, accumulate in stream sediments, and **bioaccumulate/biomagnify** up food chains.	Industrial discharges, mining acid drainage, tannery wastes
Persistent Organic Pollutants (POPs)	Synthetic compounds (pesticides, PAHs, PFAS) resist natural breakdown, causing chronic toxicity and endocrine disruption in organisms.	Agricultural runoff, chemical industries, urban stormwater

3. Biological & Microbiological Impacts

- **Pathogenic Contamination:** Ingestion of water contaminated with fecal coliforms (*E. coli*, *Salmonella*), enteric viruses, and protozoa (*Giardia*, *Cryptosporidium*) leads to severe waterborne disease outbreaks.
- **Microbial Community Shifts:** Excess organic carbon suppresses sensitive native macroinvertebrate communities while favoring anaerobic bacteria and sludge-tolerant taxa.(19,20)

4. Downstream Human & Economic Consequences

- **Drinking Water Treatment Costs:** High turbidity, organic loading, and algal toxins require costly multi-stage purification processes (e.g., coagulation, ozonation, activated carbon filtration).
- **Agricultural Yield Reduction:** High salinity (EC) and trace metal toxicity in irrigation water reduce crop yields and degrade arable soil structure.
- **Ecosystem Service Failure:** Fisheries collapse, recreational water bodies close due to microcystin algal toxins, and real estate values adjacent to degraded waters decline.(22-25)

Conclusion

River pollution remains a significant environmental challenge requiring coordinated action by governments, industries, communities, and researchers.

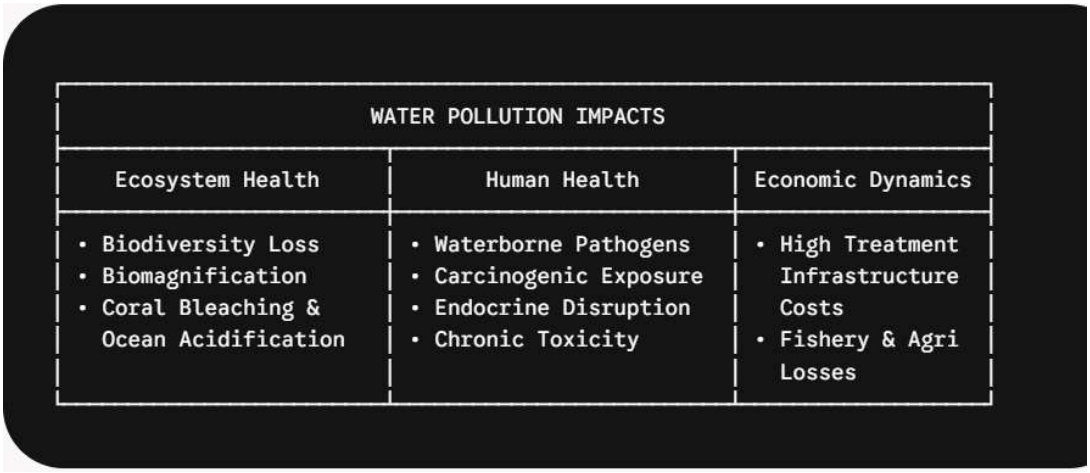
Water pollution is one of the most critical environmental challenges. Synthesizing synthesis of global research, environmental frameworks, and policy assessments reveals several

overarching conclusions regarding the causes, systemic impacts, and required remediation pathways:

1. Primary Anthropogenic Causes & Vulnerabilities

- Universal Solvent Vulnerability: Because water dissolves more substances than any other liquid, aquatic systems are exceptionally susceptible to chemical, organic, and thermal contamination.
- Dominance of Non-Point Source Runoff: While industrial point sources (pipes and outfalls) are heavily regulated, agricultural non-point source runoff (excess nitrogen, phosphorus, and pesticides) remains the leading driver of global surface water degradation, triggering pervasive eutrophication and hypoxic "dead zones".
- Infrastructure Deficits: Over 80% of the world's wastewater is discharged into the environment untreated or inadequately processed. Aging urban stormwater and combined sewer systems regularly overflow during extreme weather events, directly introducing pathogens and microplastics into river basins.

2. Environmental & Socio-Economic Impacts



- Biodiversity Depletion: Toxic heavy metals (Pb, Hg, Cd) and persistent organic pollutants bioaccumulate up food webs, impairing reproductive systems and reducing species richness in freshwater and marine environments.
- Public Health Risks: Contaminated drinking water sources remain a primary cause of global waterborne infectious diseases (e.g., *E. coli*, cholera) and long-term chemical intoxication, disproportionately affecting vulnerable communities.
- Economic Losses: Water degradation imposes severe financial burdens on municipal water treatment, commercial fisheries, eco-tourism, and agricultural productivity.

3. Strategic Recommendations & Solutions
    1. Shift to Source Control & Green Agriculture: Mitigating pollution at the origin—through precision fertilizer application, buffer strip planting along riverbanks, and eco-friendly industrial chemistry—is far more cost-effective than downstream remediation.
    2. Modernization of Wastewater Systems: Expanding biological nutrient removal (BNR), advanced membrane filtration, and decentralized septic treatment infrastructure is essential to handle urban growth and extreme precipitation.
    3. Data-Driven & AI-Assisted Monitoring: Implementing real-time IoT sensors and machine-learning models optimizes watershed-scale risk assessment and early warning systems for contamination events.
    4. Socio-Hydrological Governance: Effective water protection requires integrated catchment management policies (IWRM) that balance industrial growth, food security, and ecological flows across administrative boundaries.

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