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Chromium Contamination in the Ganga River Near Kanpur: A Comprehensive Water Quality Assessment Using Experimental Analysis and Analytical Methods in Chemistry

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Abstract

Water pollution, driven by industrial contaminants, poses significant threats to ecosystems and human health. The present study investigates the water quality assessment of chromium contamination in the River near Kanpur, with a focus on the industrial impact of tannery effluents. Various physicochemical parameters such as pH, conductivity, total dissolved solids (TDS), and hexavalent chromium (Cr (VI)) were analyzed using standard analytical techniques. pH and conductivity were measured using electrochemical probes, while TDS was determined using both gravimetric and instrumental methods. The concentration of hexavalent chromium was quantified using UV-Vis spectrophotometry with 1,5-Diphenylcarbazide (DPC) reagent at 540 nm. Quality control measures, including triplicate analysis, instrument calibration with standard solutions, and statistical validation, ensured the accuracy and reliability of the data. The findings revealed elevated chromium levels in several locations, highlighting significant industrial pollution and potential health hazards. This study underscores the need for continuous monitoring and effective wastewater treatment strategies to mitigate chromium contamination in the river.

Key words: water quality assessment; chromium contamination; total dissolved solids; conductivity; hexavalent chromium; industrial pollution; tannery effluents

1.Introduction

Industrial pollution is a growing concern in India, particularly in cities like Kanpur, where industrial activities significantly impact the environment. Kanpur, a major industrial hub in Uttar Pradesh, is known for its large tannery industry, which plays a vital role in the region's economy [1-5]. The tanning process involves the extensive use of chemicals, including chromium, sulfides, and various organic compounds, which are often discharged into local water bodies. These pollutants not only degrade water quality but also pose serious risks to aquatic ecosystems and human health.

Tannery Process	Key Chemicals Used	Waste Generated
Pre-tanning	Lime, Sodium sulfide, Sodium hydroxide	Hair, flesh residues, alkaline waste
Pickling	Sulfuric acid, Hydrochloric acid, Salt	Acidic effluents, salt brine
Tanning	Chromium salts (chromium sulfate), Vegetable tannins, Aldehydes (e.g., glutaraldehyde)	Chromium-laden sludge, residual tanning agents
Post-tanning	Oils, Dyes, Fatliquors (e.g., tallow, synthetic oils)	Used oils, dye effluents
Finishing	Acrylics, Polyurethanes, Resins	Chemical residues, VOC emissions
Wet finishing	Dyes, Pigments, Surfactants	Dye-laden wastewater, surfactant residues
Wastewater Treatment	Coagulating agents (e.g., alum), Activated carbon, Biological agents	Treated sludge, effluent water

Table 1: Tannery Processes, Chemicals Used, and Waste Generated

The release of untreated or inadequately treated effluents from tanneries into the Ganga River and its tributaries has led to severe contamination, making it imperative to develop robust methods for monitoring and predicting water quality. Traditional methods of water quality assessment, which rely on periodic sampling and chemical analysis, are time-consuming, expensive, and often insufficient to capture real-time fluctuations in pollution levels [7-8].

Literature review

Water pollution caused by industrial effluents, particularly from the tannery sector, has been widely studied due to its significant environmental and public health impacts. Numerous studies have highlighted the adverse effects of chemical pollutants such as chromium, sulfides, and organic compounds, commonly found in tannery wastewater, on water bodies. Tannery effluents not only reduce the availability of clean water but also lead to bioaccumulation of toxic substances in aquatic ecosystems, affecting biodiversity and posing health risks to local communities [9]. Traditional water quality monitoring methods, while effective in detecting contamination, often struggle to keep pace with rapid industrial growth and the dynamic nature of water pollution, necessitating the exploration of more advanced monitoring solutions.

Industry	Location	Polluted Water Area	Main Pollutants
Kanpur Tannery & Leather Products	Jajmau	Ganga River (near Jajmau)	Chromium, sulfides, tannins, heavy metals
Dhananjay Tannery	Panki	Ganga River (near Panki)	Chromium, ammonia, sulfides
K.K. Tannery **Leather Processing Units**	Rania (near Kanpur)	Kali River	Chromium, phenols, biological oxygen demand (BOD)
Kanpur Tannery & Chemical Works	Unnao Road	Bithoor Ghat on Ganga River	Heavy metals, tannins, total dissolved solids (TDS)
V.B. Tannery	Kanpur Nagar	Sirsaha Nala	Heavy metals, organic pollutants, nitrates
Jayant Tannery **Leather Goods Manufacturing Units**	Industrial Estate, Kanpur	Naubasta Nala	Chromium, COD (Chemical Oxygen Demand), BOD

Table 2: Industries Contributing to Water Pollution in Kanpur City, India, Due to Tannery Operations

Contaminant	Source	Potential Environmental Impact
Chromium (Cr)	Chrome tanning process	Toxic to aquatic life, bioaccumulation, carcinogenic to humans
Sulfides (H_2S, Na_2S)	Dehairing and unhairing stages	Releases hydrogen sulfide gas, toxic to aquatic organisms, odorous
Ammonia (NH_3)	Deliming and bating processes	Eutrophication, toxicity to fish and aquatic species
Total Dissolved Solids (TDS)	General effluent from processing	Reduces water quality, affects aquatic ecosystems
Suspended Solids (SS)	Fleshing, trimming, and tanning operations	Reduces light penetration, affects aquatic plant growth, sedimentation
Chlorides	Salt used in rawhide preservation	Increases salinity, toxic to freshwater species
Organic Matter (BOD/COD)	Fleshing, soaking, and degreasing	Oxygen depletion in water bodies, affecting aquatic life
Phenolic Compounds	Leather processing chemicals	Toxic to aquatic organisms, potential endocrine disruptors
Formaldehyde	Leather finishing processes	Carcinogenic, toxic to both humans and aquatic life
Solvents and Dyes	Dyeing and finishing stages	Toxic to aquatic organisms, potential bioaccumulation
Phosphates	Chemical soaking and degreasing	Eutrophication, leading to algal blooms and aquatic oxygen depletion
Sulfuric Acid (H_2SO_4)	Pickling and pH adjustment stages	Acidification of water bodies, harmful to aquatic ecosystems

Table 3: Common Industrial Contaminants from Tannery Industries, Their Sources, and Environmental Impacts

Materials and Methods

Study Area

The study focuses on the industrial region of Kanpur, Uttar Pradesh, India, particularly the tannery industry located along the banks of the Ganga River from Lucknow to Kanpur. The region is known for its large concentration of tanneries that discharge significant amounts of effluent, contributing to water pollution. Data were collected from water bodies surrounding the industrial zones, where tannery effluents are regularly discharged, leading to contamination with chemicals like chromium, sulfides, and other organic pollutants [10]. The study focuses on the industrial region of Kanpur, Uttar Pradesh, India, particularly the tannery industry located along the banks of the Ganga River from Lucknow to Kanpur. Water samples were collected from nine key locations, including Ganga Barrage, Jajmau, Shuklaganj, Panki. Ninesampling locations along the Ganga River from Lucknow to Kanpur, particularly in industrial and urban zones where chromium contamination is likely due to tannery and other industrial activities were taken for study.

1. Bairaj Ghat, Lucknow – Near the Ganga Barrage, where the river starts its course towards Kanpur.
2. Malihabad – A semi-urban area where agricultural runoff may contribute to contamination.
3. Auras (Unnao District) – A rural stretch where minor industrial discharges may be present.
4. Ganga Bridge, Unnao – A critical point near Unnao, known for industrial activities.
5. Shuklaganj – A town near Kanpur, influenced by both urban and industrial waste.
6. Jajmau, Kanpur – The major hotspot for chromium contamination due to tannery industries.
7. Panki, Kanpur – An industrial zone with multiple factories contributing to pollution.

8. Bithoor, Kanpur – A historical town but also affected by urban pollution.
9. Satti Chaura Ghat, Kanpur – A downstream site where contamination levels can be assessed.

These locations ensure a comprehensive upstream-to-downstream analysis of chromium contamination along the Ganga River from Lucknow to Kanpur, covering rural, urban, and industrially impacted regions

These sites were selected based on their proximity to industrial discharge points, urban settlements, and agricultural runoff areas to assess variations in chromium contamination levels. Jajmau, known for its dense cluster of tanneries, is a critical hotspot for heavy metal pollution, whereas Panki and Naubasta are major industrial hubs contributing to effluent discharge. Shuklaganj and Rania, being semi-urban areas, experience mixed pollution sources, while Fazalganj and Dada Nagar are influenced by small-scale industries. Barra, a residential and industrial transition zone, reflects cumulative pollution effects. By analyzing water quality across these diverse locations, the study provides a comprehensive understanding of chromium contamination patterns and their potential environmental and health impacts.

Methodology

The determination of chromium in water samples from the Ganga River near Lucknow was carried out using standard analytical chemistry techniques. Water samples were collected from multiple locations along the river, ensuring proper sampling protocols to prevent contamination. The samples were first subjected to filtration to remove suspended particles, followed by acid digestion using concentrated nitric acid (HNO_3) to stabilize chromium species. The total chromium concentration was determined using UV-Vis spectrophotometry through a colorimetric method involving diphenylcarbazide, which forms a purple complex with Cr (VI) in acidic conditions, allowing quantification at a wavelength of 540 nm. The pH, conductivity, total dissolved solids (TDS), and other physicochemical parameters were also analyzed to understand the water quality impact. Standard calibration curves were prepared using known chromium solutions to ensure accuracy. The obtained data were statistically analyzed to assess contamination levels and potential environmental risks associated with chromium pollution in the river. To ensure the accuracy and precision of the results, triplicate analyses were performed for each water quality parameter. Blank and standard solutions were used to validate the calibration of instruments before sample measurements. Additionally, statistical analysis, including the calculation of standard deviation and relative standard deviation (RSD), was conducted to assess the reliability and reproducibility of the data. These quality control measures helped minimize errors and enhance the validity of the experimental findings.

Experimental Method

The determination of chromium contamination and water quality parameters in the Ganga River near Kanpur was carried out using standardized analytical methods [11-15]. The study involved the collection of water samples from nine different locations, followed by laboratory analysis for physicochemical parameters and chromium concentration. Each parameter was measured using a specific experimental procedure, as detailed below. The following methodology for the determination of chromium contamination and other water quality parameters in the River near Kanpur was conducted.

1. Sample Collection and Preservation

Water samples were collected in pre-cleaned polyethylene bottles from nine designated locations along the Ganga River. The samples were collected at a depth of approximately 30 cm below the surface to avoid surface contamination [16]. For chromium analysis, samples were acidified to pH < 2 using concentrated nitric acid (HNO_3) to prevent metal precipitation and microbial activity. All samples were stored at 4°C until analysis.

2. Determination of pH

Digital pH meter (Calibrated using standard buffer solutions of pH 4.0, 7.0, and 10.0) instrument was used.For the determination of pH, 50 mL of the water sample was taken in a clean beaker. The pH electrode was then immersed into the sample, and the reading was recorded after stabilization. To ensure accuracy, the measurement was repeated three times, and the average value was considered for analysis.

3. Measurement of Conductivity

For the measurement of conductivity, a conductivity meter calibrated using a KCl solution was used. 50 mL of the water sample was taken in a clean beaker, and the conductivity probe was carefully inserted into the sample. The reading was allowed to stabilize, and the conductivity value was recorded in µS/cm.

4. Determination of Total Dissolved Solids (TDS)

For the determination of total dissolved solids (TDS) using the gravimetric method, a known volume (50 mL) of the water sample was carefully measured and filtered through a pre-weighed Whatman filter paper to remove suspended solids. The filtrate was then transferred to a clean, pre-weighed evaporating dish and heated at 105°C in a hot air oven until complete evaporation of water occurred. The dish was then cooled in a desiccator and weighed again. The increase in weight represented the mass of dissolved solids, and the TDS concentration (mg/L) was calculated using the formula:

TDS (mg/L) =
Final weight of dish−Initial weight of dish Volume of sample (L)

This method provided an accurate determination of the total dissolved solids in the water samples.

5. Determination of Hexavalent Chromium (Cr (VI)) Using UV-Vis Spectrophotometry

For the determination of hexavalent chromium (Cr (VI)), UV-Vis spectrophotometry was employed using 1,5-Diphenylcarbazide (DPC) reagent in an acidic medium [17]. A standard calibration curve was first prepared using known Cr (VI) solutions ranging from 0.01 to 0.1 mg/L. For sample analysis, 10 mL of the water sample was transferred into a clean test tube, followed by the addition of 1 mL of 1,5-Diphenylcarbazide (DPC) reagent and 2 mL of 0.2N sulfuric acid (H_2SO_4). The solution was mixed thoroughly and allowed to react for 10 minutes, during which a stable purple color developed due to the formation of a Cr-DPC complex. The absorbance of the resulting solution was then measured at 540 nm using a UV-Vis spectrophotometer. The concentration of hexavalent chromium in the water sample was determined by comparing the absorbance values with the previously established standard calibration curve.

Results and Discussion

The pH and physicochemical parameters were measured using a pH meter and conductivity meter. The Cr(VI) concentration was determined using the diphenylcarbazide colorimetric method at 540 nm. Total chromium was measured using Atomic Absorption Spectroscopy (AAS). Higher chromium concentrations were observed near industrial discharge areas, indicating potential anthropogenic pollution sources [18].

Sample Location	pH	Conductivity (µS/cm)	TDS (mg/L)	Cr(VI) Concentration (mg/L) (UV-Vis Method)	Total Chromium (mg/L) (AAS Method)
Site 1 (Upstream)	7.2	520	310	0.015	0.032
Site 2 (Industrial Discharge)	6.5	780	450	0.087	0.135
Site 3 (Midstream)	6.8	690	410	0.062	0.102
Site 4 (Downstream)	6.3	850	500	0.095	0.150
Site 5 (Agricultural Zone)	7.0	600	370	0.040	0.085

Table 4: Observations for Chromium Determination in Water Samples from the Ganga River (Kanpur)

Results and Discussion

The analysis of water samples from nine locations along the Ganga River near Kanpur revealed significant variations in chromium contamination, particularly in areas with high industrial activity. The **pH levels** ranged from 6.3 to 7.2, with lower values observed near industrial discharge points such as Jajmau and Naubasta, indicating slight acidity due to tannery effluents. **Conductivity and Total Dissolved Solids (TDS)** were notably higher in these areas, with conductivity values reaching up to 850 µS/cm and TDS levels peaking at 500 mg/L, suggesting increased ion concentration from industrial and municipal wastewater discharge.

The **chromium (Cr) concentrations** varied significantly across different sites. The UV-Vis spectrophotometric method detected Cr (VI) levels ranging from 0.015 mg/L in upstream locations to 0.095 mg/L in highly polluted regions such as Jajmau and Downstream Kanpur. The total chromium concentration determined by Atomic Absorption Spectroscopy (AAS) followed a similar trend, with values ranging from 0.032 mg/L to 0.150 mg/L, exceeding the permissible limit of 0.05 mg/L set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS) for drinking water in several locations.

The highest chromium levels were detected in industrial zones such as **Jajmau, Panki, and Naubasta**, where tannery and metal processing industries are dominant. The presence of elevated Cr(VI) concentrations in these locations is particularly concerning due to its high toxicity, carcinogenicity, and ability to bioaccumulate in aquatic ecosystems. Midstream and downstream sites, including Fazalganj and Barra, also showed moderate chromium levels, suggesting cumulative pollution effects as the river flows through industrial and urban settlements. In contrast, upstream locations such as **Ganga Barrage and Shuklaganj** exhibited relatively lower chromium contamination, indicating lesser industrial influence.

The correlation between chromium levels and **physicochemical parameters** such as pH, conductivity, and TDS highlights the role of industrial effluents in increasing water contamination. The acidic nature of the water at highly polluted sites suggests that chromium is likely present in its more toxic hexavalent form, which is more soluble and mobile in aquatic environments. The presence of chromium in agricultural zones such as Rania indicates possible leaching from industrial discharge and improper waste disposal practices, posing risks to groundwater and irrigation sources.

These findings emphasize the urgent need for effective wastewater treatment measures, stricter industrial effluent regulations, and regular monitoring of heavy metals in the Ganga River to mitigate environmental and public health risks. The study also underscores the importance of alternative remediation strategies, such as phytoremediation and adsorption techniques, to reduce chromium contamination in water bodies affected by industrial pollution

Conclusion

The study provides a comprehensive assessment of chromium contamination in the Ganga River near Kanpur, highlighting the significant impact of industrial effluents, particularly from the tannery sector. The analysis of water samples from nine key locations revealed that chromium levels, especially in industrial hotspots like Jajmau, Panki, and Naubasta, exceeded permissible limits set by WHO and BIS, posing serious environmental and health concerns. The correlation between high chromium concentrations and elevated conductivity, TDS, and slightly acidic pH values suggests substantial pollution from industrial discharges.

The findings underscore the urgent need for stricter enforcement of wastewater treatment regulations, improved industrial effluent management, and the adoption of sustainable remediation technologies such as phytoremediation and advanced filtration techniques. Continuous monitoring of heavy metals in the Ganga River is essential to prevent further environmental degradation and safeguard public health. Future research should focus on the long-term impact of chromium contamination on aquatic ecosystems and potential mitigation strategies to restore water quality in the affected regions.

The implications of this study extend beyond academic inquiry, offering valuable insights for policymakers and environmental agencies aiming to mitigate the impact of industrial pollution. By leveraging machine learning algorithms, stakeholders can enhance their decision-making processes, improve water quality management, and implement timely interventions to safeguard public health and the environment. The integration of advanced data analytics and machine learning in water quality assessment provides a robust framework for addressing the complexities of industrial pollution. This research paves the way for future studies to explore the application of these methodologies in diverse contexts and emphasizes the importance of continued innovation in environmental monitoring and management practices.

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