Theme 5

GROUNDWATER CONTAMINATION AND REMEDIATION

CHITOSAN AND CHITOSAN-GRAPHENE OXIDE NANO-BIOADSORBENTS FOR EFFICIENT FLUORIDE REMOVAL FROM WATER: PROCESS OPTIMIZATION AND ADSORPTION MECHANISMS

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Fluoride contamination in water poses a significant environmental and health problem, particularly in regions reliant on groundwater. Excess fluoride concentrations (> 1.5 mg/L) in drinking water can lead to adverse health effects such as dental and skeletal fluorosis. Thus, it is crucial to efficiently reduce high fluoride concentrations before water is used for drinking purposes. Various technologies, including ion exchange, oxidation, coagulation, electrocoagulation, and adsorption, have been employed to remove fluoride from water effectively. However, most of these methods, except adsorption, are not ideal for removing contaminants from very dilute solution and may not completely eliminate pollutants from treated water. Further, adsorption stands out due to its simplicity, low energy consumption, feasibility, and higher effectiveness in achieving complete removal of contaminants like fluoride from water. Numerous adsorbents have been explored for fluoride removal, including biochar, alumina, clay, zeolites, fly ash, activated charcoal, nano-adsorbents and nano-bio-adsorbents. Among these, nanomaterial-based adsorbents stand out due to their high surface area and surface energy, which enhance their adsorption potency. In recent years, the integration of nanoparticles into or onto porous polymeric matrices has led to the development of nanocomposite adsorbents, which demonstrate superior performance. Polymer nanocomposites are particularly effective because they combine the extensive surface area and high reactivity of nanomaterials with the structural flexibility, durability, and enhanced stability of polymers. This synergy results in greater adsorption capacity, improved stability, and enhanced selectivity for a wide array of contaminants. Chitosan, a naturally abundant, eco-friendly, and biodegradable polymer, has gained significant attention as a matrix for constructing nanocomposite adsorbents for removing harmful ions such as fluoride, nitrate, and heavy metals from water. However, in its unmodified flake or powder form, chitosan is less stable and has limited adsorption performance in field applications. To overcome these limitations, modified or composite forms of chitosan have been developed, offering a more promising solution for fluoride removal. In the present study, we evaluated fluoride adsorption capacities using two adsorbents: chitosan (CTS) beads and chitosan-graphene oxide (CTS/GO) nano-bio-adsorbent beads. Bead-shaped adsorbents made from CTS and CTS/GO are particularly effective for pollutant removal due to their higher regeneration capacity after treatment. The adsorption process involved evaluating factors such as pH, initial fluoride concentration, contact time, and adsorption capacity (mg/g). Response Surface Methodology (RSM) with a Box-Behnken Design (BBD) was used for process optimization, helping identify the optimal conditions for fluoride removal. The adsorbents were thoroughly characterized using a suite of spectroscopic and microscopic techniques including UV-Vis spectroscopy, SEM-EDX, TEM, and FTIR, confirming the successful incorporation of GO into the chitosan matrix.

RSM-BBD was utilized to optimize the operating conditions, achieving maximum fluoride removal efficiencies of 44.72% for CTS and an impressive 74.31% for CTS/GO under optimal parameters. The adsorption behavior was further analyzed by evaluating the effects of key variables, with equilibrium data fitting well to the Langmuir isotherm model. The maximum adsorption capacities were 7.29 mg/g for CTS and a significantly higher 45.32 mg/g for CTS/GO, showcasing the superior performance of the composite. Kinetic studies indicated that the pseudo-first-order model best described the adsorption kinetics, with rate constants of 0.059 min^{-1} for CTS and 0.038 g/mg/min for CTS/GO. Thermodynamic analysis revealed that the adsorption process for CTS/GO was spontaneous and exothermic, with a Gibbs free energy change (ΔG) of -5.89 kJ/mol, while CTS exhibited a non-spontaneous process ($\Delta G = +2.31$ kJ/mol). It was also demonstrated that the adsorption rate was dependent on the number of available adsorption sites on the adsorbent surface, and was eventually controlled by the binding of fluoride to the surface. Furthermore, the adsorption capacity of CTS/GO was higher than that of CTS indicating that the number of available adsorption sites increased when CTS is modified but GO nanoparticles. Desorption studies highlighted the reusability of the adsorbents, with CTS/GO maintaining an 80.56% desorption efficiency after three cycles, further enhancing its potential as a sustainable solution. Applied to real wastewater, CTS/GO consistently outperformed CTS, reinforcing its promise as a highly effective material for fluoride de-fluoridation. This study positions CTS/GO as a viable and long-term solution for efficient fluoride removal from water resources. The incorporation of GO into the CTS matrix not only enhanced adsorption capacity but also improved adsorption kinetics and regeneration potential. The CTS/GO composite exhibited higher desorption efficiencies over four cycles compared to pure CTS beads, making it a promising candidate for reusable and cost-effective fluoride removal from water. Future work will focus on further optimization and scale-up of the CTS/GO composite synthesis process in column studies to ensure its practical application for large-scale wastewater treatment.

Keywords: *Fluoride, chitosan, chitosan-graphene oxide, adsorption isotherm, adsorption kinetics*

ASSESSING GROUNDWATER QUALITY: VARIABILITY AND DISTRIBUTION OF MAJOR AND TRACE IONS IN CHHATTISGARH, INDIA

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Groundwater is considered as safest source of freshwater for drinking and domestic purposes. The quality of groundwater is an important aspect to be considered for use of water. Globally, only 2.5% water can be ascertained as fresh water. The fresh water sources are being contaminated due to anthropogenic activity, agriculture practices and industrialization. Also, the quality of groundwater can be ascertained to geogenic origin, i.e. role of geology on groundwater quality. The objective of this study is to understand the groundwater quality in terms of major and heavy metal concentration across the Chhattisgarh state. The purpose is to ascertain the variability and distribution of the chemical constituents of the groundwater, thereby helping to understand the status of groundwater quality in Chhattisgarh. It will also enable to identify freshwater and contaminated zones. Also, it will help to identify the sources of contamination, and comment on the role of geology on groundwater quality. This paper is a review of literature to understand the variability and distribution of major and trace ions in groundwater in the northern, central and southern region of Chhattisgarh. CGWB has published district hydrogeology reports, which has helped to understand groundwater occurrence, movement and groundwater quality of Chhattisgarh. The work includes compilation of previous work on geochemistry of groundwater, thus ascertaining the status of groundwater quality in Chhattisgarh. The status of groundwater quality is demonstrated by compilation of analytical data of work on groundwater quality in the northern, central and southern regions of Chhattisgarh.

Korba coal field area is the major coal mining area in the northern part of Chhattisgarh. According to CGWB, the groundwater geochemistry reports concentrations of barium, iron, nickel, manganese and aluminum exceeding a desirable limit in groundwater sample. Also, a high concentration of lead, cadmium and chromium is reported in Korba. The Balrampur, Korba, Koriya, Raigarh, Surajpur, Sarguja and Jashpur has fluoride above permissible limit (above 1.5mg/l). In the Korba, Jashpur and Raigarh regions, elevated level of nitrate (above 45 mg/l) is reported. Also, elevated level of iron is reported in Koriya, Raigarh, Surguja, Korba, Jashpur, Surajpur areas. In the central region of Chhattisgarh, salinity, arsenic and fluoride are the major contaminants. In Bemetera distict, high concentration of sulfate, magnesium, calcium, chloride and fluoride is found in groundwater. The elevated level of arsenic and fluoride is observed in Ambagarh chowki of Rajnandgaon district. Water Quality Index (WQI) of Raipur reported, 76 % area comes under good category while 24 % is classified as poor or unfit for consumption. It has also found elevated levels of lead, chromium and calcium in the Arang block. Rapid extraction of groundwater has raised concern on groundwater quality particularly nitrate, fluoride, manganese in Kasaridhi village of Durg, and that of iron and manganese in Durg-Bhilai region. In the Janjgir-Champa region, copper, cadmium, chlorine, zinc, lead, nickel, chromium, calcium, manganese and iron has been reported at higher levels due to fly ash dumping. According to CGWB, the groundwater in Balod, Bemetera, Durg, Kanker, Dhamtari, Mahasamund, Bilaspur, and

Raipur region contains fluoride concentration above the permissible limit. In the central region high concentration of nitrate is observed in Bilaspur, Dhamtari, Kanker, Kawardha, Mahasamund, and Raipur. Iron is reported in the regions of central Chhattisgarh namely, Kanker, Raipur, Durg, Bilaspur, Dhamtari, Kawardha, Mahasamund, Rajnandgaon, and Jhanjgir-champa. In the southern region of Chhattisgarh, 50% of groundwater samples are found to be contaminated with fluoride in Bijapur district due to geogenic process. Bastar, Bijapur and Kondagaon also contain fluoride above permissible limit. Nitrate and iron are reported above desirable limit in Bastar and Dantewada districts. This review highlights the variation in groundwater quality across the state. The quality of groundwater is a serious issue as the groundwater is the sources for drinking and agriculture practices for overall population.

Keywords: *Groundwater, groundwater quality, groundwater contamination, groundwater analysis, Chhattisgarh*

STRATEGIC ANCHORING OF CERIA ON GRAPHITE SURFACE FOR OPTIMAL GROUNDWATER ARSENIC REMOVAL

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Arsenic (As) contamination is a significant environmental pollutant largely resulting from human activities through mining, industrial processes, agricultural practices and geological disturbances. Prolonged exposure to arsenic-contaminated water poses serious health risks, leading to diseases like cancer and skin lesions. Groundwater arsenic concentrations are notably varied, with studies reporting levels ranging from less than 0.005 ppm to 5 ppm across different regions. In arid and semi-arid areas, developing nations heavily rely on groundwater for irrigation and drinking due to its relative availability. However, this water often contains trace elements that exceed safe drinking standards established by the Bureau of Indian Standards (BIS), Indian Standards (IS), and the World Health Organization (WHO). Contaminants such as lead (Pb), selenium (Se), chromium (Cr), cadmium (Cd), nickel (Ni), aluminum (Al), As, fluoride (F-), and nitrate (N) present substantial health risks that challenge the achievement of Sustainable Development Goals (SDGs) focused on clean drinking water. More than 200 million individuals are exposed to water that has an As content greater than standards. More than 105 nations have reported having arsenic in their water. Over 200 million individuals worldwide are exposed to water with arsenic concentrations exceeding safety standards, with more than 105 nations reporting arsenic contamination in their water supplies. This widespread issue underscores the urgent need for effective solutions to mitigate the health risks associated with arsenic exposure in affected populations. In the present study, synthesized ceria particle demonstrates exceptional effectiveness as an adsorbent for arsenic removal, offering unique advantages over conventional adsorbents through its superior efficiency, cost-effectiveness, and minimal need for pre-treatment processes. This research establishes ceria as a leading candidate for practical applications in community water purification systems, enhancing overall accessibility and safety in arsenic-affected regions.

Ceria particles were synthesized using a micellar route, employing cetyltrimethylammonium bromide (CTAB) as a surfactant to stabilize the process. Ammonium oxalate and cerium (III) nitrate served as precursors, facilitating the controlled formation of the ceria structure. Additionally, graphite was incorporated to provide a high surface area for effective adsorption, enhancing the overall efficiency of As removal from water. This methodology not only ensures uniform particle size but also optimizes the interaction between ceria and targeted contaminants. The synthesized cerium oxide (CeO_2) particles were characterized through PXRD, revealing Bragg reflections at specific angles (2θ) of 20.8°, 30.3°, 40.8°, and 50.6° indicating the formation of a pure phase of cubic cerium dioxide with space group Fm-3m (225). The enhanced intensity of the diffraction peaks in sample confirms its higher crystallinity. To investigate the morphology of the prepared samples, FESEM analysis was conducted, which revealed a flake-like morphology with an average flake size of 1.2 µm. Furthermore, the surface area of the ceria was determined through BET analysis, yielding a substantial surface area of 50.380 m^2/g. This significantly high surface area enhances interactions between As and the CeO_2 surface, providing a greater number of active sites for arsenic molecules to contact, thereby facilitating their conversion into degraded products. The pore volume and average pore radius were measured at 0.096 cc/g and 18.873 Å, respectively.

In the present study, cerium oxide (CeO_2) colloidal particles were synthesized using a micellar route and subsequently anchored onto graphite for the removal of As from groundwater. The effectiveness of these ceria particles in removing As through adsorption was investigated across various parameters, including contact time, pH (ranging from 2 to 8), and adsorbent dose (from 1% to 5% w/v) .The results indicate that nearly complete removal of As, achieving 98% efficacy, occurs within 30 minutes at an optimal adsorbent dose of 50 mg for an initial arsenic concentration of 10 ppm. This process demonstrates remarkable effectiveness across a wide pH range, specifically from pH 2 to pH 8. Furthermore, in the presence of competitive ions, the ceria-based adsorbent exhibited substantial adsorption capacity, effectively removing various pollutants such as aluminum (Al), chromium (Cr), nickel (Ni), copper (Cu), selenium (Se), cadmium (Cd), mercury (Hg), lead (Pb), uranium (U), and iron (Fe), with removal efficiencies ranging from 60% to 90%.

In this study, CeO_2 particles were successfully synthesized. The findings can be summarized as follows (i) Kinetic analysis demonstrated that arsenic removal occurred rapidly, with approximately 98% elimination within the first 30 minutes; (ii) The adsorption data were well-fitted to the linear forms of Freundlich, Langmuir isotherm models, indicating that the adsorption process followed first-order kinetics; (iii) The presence of other ions, including Al, Cr, Ni, Cu, Se, Cd, Hg, Pb, U, and Fe influenced adsorption dynamics. Nonetheless, the high adsorption capacity of CeO_2 particles suggests significant potential for the removal of arsenic from water. This work highlights the efficacy of CeO_2 particles as a promising material for arsenic remediation in aquatic environments.

***Keywords**: Groundwater, ceria, graphite, arsenic removal, adsorption, environmental pollutant*

GROUNDWATER QUALITY ASSESSMENT IN SEMI-ARID REGION OF NORTH-WESTERN PART OF ODISHA, INDIA

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Groundwater as a vital resource is being utilized by human beings since the dawn of civilization. The utility of groundwater for both drinking and irrigational purposes demands constant scrutiny of its quality. Increase in mining activities, improper use of wastes on land, excessive use of fertilizers and pesticides in agricultural field and other anthropogenic activities have challenged the purity of groundwater. Other than human involvement, geogenic actions such as degree of chemical weathering of various rock types, quality of recharge water and inputs from resources other than water rock interaction influences the chemistry of groundwater. The alarming increase in rate of groundwater pollution throughout the world has imposed serious health hazard to humans and hampered agricultural productivity. The present study encompasses the geochemical characterization of groundwater and its suitability in north-western part of Odisha for domestic and irrigational purpose. Around 15 samples of groundwater were collected from tube-wells, bore-wells and dug-wells during the month of January, 2023 (post-monsoon period). The physico-chemical parameters such as total dissolved solids (TDS), total hardness (TH), Calcium, Magnesium, Sodium, Potassium, Sulphates, Fluoride, Bicarbonates and Nitrates were determined using standard analytical methods. The concentration of Ca^{++}, Cl^{-}, HCO^{-} and TH were determined through standard titration. The concentration of Mg^{++} was calculated from the concentration of Calcium and Total Hardness. The concentration of Na^{+} and K^{+} were estimated with the help of flame photometer. The concentration of SO_4^{2-}, F^{-}, and NO_3^{-} were determined using UV Spectrometric method. The parameters such as pH, EC were measured insitu. The estimation of pH and EC revealed that the groundwater is generally fresh water but slightly alkaline in nature. The presence of hydroxides, carbonates and bicarbonates affects the alkalinity of groundwater. From the analysis, it was found that the concentration of major cations such as Na^{+} ranges between 2.8-56 mg/l, K^{+} ranges between 2.6-37.5 mg/l, Ca^{++} ranges between 25-165 mg/l, Mg^{++} ranges between 6.09-40 mg/l. The concentration of major anions are as follows: SO_4^{2-} is between 6-84 mg/l, NO_3^{-} is between 5.51-105 mg/l, Cl^{-} ranges from 20-180 mg/l, HCO^{-} ranges from 54.9-311.1 mg/l and F^{-} ranges from 0.008-1 mg/l. The TH ranges between 60-530 mg/l and reveals the water can be classified as moderately hard to very hard water. Hardness in groundwater makes it undesirable to be used as drinking water. The high concentration of K^{+} in the post-monsoon period is likely the cause of leaching of silicate minerals such as orthoclase, microcline, hornblende, muscovite and biotite in igneous and metamorphic rocks. Agricultural activities might also escalate its concentration in the groundwater. Furthermore, high concentration of potassium might cause significant disorder to people suffering from kidney diseases, coronary artery disease, high blood pressure and diabetes. High concentration of potassium in irrigation water can affect the hydraulic conductivity of the soil. The increase in alkalinity of groundwater affects the alkalinity of the soil and this might play a significant role in crop failure. The concentration of all the other ions falls under the permissible limit determined by BIS (2012) and WHO (1993). TDS ranges between 105.4- 658.5 mg/l indicating non saline water and that the groundwater is suitable for human consumption. The suitability of groundwater for agricultural purpose is determined using sodium ratio, Kelly's ratio, sodium adsorption ratio (SAR) and Wilcox diagram. Salts like sodium, potassium, calcium and magnesium affects the growth of plants as they can modify their osmotic processes and metabolic reactions. These salts also affect the structure, permeability and aeration in soil. The sodium concentration is basically expressed in terms of Na%. The Sodium Adsorption Ratio is defined by SAR and Kelly's Index is calculated as KI. The Wilcox diagram is used to determine the viability of groundwater for irrigation. It is a graphical representation in which EC is taken along X-axis and Na% along the Y-axis. The sodium ratio ranges between 0.020-1.80. According to the sodium adsorption ratio, 80% of the sample falls under the excellent category while 20% of the samples falls in the good category. As per the Kelly's index it has been found that around 60% of the sample are recommendable while the rest 40% show slight increase in alkalinity of the water. From the overall study, it is concluded that almost all the water samples of this area are suitable for irrigational practices as well as for human consumption. The hardness in groundwater can be eliminated by lime-soda process, reverse osmosis, ion exchange method, distillation etc. Water softeners can be used for elimination of potassium in groundwater and can be made desirable for susceptible individuals before consumption.

Keywords: *TDS, agriculture, Na%, Wilcox diagram, Kelly's ratio, SAR*

ARSENIC CONTAMINATION IN GROUNDWATER AND HEALTH RISK ASSESSMENT IN PARTS OF THE BRAHMAPUTRA FLOODPLAINS IN ASSAM, INDIA

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Arsenic (As) is a toxic metalloid that can contaminate groundwater posing significant health risk to humans and as such is a growing global concern. As occurs naturally in rocks and soil on the earth surface and can leach into water through geogenic or anthropogenic sources. The As concentration in the groundwater of many parts of the world, notably South Asian countries like Bangladesh, India and Nepal, have far exceeded the safe drinking water standard leading to widespread public health issues. Previous studies in India, have reported that more than 20 states have been affected with As (>10µg/l) in the groundwater including Assam. As in groundwater of Assam was first reported in 2004 and thereafter several studies have been undertaken to understand the sources, distribution and release mechanism of As. Various As release mechanism has been discussed in the studies globally, however, reductive dissolution of Fe oxyhydroxide is widely accepted. The present study has, thus, been undertaken in parts of the Upper Brahmaputra floodplains in Jorhat and Golaghat districts of Assam, India to assess the distribution of geogenic contamination of As in groundwater and its health risk on exposed population. Groundwater samples (n=100) were collected from shallow (<30m) aquifers covering the two districts. Major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{-}) along with the heavy metals (As, Fe, Mn) were analyzed for the present study. The heavy metals and cations were analyzed in ICP-OES with precision of nearly ~2%, whereas the anions were analyzed following the procedure of APHA 2017. Potential health risk associated with arsenic contamination, focusing on human exposure through drinking water was evaluated for 6 administrative blocks (where As>10µg/l). The population was divided into children (2-14 yrs), adult male and female (>18 yrs). Hazard quotient (HQ) was calculated to determine non carcinogenic risk. HQ <1 signifies the absences of detrimental effects on human health, while, HQ>1 depicts the possible chance of non-carcinogenic health risk. The cancer risk was determined where cancer slope factor for arsenic was considered as 1.5 per mg/kg/day as given by USEPA and Cancer index (CI) was calculated.

The average cations and anions concentration in groundwater of the southern bank of the Brahmaputra River are in the order of $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$ and $HCO_3^{-}>Cl^{-}\ ^{-}>SO_4^{2-}$. The trilinear piper plot indicates Ca-Mg-HCO_3 as the primary water type followed by Na-Ca-HCO_3-Cl. In addition to it, Gibbs plot indicates rock water interaction as a dominant process that controls the groundwater chemistry of the region. As concentration in the groundwater of the study area ranges from 0.07 to 480µg/l with a mean value of 54.5µg/l. 71% of samples have exceeded the WHO permissible limit of 10 µg/l while 41% samples have As concentration >50 µg/l. 97% and 69% of samples are observed to have exceeded the permissible limit of 0.3mg/l and 0.4 mg/l for Fe and Mn with their mean values of 12.41 mg/l and 0.73 mg/l respectively. Elevated As is mostly found in the aquifers adjacent to the foothills of Naga hills, while low As (<10 µg/l) is found near the Brahmaputra floodplain. The subsurface study reveals the presence of thick clay layer capping the aquifers near the

Naga foothills, whereas mostly sandy layers are found near the river Brahmaputra. XRD peaks indicates the presence of illite and kaolinite minerals in the clay sediments which might have acted as an adsorbing site for As and these clay layers might have behaved as a host for As in the region. Upon receiving the conducive environment, the adsorbed As is released into the groundwater, thus contaminating the aquifers. Health Risk assessment indicates that the HQ values of children (range 1.86 - 25.45) are higher than the HQ values of adult male (range 1.12 – 19.33), and adult female (range 1.09 – 17.03), making them highly vulnerable for non-carcinogenic risk. Moreover, the cancer risk ranges from 1.1×10^{-3} to 8.7×10^{-5} which is much higher than USEPA limit 10^{-6} making the entire population at high risk of cancer.

The present study concludes that the groundwater of the study area is highly contaminated with heavy metals particularly As, Fe and Mn, raising concerns regarding safe drinking water. The evaluation of health risk assessment indicated that the entire population is at potential risk of both carcinogenic and non-carcinogenic risk, while children are most vulnerable as compared to adult male and female. The results of the study will facilitate in understanding the As distribution and its adverse impact on human health in the southern bank of the Brahmaputra floodplains and will also be helpful for stakeholders to take evidence based decision that aims in providing safe drinking water and protect human health.

Keywords: *Arsenic contamination, health risk assessment, sediment chemistry, hydrogeochemistry, Brahmaputra floodplains*

HEAVY METAL CONTAMINATION IN GROUNDWATER OF THE GUWAHATI CITY, ASSAM, INDIA

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Assessing groundwater quality is crucial for ensuring safe drinking water, as it is the primary source of drinking water. Groundwater quality is progressively worsening due to population growth and subsequent urbanization. Groundwater is contaminated due to lack of proper management and protection, mainly in urban centres. Preventing groundwater from contamination is a major concern as it can cause dangerous health problems. Heavy metal contamination in groundwater causes a serious health impact on human beings causing various cancers and some neurological issues. Therefore, proper research on the sources of groundwater pollution is essential for sustainable development. Many researchers have assessed groundwater quality in urban areas throughout the world. In urban areas, heavy metals like Mn and Pb contamination in groundwater is increasing. Lead in groundwater is like a curse for humans since it is a carcinogen and can affect every system and organ of the human body. Groundwater in Guwahati City, Assam, India is already contaminated with the heavy metals Cu, As, Mn, Pb, Ba, Cu and Fe. Therefore, proper research on the sources of groundwater pollution is essential for the protection of the source.

This study's objective is to evaluate the groundwater quality of rapidly urbanizing Guwahati city, Assam, emphasizing heavy metal contamination. The study focuses on evaluating the groundwater quality in Guwahati City, Assam emphasising six heavy metals (Fe, As, Cu, Zn, Mn and Pb). The study also aims to delineate the spatial distribution pattern of the different parameters and establish the relationship between the parameters and the geology of the area. Sixty-three groundwater samples were collected from ring wells in 250 ml HDPE bottles. Samples were preserved with HCl for As, Fe and HNO_3 for Cu, Zn, Mn and Pb in two different bottles for heavy metal analysis. Physical parameters pH, Temperature, Total dissolved solids (TDS) and Electrical Conductivity (EC) were measured in the field using a Hanna handheld instrument (HI98129 pH/conductivity/TDS tester). Samples were well-preserved at 4°C at the laboratory prior to analysis. Heavy metals (Fe, As, Cu, Zn. Mn and Pb) were analysed in Atomic Absorption Spectrophotometer (PG Instruments AA8000) following standard protocols provided by the American Public Health Association (APHA). Heavy Metal Pollution Index (HPI) and Metal Index (MI) were computed using MS-excel and spatial distribution maps were prepared using ArcGIS 10.8. The heavy metals analyzed for the samples revealed that Cu and Zn metals are below the detection limit (bdl). As concentration exceeds the WHO limit of 10µg/l in only one sample out of 63. Mn concentration exceeds the WHO guideline value of 0.4mg/l in 39.68% of samples indicating serious health concerns for the exposed communities, whereas the concentration of Pb exceeds the permissible limit of WHO i. e. 10µg/l in 100% of samples. Based on the analysis of the six heavy metals in the city inferred that it is in a critical position where groundwater is polluted with poisonous contaminants like Pb, Mn, and Fe. The groundwater in the entire city is heavily loaded with Pb.

The spatial distribution pattern of the metals inferred that the city is contaminated with Fe and Mn except in small pockets, whereas the entire city is contaminated with Pb. As

contamination occurred only in a small area in the northwestern part of the city. The plot of the concentration in the geological map indicates the contribution of geology in As and Fe contamination as their concentration is highest adjacent to the Archean group of rocks, while no coordination has been found between Mn and Pb concentration with geology. This contamination may be attributed to the anthropogenic contribution through the leaching of urban sewerage load. HPI computed for six metals (Fe, As, Cu, Zn, Mn, and Pb) ranges from 95.84 to 1467.18 with a mean of 795.86. The HPI value greater than 100 in 98.41% of samples indicates the unsuitability of groundwater for consumption. The spatial distribution of HPI reveals groundwater only in a small area in the extreme northernmost portion of the city is suitable for human consumption. Metal index (MI) calculations also reveal that groundwater is seriously affected (>6) by heavy metals, and 4.76% of samples are strongly affected (4 – 6). This insight allows for a targeted intervention in the city to prevent further water quality degradation. HPI and MI computed for the metals also suggested that there is a need for another source of drinking water in the absence of a proper mitigation plan. The spatial distribution pattern and the distribution with geology are suggestive of the anthropogenic influence on groundwater contamination. Therefore, preventing and mitigating these groundwater problems are necessary by intervening in the resource with a systematic scientific approach.

Keywords: *Heavy metals, heavy metal pollution index, metal index, spatial distribution, Guwahati*

IMPACT OF MUNICIPAL SOLID WASTE LEACHATE ON GROUNDWATER QUALITY AND ITS POTENTIAL PUBLIC HEALTH RISK

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The efficient waste management is a global challenge, with a direct public health effect. The global solid waste generation rate is rising quickly due to the result of ongoing urbanization and industrialization. According to the CPCB 2020-21 report, India produces 160038.9 tonnes per day (TPD) out of which waste collected only 152749.5 TPD, further 79956.3 TPD of waste is treated, 29427.2 TPD is landfilled and the rest 50655.4 TPD of total waste remains omitted. A major global environmental and public health concern is the inappropriate handling of municipal solid waste (MSW). Among the numerous issues, the leachate produced by MSW landfills poses a serious risk to groundwater supplies and, by extension, public health. Highly concentrated dark brown color leachate is generated from landfill, which contaminates both groundwater and soil as well. The leachate properties are often characterized by high concentrations of Biological Oxygen Demand (BOD), Ammoniacal nitrogen (NH_3-N), Chemical Oxygen Demand (COD), COD/BOD_5 ratio. It also contains persistent organic pollutants (POPs) like dioxins, which impair immune function and upset hormonal balance, and volatile organic compounds (VOCs) like benzene, a known carcinogen. These substances have extensive negative effects on health, including harm to reproduction and problems with development in infants. Many of these compounds are very soluble, which makes it easier for them to migrate through soil into nearby groundwater, degrading sources of drinking water and posing serious health concerns to people.

In order to synthesize information on the effects of landfill leachate on groundwater quality and human health risk assessment, 118 selected studies from the Google Scholar database were reviewed. Leachate from unlined or insufficiently lined landfills percolates into groundwater, which is the primary contributing factor to groundwater contamination. Water quality is severely degraded when leachate migrates into groundwater, introducing a wide range of contaminants. Vital organ damage is negatively impacted by the high concentration of heavy metals found in leachate, which seeps through the soil to groundwater near dumpsites. In geographical areas with permeable soils, broken bedrock, or poorly managed landfills without sufficient containment measures, leachate has a very negative effect on groundwater. Because of the subterranean flow of contaminants and the sluggish natural recharge rate, cleaning up contaminated groundwater is difficult and expensive. This emphasizes the significance of stringent landfill design guidelines, frequent inspections, and efficient leachate treatment systems to protect groundwater resources from contamination.

Groundwater quality is impacted by MSW leachate, which emphasizes the importance of sustainable waste management techniques. In addition to endangering essential water resources, leachate pollution causes serious health dangers to the general public. Children exposed to lead and cadmium suffer from developmental problems, kidney failure, and brain impairment. Mercury and arsenic have been connected to organ damage, immunological

system inhibition, and cancer. Elevated nitrate and ammonia concentrations in leachate can contaminate drinking water, causing nitrate-induced oxygen depletion in the blood, which causes blue baby syndrome (methemoglobinemia) in infants. Adults exposed to ammonia may experience respiratory discomfort and other systemic consequences. Human health is also at risk from biological pollutants found in leachate. Pathogens include bacteria (like Salmonella and E. Coli), viruses (like Hepatitis A), and parasites (like Giardia) that can cause serious liver infections, gastrointestinal disorders, and in rare situations, potentially fatal dehydration. Although leachate can produce toxic gases and aerosols when exposed to air, it also presents a risk to human health. Methane and carbon dioxide are produced by decomposing organic matter in landfills, and volatile chemicals that irritate the skin, eyes, and respiratory system can be released by leachate. Due to the presence of airborne contaminants and unpleasant odors, communities close to landfills frequently complain of headaches, respiratory issues, and stress-related diseases. Additionally, exposure to polluted soil or agricultural water can cause toxins to bioaccumulate in crops, which can have an indirect impact on human health by way of the food chain. People who live close to landfills, landfill employees, and vulnerable populations like children and the elderly are the most in danger since they are more likely to suffer negative consequences from hazardous exposure. The long-term effects of landfill leachate, such as neurological harm, reproductive issues, and cancer risks, highlight how urgently appropriate waste management and leachate treatment are needed to safeguard public health. For groundwater resources to be sustainable over the long run and to protect public health, MSW leachate must be managed effectively. This study provides a comprehensive review of the impact of leachate generated from landfill sites on groundwater quality and its possible human health risks. An integrated strategy that incorporates better landfill management, cutting-edge leachate treatment technologies, regulatory enforcement, and community involvement is needed to address the issue of municipal solid waste (MSW) leachate. Communities may minimize the threats leachate poses to the environment and public health by enhancing landfill infrastructure, using cutting-edge treatment technology, reducing trash production, and encouraging cooperation. These actions will save essential water resources for future generations and open the door for sustainable waste management systems when paired with proactive monitoring and public involvement.

Keywords: *MSW leachate, dumping site, groundwater, human health, leachate management*

USE OF HYDRO CHEMICAL INDICES FOR MINERAL DISSOLUTION AND POLLUTANT IDENTIFICATION IN THE MIDDLE GANGA BASIN, INDIA

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This study aims to characterize the parameters (cations, anions, pH and EC) and factors (Geology, Water-rock interactions, and the degree of chemical weathering**)** controlling groundwater geochemistry using various hydro chemical indices, and a comparative analysis of data. The spatial distribution of the points from where the groundwater samples have been extracted for the estimation of the nine parameters is not the same. Rather the number of points as well as the location of the points is different for all the nine parameters. However, at some places there is common point where all or more than one parameter has been estimated for the groundwater samples. The number of points or stations for pH, Electrical Conductivity (EC), Chloride (Cl^-), Bicarbonate (HCO_3^-), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulphate (SO_4^{2-}), and Nitrate (NO_3^-) are 134, 190, 4, 353, 11, 10, 10, 9, and 10 respectively. In the case of pH, EC, and Cl the distribution of points is more towards north rather than southern portion of the basin. In statistics, control charts are the tools in control processes to determine whether a process is in a controlled statistical state or not. This chart is a graph which is used to study process changes over time. These charts are also known as Shewhart charts or process-behavior charts. The control charts are used for monitoring the quality of the groundwater that can easily tell about the lower and upper limits of the water quality parameter from the center lines. Control charts are essential tools for monitoring groundwater quality by tracking variations in key water parameters over time. The X-bar chart is used to monitor the average concentration of a parameter, such as nitrate levels or pH, across multiple subgroups of samples, while the I chart tracks the average performance of individual measurements without subgroups. The R chart and S chart help assess variation, with the former measuring the range within subgroups and the latter focusing on the standard deviation, both important for understanding the consistency of water quality. The MR chart is used to observe variation between consecutive individual measurements, while the C chart tracks the number of defects or exceedances of a threshold in a subgroup, such as contamination levels exceeding safety limits. The P chart monitors the proportion of defective samples exceeding a predefined threshold, and the U chart tracks the number of defects or exceedances per unit of water, helping to ensure the water remains within safe quality standards. These charts enable water quality managers to identify trends, shifts, or anomalies, ensuring timely intervention to maintain safe and sustainable groundwater resources. In this study, a total of 117 control charts (all nine types for all nine parameters for different groups) have been prepared.

In other studies, the principal component analysis (PCA) has been widely applied to assess major geochemical processes in aquifers and to choose hydro chemical indicators to address each geochemical process. When PCA is conducted using the isometric log-ratio (^{i}lr) transformed hydro chemical parameters, the ^{i}lr coordinates of a sub composition can be recommended as a method to integrate the selected ions. This process is cumbersome. Hence, for this study, traditional hydro chemical indices are used to classify groundwater according

to flow path to evaluate groundwater salinity problems to assess the impact of microbial activity and chemical fertilizers, and the impact of anthropogenic activities, and quantify the impact of landfill on groundwater quality used hydro chemical indices to promote sustainable development and effective management of groundwater resources. For the development of hydro chemical indices, hydro chemical indicators should be so selected as to determine the dominance of rainwater. Then the hydro chemical indicators (as Ca^{2+}/Mg^{2+}) should be coupled to provide a single index. A number of hydro-chemical indices are available such as Sodium Absorption Ratio (SAR), Percentage Sodium (%Na), Permeability Index (PI), Kelly Ratio (KR), and Magnesium Hazard (MH). These indices can help analyze the quality of the groundwater for as large area as the middle Ganga basin. Apart from these indices, Total Dissolved Solids (TDS), water hardness, nitrate to chloride ratio, and nutrient pollution index (NPI) have been used to identify the source of pollution (i.e, industries, agriculture, manure etc.). The use of Empirical Cumulative Distribution Function (ECDF) in our study tells the probability of occurrence of certain quantity (ppm) of the chemical parameters in the groundwater for the entire study area. Hence, a comprehensive statistical analysis of groundwater in the entire basin has been done to gain valuable and crucial insights for the assessment of the groundwater quality. The groundwater quality in Uttar Pradesh (middle Ganga Basin) was investigated by collecting samples and analyzing key geochemical parameters, including pH, Electrical Conductivity (EC), Chloride (Cl^-), Bicarbonate (HCO_3^-), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulphate (SO_4^{2-}), and Nitrate (NO_3^-) with values varying from 6.9 to 8.7, 130 µS/m to 1620 µS/m, 0.32 ppm to 549 ppm, 0 ppm to 557 ppm, 7.8 ppm to 729 ppm, 23 ppm to 175 ppm, 4 ppm to 155 ppm, 11.9 ppm to 946 ppm, and 0 ppm to 174 ppm respectively. The spatial analysis of these quality parameters can identify the route of the mineral dissolution (anions like chlorides, bicarbonates, sulphates, and nitrates of cations like sodium, calcium, and magnesium along with many others) along with the pollutant (sources could be from industries, agriculture, and domestic waste) discharge into the aquifers. The geochemical analysis (using Ion Chromatography, Titration, pH Meters, and Conductivity Meters) of the study area can give information about the soil, agriculture, rocks (Carbonate Rocks, Sulfide Minerals, and Silicate Weathering), non-point and point sources of pollution, and chemical reactions causing changes in pH and EC. This study can be useful for various domains like geology, health department, and water resources development.

Keywords: *Hydro-chemical indices, groundwater quality, mineral dissolution, pollutant discharge, water resources*

CO-TRANSPORT OF ENGINEERED NANOPARTICLES AND BACTERIA IN WATER SATURATED POROUS MEDIA

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Expanding manufacture and widespread use of engineered nanoparticles (ENPs) in several industries such as medicine, personal care, food, energy storage, and site remediation leads to the unavoidable release of ENPs into the environment, thereby contaminating the soil and groundwater resources. Thus, introduction of ENPs into the soil and water occurs through release of untreated industrial nano-waste, waste water treatment plant discharges, landfill leachates, agricultural discharge and stormwater runoff. Among the metal oxide ENPs, ZnO is one of the most widely used ENPs in the world due to advancement of nanotechnology. Therefore, understanding the transport pathways, and related retention mechanisms of ZnO nanoparticles in the subsurface is critical for protecting drinking water sources from contamination and minimizing possible ecological consequences. Soil is inhabited by diverse bacterial communities of which *Escherichia coli* is ubiquitously found everywhere which is associated with the occurrence of water borne diseases. Bacteria have been found to significantly affect the transport behavior of engineered nanoparticles and other colloids. Profound research has been undergone on individual transport studies of nanoparticles and bacteria, however studying the cotransport behavior of nanoparticles and bacteria needs more vivid investigation. Modeling the cotransport of nanoparticles and bio-colloids in an efficient way is also lacking in the literature which has been addressed here efficiently.

For understanding the cotransport behaviour of ZnO nanoparticles and *E. coli*, lab scale column experiments have been performed to understand the fate and transport of ZnO nanoparticles and *E. coli*, both in the absence and presence of each other. Interactions between ZnO nanoparticles and *E. coli* along with the interference of one on the transport of the other has been studied here as well. In this work, we have observed higher retention of ZnO nanoparticles onto soil when present alone, in comparison to its retention in presence of *E. coli* during its co-transport. In contrast, we have observed retarded transport of *E. coli* in the presence of ZnO nanoparticles in comparison to its individual transport. The contrasting transport behaviour of ZnO nanoparticles and *E. coli* during their cotransport is attributable to their competition for attachment sites on the grain surfaces and due to nZnO-*E. coli* hetero-aggregates formation. Our developed model well supported our experimental results, accounting for ZnO nanoparticles and *E. coli* deposition in soil, hetero-aggregation kinetics, and hetero-aggregate retention in soil. We have observed the formation of hetero-aggregates during the cotransport which has introduced a new entity in the transport pathway, thus interfering in the transport of both ZnO nanoparticles and *E. coli* by effecting the interaction energies within the nanoparticles, bacteria, and the porous media. The hetero-aggregates formed were found to have higher tendency of transport than deposition.

Altogether the upshot of this work explains that ZnO nanoparticles and *E. coli* transport behaviour gets altered in the copresence of each other, which help to understand the risks posed by releasing wastewater rich in ZnO nanoparticles into the subsurface inhabited with bacteria. In both natural and artificial systems, the transport of microorganisms through

porous media (such as aquifers and sand filters) is also a significant problem along with groundwater contamination by engineered nanoparticles like ZnO nanoparticles. We have seen in our study that the bacterial transport in saturated porous media is severely hampered in the presence of ZnO nanoparticles. Thus, by incorporating these nanoparticles into the sand beds, presents the opportunity to create an efficient bacterial barrier, either as a preventative measure, an enhancer for drinking water filters, or for retaining active bacteria and inhibiting biofilm growth during bioremediation processes within the contaminant plume boundaries. However, this addition of nanoparticles should be designed carefully, considering the potential risks which can arise due to sudden release of the previously retained bacteria, once the nanoparticle input is hindered. Also, we have observed facilitated transport of ZnO nanoparticles in presence of *E. coli*, which increases the risks of groundwater contamination by ZnO nanoparticles when co-present with *E. coli*. Altogether, our results provide comprehensive understanding of the mechanisms underlying the transport and deposition of engineered nanoparticles and bacteria in ground water environments. These findings suggest a significant likelihood of bacterial aided transport of engineered nanoparticles in the subsurface, increasing the risks of groundwater contamination by engineered nanoparticles in presence of bacteria and also showcases retarded bacterial transport in the subsurface in the presence of ZnO nanoparticles which works as a filter for bacteria, thus reducing bacterial contamination of groundwater.

Keywords: *ZnO nanoparticles, bacteria, soil, cotransport, modeling*

FLUORIDE TOXICITY AND ITS IMPACTS ON HUMAN HEALTH IN WAZIRGANJ BLOCK, DISTRICT GAYA, BIHAR, INDIA

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There are many elements which are important for the healthy growth of human body and fluorine is one such element whose presence in small quantity is important for good dental health and bone structure. But, when it finds its way in excess, it becomes a problem leading to adverse impacts. The presence of excess fluoride ion in groundwater is one of the major toxicological environmental hazards worldwide. In groundwater, the natural concentration of fluoride depends on the geological, chemical and physical characteristics of the aquifer, the porosity and acidity of the soil and rocks, the temperature, the action of other chemical elements, and the depth of the aquifer. Fluoride is a naturally occurring substance found in some igneous and metamorphic rocks. These rocks often contain fluoride-bearing minerals such as fluorite, biotite, apatite, hornblende etc. Fluoride commonly occurs in groundwater due to the weathering and leaching of these minerals and also through overuse of phosphate fertilizers. It has been observed globally that fluoride is one of the most abundant anions in groundwater. The surplus concentration of fluoride in groundwater has a direct implication on human health leading to issues like dental and skeletal fluorosis. In this concern, a study has been conducted in Wazirganj block, Gaya district, Bihar, India to understand the geochemical processes and mechanisms responsible for the release of fluoride contaminant in groundwater, its health implications in the study region and to suggest some mitigation measures.

A total number of 50 groundwater samples were collected from different locations in Wazirganj. The samples were collected in one litre high-density scientific polyethylene bottles. The physical parameters such as pH, EC and TDS were measured in the field itself. These samples have been further analyzed in the water testing laboratory using a UV Spectrophotometer to determine the concentration of fluoride. Apart from water samples, rock samples were also collected from the vicinity. After doing the thin-section preparation of the rock samples, petrographic study was undertaken to understand the petrography of the rocks present in the study area. Electron Probe Microanalysis (EPMA) of the rock thin sections was also performed at IIT Bombay to fathom the elemental composition of the common rock-forming minerals. All the data have been pieced together to trace the potential source of fluoride contamination in groundwater. Additionally, health risk assessment was carried out based on field survey comprising of discussion with the villagers and empirical study based on the obtained data.

The chemical analysis of water samples has shown that the highest value of fluoride was recorded at Budhaul village (2.40 mg/L) whereas the lowest value was found to be 0.85 mg/L at Dharampur village. The petrographic study and EPMA of rock thin sections have yielded that there are fluorine-bearing minerals present in the rocks of the study region. The major rock types are quartz-mica schist, phyllite, slate, quartzite and granite. Minerals that have fluorine in their composition are biotite, muscovite, apatite, hornblende etc. Long-term weathering of the rocks has a potential bearing on presence of fluoride in water. Since groundwater flows at a considerably low rate, there are high chances of the contaminants

being persistent in the groundwater system once it gets contaminated as evident from the analysis results. In addition to the chemical and petrological studies, field-based survey has revealed that many villagers are suffering from several health issues such as dental fluorosis and deformed bones (sign of skeletal fluorosis) present in the study area due to excess of fluoride in water and its consumption. There are several factors that lead to fluoride toxicity, some of them being doses, exposure, age and genetics. People of different age groups are differently susceptible to fluoride contamination as the instances of dental fluorosis and skeletal to some extents were observed frequently among the children.

The maximum permissible limit of fluoride in groundwater is 1.5 mg/L as per the World Health Organization (WHO) and Bureau of Indian Standards (BIS), 2012. Thus, Public Awareness Programmes are indeed a need of the hour in the region affected by high fluoride pollution and also about the associated health risk. There are some De-fluoridation techniques/measures that could be followed to reduce the level of fluoride in drinking water. These include membrane filtration process such as Reverse osmosis and Electrodialysis, Adsorption using activated alumina, Distillation, Ion Exchange etc. These must be adopted in regions with high fluoride concentration in groundwater (International Groundwater Assessment Centre). It will be helpful for the local people to mitigate the fluoride toxicity and to ensure the availability of clean and safe drinking water.

Keywords: *Fluoride, groundwater, toxicity, health risk, de-fluoridation*

ASSESSMENT OF GROUNDWATER AND SURFACE WATER QUALITY IN THE SOUTHERN BRAHMAPUTRA FLOODPLAINS, ASSAM, INDIA: INSIGHTS FROM HYDROCHEMICAL ANALYSIS AND ISOTOPE STUDY

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Groundwater is a vital resource. Globally the hydrological and hydrochemical conditions of groundwater are significantly anthropogenic activities. Thus, it has arrived at a point where restoration is required as a result of environmental degradation. In the past few year's studies have found a notable decline in the quality of water, used for drinking and irrigation purposes raising concerns across various regions of the world. (Bhunia et al. 2018). Therefore, this study seeks to evaluate the quality of groundwater and surface water in the Brahmaputra floodplains in Assam by utilizing the Water Quality Index (WQI) along with relevant statistical methods. This research investigates the quality of the surface water and groundwater in the Southern bank of the Brahmaputra River floodplains in Assam, India which covers the area between 94° 25' to 95° 22' east longitudes and 26° 45' to 27° 15' north latitudes bounded by the Disang river to the east and Jhanji to the west. To the South, it shares border with Tirap district of Arunachal Pradesh and is bounded by Naga-Patkai Hill Range while the Brahmaputra flows to the North.

Forty groundwater and ten surface water samples were systematically collected during pre-monsoon and post-monsoon seasons during the year 2023. The analysis comprises twelve physico-chemical parameters, covering a variety of cations and anions, including pH, EC, hardness, TDS, HCO_3^-, Na^+, SO_4^{2-}, Ca^{2+}, Cl^-, Mg^{2+}, K^+ and F^-. Sampling was done following standard methods proposed by APHA, 2017 (23rd Edition). Piper, Gibbs plot, box plots and various statistical methods were generated to illustrate the variations in the data. Stable isotope analysis ($\delta^{18}O$ and δ^2H) of groundwater, surface water and rainwater were done to find the primary source of groundwater recharge. All the physico-chemical parameters fall within acceptable limits, with the exception of Mg^{2+}(15%), Na^+(12%), K^+(1%) and F^-(2%) which exceed the permissible thresholds of WHO and BIS. Among the four blocks investigated under the present study, Nazira block shows the highest concentrations of Mg^{2+} (15%) and Na^+ (12%) followed by Sivasagar, Amguri, and Demow blocks. High amount of K^+(1%) and F^- (1%) were found in Demow block followed by Nazira block. Water Quality Index (WQI) indicates that the overall water quality in the area is good. The Piper diagram reveals that the predominant facies for groundwater during the pre-monsoon season is Ca^{2+}-Mg^{2+}-HCO_3^-, whereas surface water is classified as Ca^{2+}-Mg^{2+}-Cl^--HCO_3^-. In contrast, post-monsoon groundwater shifts to a Na-HCO_3^- type, while surface water is characterized by a Na-Cl^- type. The Gibbs plot illustrates that the chemical composition of the samples is largely influenced by atmospheric precipitation, underscoring the significant impact of rock weathering on water chemistry. Additionally, stable isotopes ($\delta^{18}O$ and δ^2H) from groundwater, surface water, and rainwater suggest that local precipitation is the main contributor to groundwater recharge in the area.

The study concludes that the quality of groundwater in the region is generally good, exhibiting neutral to slightly alkaline characteristics. Groundwater recharge primarily occurs through local precipitation which can be inferred from the stable isotopes ($\delta^{18}O$ and δ^2H).

Elevated levels of sodium (Na^+) and magnesium (Mg^{2+}) are attributed to geogenic processes, while the presence of higher fluoride (F^-) and potassium (K^+) concentrations is linked to anthropogenic activities. This interplay between natural and human factors shapes the overall water quality and highlights the need for ongoing monitoring and management although according to the WHO it is not considered an issue of health concern. Analysis of stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) from rainwater, surface water & ground water indicates that the local precipitation acts as the primary source for the recharge of GW in the region. Thus, this study provides valuable insights for effective planning and management of water resources intended for household and consumption purpose.

Keywords: *Groundwater, water quality, water quality index, isotope, Piper diagram, Gibbs Plot*

SEASONAL ASSESSMENT OF GROUNDWATER QUALITY AND PRACTISE OF WATER USE MANAGEMENT IN CHAMPHAI AND MAMIT DISTRICT OF MIZORAM, INDIA

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Surface water and ground water suitability for various purposes is largely determined by the kind and composition of dissolved substances in the water. Surface water is more easily accessible than groundwater and also more prone to contamination than groundwater. The contamination of groundwater has been caused by human activities, growing population growth, industrialization, urbanization, and other human activities. This is despite the fact that groundwater is often better protected than surface water. When groundwater is contaminated, it becomes a challenging endeavor to locate and remove the substances that have caused the contamination. As a result, it is essential to conduct regular evaluations of the quality of groundwater in order to ensure its protection. This makes it possible to quickly identify all of the possible sources of contamination, which in turn makes it easier to carry out the measures that are necessary to safeguard groundwater from future contamination. Groundwater is an essential resource that is found all over the globe and plays an important part in the maintenance of ecosystems, agricultural operations, and the well-being of people. Assessing and protecting the quality of groundwater is particularly important for maintaining life in areas that have limited access to water resources, such as the Champhai and Mamit Districts in the Indian state of Mizoram. A location that is facing challenges with water scarcity is the impetus for this study since there is an urgent need to find solutions to water quality concerns. In some regions where there is a scarcity of surface water, groundwater is an essential source of drinkable water that may be used for drinking. As a consequence of human activities, contaminants are introduced into the groundwater, which leads to an imbalance. The objectives of the present study are (i) enhancing the management and quality control of regional groundwater resources, (ii) addressing current groundwater quality challenges while providing stakeholders with insights into future patterns, and (iii) improving operative groundwater protection and management techniques.

A seasonal evaluation of physicochemical features, heavy metal analysis, and microbiological analysis is performed in order to get an understanding of the quality of groundwater and to identify the degrees of contamination according to the guidelines set out by the WHO and BIS. In each of the two groundwater samples, the presence of faecal coliforms as well as total coliforms was found. Both of the groundwater samples were found to contain trace amounts of heavy metals such as arsenic, cadmium, chromium, and iron. Through the use of the Weighted Arithmetic Water Quality Index (WAWQI) methodology, the study endeavors to determine the Groundwater Quality Index (GWQI), which is used to assess the quality of groundwater for drinking purposes. The use of a consistent index makes it possible to identify changes in the trends of water quality and to identify potential areas of concern or improvement in relation to drinking water systems. In light of the consequences of climate change and the expanding population, the need of protecting groundwater resources has become even more pressing. Due to the fact that there is a lack of water, the hilly topography of Mizoram provides further evidence of the critical need of conserving the quality of groundwater. The results help to improve the management and quality control of regional groundwater resources. The use of the results will be a significant advancement that not only tackles the existing problems with groundwater quality but also offers stakeholders insights into the patterns that may emerge in the future. The study helps to lead sustainable groundwater resource management in the area, which paves the way for a future in which the availability of safe and clean groundwater has a significant impact on quality of life. This, in turn, enables decision-makers to design policies for the preservation of groundwater quality. In this particular setting, it is of the utmost importance to emphasize the need of increasing awareness about the degradation of the quality of groundwater. Furthermore, the local authorities in the water-scarce regions of Champhai and Mamit District in Mizoram, India, are interested in implementing preventive measures in order to improve the overall quality of the groundwater resources situated in these areas.

Keywords: *Climate change, contaminants, groundwater, sustainability, pollution, water quality*

GEOCHEMICAL ASSESSMENT OF GROUNDWATER CONTAMINATION WITH SPECIAL EMPHASIS ON FLUORIDE CONCENTRATION IN SONO RIVER BASIN, BALASORE DISTRICT, ODISHA, INDIA

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Groundwater rich in fluoride is well-known in aquifers of granitic terrain in India. Nevertheless, a detailed investigation is essential to explain the behavior of fluoride in natural water resources, taking into account regional hydrogeological conditions, climatic influences, and agricultural activities. This study examines the content of fluoride in groundwater of Sono River Basin in the Balasore district, Odisha, with the aim of understanding the spatial distribution of fluoride and identifying the geochemical parameters contributing to its dissolution. Balasore district is one of the thickly populated districts of the Odisha state in Eastern India. The study area falls under Survey of India toposheet no 73K/10, 11 and 14. Climatic condition is tropical to subtropical with hot summer, high and well disturbed rainfall during monsoon and cold winter. The drainage is controlled by Sono River and its tributaries and distributaries. The drainage pattern is mostly dendritic to sub-dendritic. The groundwater generally occurs through fracture, fissure and consolidated basement rock formations with shallow levels during pre and post monsoon period. Nilgiri granites of Archean age are the primary rock types in the study area. These rocks are weathered moderately in the valley areas of the terrain. For 2,321,419 residents in that area, groundwater serves as their primary supply of drinking water. The study area belongs to Balgopalpur industrial estate. A total of 35 groundwater samples were collected during pre-monsoon season of 2024. The quality of water was evaluated by estimating pH, EC, total dissolved solids (TDS), total hardness (TH), major cations like sodium (Na^+), potassium (K^+), calcium (Ca2+), magnesium (Mg2+) and anions like Bicarbonate (HCO3-), chloride (Cl-), sulphate (SO42-), Fluoride (F-) and Nitrate (NO3-). Measurements of physical parameters like pH, EC and TDS were carried out in-situ by pH and EC meter. The groundwater samples were analyzed using standard techniques (APHA 2012).

Chemical analysis results reveal that the groundwater is severely contaminated with fluoride ions and 45% of samples have higher content than prescribe WHO standards (≤1.5mg/l) for domestic uses. The fluoride content ranges from 0.5 to 5.90 mg/l with an average of 2.34mg/l. The higher concentration is seen near Kuanpur, Chakulia, Hatiagand, Balipal and Bhimeswar villages. The pH of the groundwater samples varies from 7.1 to 8.5 with an average of 7.8 which indicates alkaline character of groundwater. Besides that, most of the samples with respect to TDS, calcium, magnesium, chloride, sodium, potassium, nitrate, sulphate and iron have values of more than the acceptable limit of BIS (2012) rendering them unfit for drinking purpose. From the statistical analysis cations shows dominance of Na> Ca> Mg> K and anion dominance is in the order of HCO_3> Cl> NO_3> SO_4. From the statistical analysis it is observed that fluoride has positive correlation with bicarbonate and pH and negatively correlated with calcium. Sample location, geological, geomorphological, structural, LULC, spatial distribution maps of different chemical parameters and isoconcentration maps were prepared in ArcGIS10. From this application the spatial variation of fluoride content has assessed that helped in demarcation high fluoride areas. Also, GIS is used to delineate the groundwater potential zone. The Gibbs diagram reveals that the chemistry of groundwater is principally influenced by weathering characteristics of rocks. The groundwater samples are plotted in the Piper Trilinear diagram. Higher concentration of fluoride is observed in Na-HCO_3 facies of groundwater. The important processes responsible for transportation and mobilization of fluoride into the groundwater are decomposition, dissociation, and dissolution. The study indicates that fluoride ions predominantly originate from the dissolution of fluoride-bearing minerals such as fluorite, apatite, biotite, and hornblende present in the granitic bedrock, particularly under alkaline conditions. Secondary sources contributing to fluoride contamination include domestic and industrial effluents, as well as return flow from irrigation, which contains components of phosphate-based fertilizers. Communities consuming non-potable water with elevated fluoride levels may experience health issues such as dental fluorosis, skeletal disorders, and accelerated aging. Groundwater being the sole source of drinking water, high fluoride causing obstruction in water supply schemes. De-fluoridation based on latest technology i.e. reverse osmosis system and adsorption technology should be provided in the area having higher concentration of fluoride in drinking water. Also, rainwater harvesting and artificial recharge structure will achieve the dual purpose of resource augmentation and quality improvement. Alternate defluorination methods include passage of water through a matrix where the fluoride ions are selectively trapped inside the bed. It is suggested that people living in the study area should use activated alumina domestic de-fluoridation filters to remove fluoride.

Keywords: *Fluoride, water quality, hydrochemistry, geochemical, Sono River basin, groundwater*

ANALYSIS OF THE QUALITY, AND IDENTIFICATION OF THE SOURCES OF IONS IN THE GROUNDWATER- A CASE STUDY IN SILIGURI AND MATIGARA BLOCKS, DARJEELING DISTRICT, WEST BENGAL, INDIA

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A systematic study of groundwater quality has been carried out for the areas of Siliguri and Matigara Blocks of West Bengal, India. Groundwater samples were collected from thirty-three wells and analyzed for various physio-chemical parameters such as conductivity, Total Dissolved Solids (TDS), pH, salinity, Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, and NO_3^- in the laboratory to determine the quality of the groundwater in the study site. All the physio-chemical analysis of the samples was carried out according to the standard procedure of APHA. TDS, pH, salinity, and conductivity have been analyzed using a portable water analyzer. Ca^{2+} and Mg^{2+} were analyzed using the EDTA titration method, Na^+ and K+ were measured using flame photometry, and Cl was analyzed using the argentometric titration method. $SO_4^{2-}$and NO_3^- were analyzed using UV Photospectrometer. The analytical results indicate significant cations as $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$, and anions as $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. To know the suitability of water for drinking purposes, all the analytical parameter results were compared with WHO and BIS drinking water standards. The highest and lowest values of the salinity were noted at Mathapari and Pradhan Nagar, which are 0.05 ppt and 0.45 ppt, respectively, with an average value of 0.17 ppt. The minimum and the maximum pH values have been noted for the places of Dagapur and Subhas Pally with values of 5.77 and 7.0, respectively, with an average value of 6.26. The maximum value of TDS was observed as 421 mg/l at Pradhan Nagar, and the minimum value as 55 mg/l at Subhas Pally, and its mean value is 167.24 mg/l, which is indicated within the permissible limit of drinking water standards. The concentration of Ca^{2+} ranges between 4 (at Mathapari) and 32 mg/l, (at Champasari) with an average value of 13.14 mg/l. Mg^{2+} concentration ranges from 2.4 (at Mathapari) to 24.8 (at Pradhan Nagar) with a mean value of 9.73 mg/l. The concentration of Na^+, which is more predominant than Ca^{2+} and Mg^{2+}, has the lowest value of 2 mg/l, which was observed at Uttarayon twp, and the highest value of 68 mg/l is observed at Pradhan Nagar and its mean value is 22.82 mg/l. The results of the bivariate plot and coefficient correlation show that the K+ contamination might be from both anthropogenic (such as pesticide usage in agricultural lands) and geogenic sources. The minimum (16.8 mg/l) and maximum (100.8 mg/l) amounts of HCO_3 were obtained at the sample locations of Mathapari and Pradhan Nagar, respectively with mean values of 49.68 mg/l. NO_3^- ranges from 0.0268 mg/l to 2.61 mg/l at the places of Champasari and Bara Gharia, respectively, with an average value of 0.4 mg/l.

Based on the Piper diagram, the maximum number of samples fall under Na-Cl type (16 samples), followed by $Ca\text{-}Cl_2$ type (9 samples), and the mixed type (8 samples). Gibbs plot exhibits that most of the samples (24 samples) belong to the evaporation-precipitation domain, and few samples fall under the rock-dominance domain. To know the irrigation suitability of the waters, the following indexes as Residual Sodium Carbonate (RSC), Kelly's Index (KI), Total Hardness (TH), Sodium percentage (Na%), and Sodium Adsorption Ratio (SAR) were used and results were obtained from the analytical data. According to RSC, all

the samples fall under the safe class (less than 1.25) and Kelly's Index, the sample ranges from 0.025 (Champasari) to 3 (Shanti Nagar) with a mean value of 0.08; most of the samples (except 11 samples) having a value of less than 1. It reveals that the groundwater is suitable for irrigation. The range of total hardness varies from soft to hard, where most of the samples (23 samples) fall under the class of soft, a few samples (9 samples) falling in the moderate class, and one sample falls in the hard class. The samples of the study region showed a wide range of variation in terms of Na% with 2 samples falling under the excellent category, 7 samples under the good category, 15 samples under the permissible category, 8 samples under the doubtful category, and 1 sample was noted as falling under the unsuitable category. The Sodium Adsorption Ratio (SAR) value varies from 0.095 (Champasari) to 4.85 (Shanti Nagar) and indicates that all the samples belong to the excellent range. Based on GWQI (Ground Water Quality Index), the groundwater quality of the study region was categorized as excellent to good water quality.

Keywords: *Groundwater quality, water quality index, irrigation suitability, hydro-geochemical facies, Darjeeling district*

A HYDROGEOCHEMICAL APPROACH TO EVALUATE THE GROUNDWATER QUALITY IN THE COASTAL AQUIFERS OF NORTH EASTERN PART OF ODISHA, INDIA

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Odisha, a coastal state in eastern India, has significant coastal aquifers that supply freshwater to various regions. The coastal aquifers of Odisha encounter severe threats from urbanization and pollution, compromising their quality, quantity and sustainability. There is a high population density and significant agricultural activity in these regions, and the need for freshwater is always rising. They are extremely vulnerable to various natural processes locally and regionally such as climate change, sea level changes, storm surges, coastal erosion, floods, etc. The coastal aquifers are also vulnerable to groundwater pollution due to anthropogenic activities, reflecting in seawater intrusion, depletion of the static water levels, and infiltration of industrial and agricultural pollutants. Coastal aquifer systems have unique geological and hydrogeological settings posing difficulties in managing groundwater supplies. Therefore, an attempt has been made to evaluate the groundwater quality and to identify the probable zones of contamination on the eastern coastal regions of Odisha.

The present study focuses on Matei River Basin, a part of Bhadrak district, situated in the north-eastern part of Odisha along the stretch of Bay of Bengal. Bhadrak is bounded by Jajpur district on its south, Keonjhar district on its west and by Bay of Bengal on the east. There are 4 major distinct geomorphic units in the study area- inter tidal zone, coastal plain, alluvial plain and flood plain (CGWB,2017). It experiences humid tropical climate with an average temperature of 27ºC (CGWB,2017). The study area receives an annual rainfall of 1431 mm with a maximum rainfall during southwest monsoon (SWM). Agriculture is the main occupation and maximum area comes under agricultural landuse. Paddy is grown as main crop in Kharif. Due to high population density, there is enormous stress on groundwater resources. Few aqua culture ponds are also present the northern most part of the study area. The vast alluvial deposits form the main repository of groundwater in the study area. Alluvium of recent deposits forms the main rock type of the study area. These deposits consist of clay, sand, silt and gravel. A total of 80 groundwater samples were collected during pre-monsoon season (April, 2024) from the study area. Using mobile pH and EC meters, the physical variables, such as pH and electrical conductivity (EC), were measured on-site. Further the pH and EC of each sample were analysed in laboratories for accuracy and precision. The electrical conductivity (EC) in µS/cm was multiplied by 0.65 to determine the total dissolved solids (TDS) (Subba Rao, 2017). Murexide and Eriochrome black T solution as indicators, titration techniques were used to measure the concentration of calcium (Ca^{2+}) and total hardness (TH) using standard EDTA solution. $TH = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$ was the formula used to calculate magnesium ($Mg^{2+)}$ from the total hardness and Ca^{2+} values (Todd, 1980). Using potassium chromate, bromocresol green, phenolphthalein, and methyl orange indicators, respectively, titrations with silver nitrate solution and sulfuric acid were used to quantify the levels of chloride (Cl^-), total alkalinity (TA), and bicarbonate (HCO^{3-}). A flame photometer was used to measure the amounts of potassium (K^+) and sodium (Na^+). A UV-visible was used to measure the levels of sulphate ($SO_4{}^{2-}$), nitrate (NO_3^-), and fluoride (F^-). The major cation and anion analysis was done following the standard procedure maintaining an ionic balance error between 5 to 10%.

Statistical analysis of all physico-chemical parameters and its comparison with WHO (World Health Organization) and BIS (Bureau of Indian standard) drinking water standard was carried out to identify the number of samples exceeding the standard and the suitability of groundwater for drinking purpose. Considering the average value of chemical constituents (Table 2), the order of dominance is identified for cations as $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and for anions as $HCO_3{}^- > Cl^- > NO_3{}^- > SO_4{}^{2-} > F^-$. The Domestic Water Quality Index (DWQI) was calculated to understand the suitability of groundwater for drinking water purpose, and it is inferred that most of the samples represent under bad category and groundwater is unfit for drinking in the central part of the study area. Irrigation water quality index (IWQI) was calculated using five parameters namely SAR, RSC, EC, Na% and Kelly's ratio (KR). The weighted overlay analysis was performed by compiling parameters like SAR, EC, Na^+, Cl^- and $HCO_3{}^-$ to identify the regions suitable for irrigation water quality. It is identified that most of the samples are suitable for irrigation purposes, except for a few in the central part of the study area (Fig.3). Further, it is confirmed by Wilcox diagram that most of the samples fall under permissible to doubtful category. Three major water types were identified from the Piper's Plot (Piper 1944) such as Ca-Na-HCO_3 type, Na-Cl type and Mg- HCO_3 type. Geo-statistical analysis was performed to identify the factors influencing the groundwater composition. Factor 1 is represented by loadings of EC, magnesium, sodium, chloride and sulphate which infers saline water ingression along the coastal tract of the study area. Factor 2 has high positive loadings of sodium, potassium, bicarbonate and pH reflecting the process of weathering. Factor 3 has high positive loading of fluoride which might be due to anthropogenic activities. Thus, it is concluded that saline water ingression, weathering and anthropogenic activities are the major factors influencing the groundwater chemistry of the study area.

Thus, the study infers that the groundwater is not suitable for drinking purpose but could be used for irrigation with caution in certain places. Further the major factor controlling the chemistry of the region is seawater intrusion. To accomplish the sustainable development goal, more research into the fit for purpose could improve groundwater's utility for other uses.

***Keywords**: Groundwater quality, coastal aquifers, DWQI, IWQI, geo-statistics*

TRENDS IN GROUNDWATER QUALITY AND HEAVY METAL POLLUTION IN HARIDWAR DISTRICT, UTTARAKHAND, INDIA: A CALL FOR SUSTAINABLE MANAGEMENT

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This study investigates the quality of groundwater and its suitability for drinking in the Haridwar district of Uttarakhand, India, utilizing the Water Quality Index (WQI) and assessments of heavy metal pollution. Haridwar district encompasses an area of 2,360 km², characterized by diverse geological formations, including the Siwalik Range and the alluvial plains of the Bhabar region situated in the southwestern part of Uttarakhand. These unique geographical features contribute to the hydrological dynamics of the area, making it essential to evaluate groundwater quality, especially given the rapid urbanization and industrialization that have intensified in recent years. As urban development and industrial activities expand, concerns regarding groundwater contamination have increased significantly. The discharge of untreated and treated wastewater into the environment has raised alarms about the accumulation of heavy metals in groundwater, posing serious health risks to local populations. This study aims to provide a comprehensive assessment of groundwater quality in Haridwar, focusing particularly on the presence of heavy metals and the potential health risks associated with their consumption.

Groundwater samples were systematically collected from various locations across the district over three years (2021 to 2023). The samples were analyzed for a range of physicochemical parameters, including pH, electrical conductivity, carbonate, bicarbonate, chloride, fluoride, sulfate, and nitrate. Additionally, major cations such as calcium, magnesium, sodium, and potassium were measured. The analysis also included heavy metals such as iron (Fe), manganese (Mn), zinc (Zn), Copper (Cu), Arsenic (As) lead (Pb) and Uranium (U). These analyses were conducted at the Central Ground Water Board (CGWB), NR, Lucknow Laboratory, utilizing standard procedures to ensure reliability and accuracy. Chemical analysis of groundwater constituents in Haridwar involves various standardized methods. pH and electrical conductivity are measured using pH and EC meters, respectively. Carbonate and bicarbonate are quantified through titrimetric methods, while chloride is assessed using Mohr's method. Other ions, such as fluoride, nitrate, and sulfate, are analyzed via spectrophotometry, sodium and potassium levels are determined using flame emission photometry.

The results indicated a predominance of magnesium bicarbonate-dominated water, as represented in the Piper diagram, with alkaline earths exceeding alkalis and weak acids surpassing strong acids. The Durov diagram revealed that reverse ion exchange processes dominate the area, suggesting significant rock weathering influences along with some evaporation and crystallization effects. These geochemical processes underscore the freshwater recharge nature of the groundwater in Haridwar. The WQI was employed to categorize water quality into several classifications: excellent, good, poor, and very poor. This index serves as a valuable tool for stakeholders and policymakers, facilitating a clearer understanding of the groundwater conditions. The results revealed significant variations in groundwater quality over the three-year period. In 2021, the WQI values ranged from 35 to

111. Notably, 26.2% of the samples were classified as good quality, while 45.23% and 26.19% were categorized as poor and very poor, respectively. Alarmingly, 2.38% of the samples were deemed unfit for drinking. These findings highlight the concerning state of groundwater quality in Haridwar at the outset of the study. By 2022, the WQI values exhibited a range from 32 to 240. This year saw a marked improvement, with 40.53% of the samples classified as good quality. However, despite the positive trend, 19% of the samples remained unfit for consumption. This suggests that while some areas experienced improvements, significant pockets of contamination persisted, necessitating ongoing monitoring and intervention. The year 2023 showed a further decline in groundwater quality, with WQI values ranging from 38 to 404. In this year, only 31.72% of samples were classified as good quality, while 43.9% and 12.19% fell into the poor and very poor categories, respectively. A notable concern is that 12.19% of the samples were entirely unfit for drinking, particularly in certain regions of the district. This downward trend in water quality raises alarms about the sustainability of groundwater resources and the health implications for local communities.

In addition to assessing overall water quality, the study evaluated heavy metal contamination using the Heavy Metal Pollution Index (HPI). This index provides a quantitative measure of the impact of heavy metals on groundwater quality. The analysis revealed that most samples in both 2022 and 2023 fell under the low pollution category. In 2023, only one sample exceeded acceptable pollution levels, indicating localized issues that necessitate further scrutiny. In 2022, the pollution levels were similarly low, with just one sample classified as medium pollution. In 2021, all samples remained well below risk thresholds, suggesting that heavy metal contamination was less pronounced at that time. Moreover, the Heavy Metal Evaluation Index (HEI) was utilized to assess the overall quality of groundwater concerning heavy metals. In 2023, the analysis indicated that 65.85% of samples fell under the low HEI category, while 14.63% and 19.52% were categorized as medium and high risk, respectively. In 2022, 59.52% of samples were classified as low HEI, with 21.42% and 19.06% falling into medium and high categories. In 2021, 53.48% of samples were classified as low HEI, while 11.63% and 34.89% were medium and high, respectively. High risk zones are mostly restricted in the Bahadrabad, Khanpur, Laksar and parts of Bhagwanpur blocks of the Haridwar district. These results highlight a troubling trend of increasing heavy metal risk over the study period.

The study highlights the overall poor groundwater quality in the Haridwar district over the past three years, as indicated by WQI assessments. The analysis demonstrates that while some improvements have been made, the overall trend points to a concerning decline in water quality, particularly in 2023. Although the HPI indicates a predominance of low pollution levels, the troubling trends in both WQI and HEI underscore the urgent need for continuous monitoring and comprehensive management strategies to ensure safe drinking water availability in the region. The findings of this research underscore the critical importance of implementing sustainable water management practices to mitigate the adverse effects of urbanization and industrial growth on groundwater resources. Policymakers and local authorities must prioritize efforts to enhance wastewater management, reduce pollution sources, and invest in community awareness programs to safeguard public health. Continued research and monitoring will be essential to track groundwater quality trends and address emerging contamination challenges effectively.

Keywords: *Durov Diagram, groundwater, heavy metal, risk assessment, water quality*

EVALUATION OF HYDRO CHEMICAL CHARACTERISTICS AND HEAVY METAL CONCENTRATION OF GROUNDWATER AT KALPAKKAM COASTAL SITE, TAMILNADU, INDIA

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The chemical composition of groundwater is essential for evaluating water quality. In unpolluted systems, major ions in groundwater originate from the weathering of rocks. The water quality of a region is influenced by various factors such as geology, weathering regime, the quality and quantity of recharge water and water-rock interaction. Rapid industrialization and activities like agriculture can elevate the concentration of various ions and trace elements in groundwater, leading to a decline in water quality. Over exploitation of groundwater can result in diminished water quality, as increased salinity levels may arise near the terminus of groundwater flow lines. The intrusion of seawater into inland aquifers due to the over-exploitation of groundwater in coastal areas represents a major environmental issue. Investigating the sources of saline water and their mobility mechanisms is crucial for the sustainable development of coastal groundwater resources. Environmental hazards cannot be entirely prevented or controlled; however, they can be mitigated through appropriate measures such as effective land use planning, development, and management. Therefore, this study aims to identify the sources of salinity and the mechanisms by which they migrate into groundwater, with the goal of developing effective management strategies to address salinity issues in the studied region. The study area is located between Chennai and Pondicherry on the southeast coast of India. The site is bounded by Bay of Bengal on the eastern side, the Buckingham Canal on the north western side and agricultural fields on the western side. The physicochemical characteristics and heavy metal concentrations in the groundwater of the coastal region of Kalpakkam, Tamil Nadu were examined during the pre-monsoon and post monsoon seasons. Cations and anions were determined using ion chromatography. The concentration levels of six heavy metals (Zn, Cd, Pb, Cu, U and Fe) in the groundwater were analyzed through the analytical procedures of Voltammetry (Zn, Cd, Pb, Cu and U) and UV Spectrometry (Fe). The cations were present in the descending order of sodium > calcium > magnesium > potassium and anions as chloride > bicarbonate > sulfate > nitrate. pH and alkalinity were observed to be higher in post-monsoon season. Electrical conductivity and total dissolved solids of ground water samples was observed to be less during post monsoon as compared to pre monsoon. Total dissolved solids, total alkalinity and total hardness exceeded the guideline values in majority of wells in both the seasons. The concentration of fluoride in the studied region was observed to be less than the optimal range prescribed by WHO. In the study area's groundwater, chloride is the most abundant ion. A strong correlation of Cl^- with Ca^{2+}, Mg^{2+} and Na^+ indicates that these ions have same origin. Sodium and chloride are substantially positively correlated in correlation matrices, indicating an increased mixing influence of seawater. When compared to the Piper and Chadhas diagrams, it is clear that the bulk of groundwater samples are in the sodium and chloride zones particularly during pre-monsoon period. The Na–Cl and Ca-Mg-Cl water type were the most dominant water types observed in the study region followed by the Ca-Mg–HCO3 water type. Simpson's ratio and chloroalkaline indices also demonstrates that the interaction between seawater and groundwater in the study area is a major factor in the aquifer's contamination by seawater intrusion. The study also tries to explore the applicability of chloride to bromide ratio in understanding freshwater saline interface in coastal region. The concentration of bromide in seawater is around 65 ppm while that of the water samples collected in our study area ranged from 0.68 to 6.86 ppm. The chloride to bromide ratio of ground water samples in the study area ranged from 55 to 305 whereas the same for seawater was 288. The concentration of studied heavy metals was found to be well within the stipulated guideline values. The concentration of zinc was found to be in the range of 80-200 ppb which is much below the permissible limit of 5 ppm. Cadmium was below detection limit of 0.02 ppb in most of the samples analysed. The Uranium levels in most of the samples were below detection limits (1 ppb) except for the samples collected from sources close to agricultural fields where the concentration was found to be in the range of 1 to 5 ppb. This could be attributed to the usage of fertilisers. The concentration of heavy metals was found to be high in pre monsoon period as compared to post monsoon period. In order to prevent seawater intrusion in the study region, appropriate preventive measures are required. It is recommended that adequate recharge structures be built, the current pumping rate be reduced, pumping wells be relocated, and intrusion barriers be built to restore groundwater quality.

Keywords: *Ground water, trace elements, ionic ratio, seasonal changes, water quality*

ROLE OF GEOLOGY AND GEOMORPHOLOGY IN ARSENIC DISTRIBUTION IN GROUNDWATER OF THE CACHAR FOLD BELT, BARAK VALLEY ASSAM, INDIA

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Geological, hydrogeological, and human activities can interact in complex ways to influence the levels of arsenic in groundwater. In Northeastern States of India, understanding the prevalence of arsenic contamination is essential for effective water resource management. The study was conducted to explore the influence of various geological-geomorphological features scattered throughout the Barak Valley region in the Cachar Fold Belt (CFB) in Assam on the occurrence and distribution of arsenic in groundwater. Geologically, CFB is situated in between two orogenic belts i.e., the Himalayan to the north and the Indo-Myanmar range to the southeast. The CFB is characterized by a thick pile (10–11 km) of sedimentary deposit (upper Cretaceous to Cenozoic) folded into a series of NNE–SSW trending, sub-parallel and highly faulted anticlines and synclines. Hydrgeologically, the valley has unconfined and semi-confined to confined type of aquifer. The major aquifers are Quaternary alluvium and Tertiary sandstone. Geomorphologically, the region represents a ridge and valley province with meridional to sub-meridional anticlines and synclines. The main valleys of the region are the Silchar-Dhalai, Hailakandi-Lala and Anipur Valleys. The geological-geomorphological units are classified as Younger Alluvium (YA), Older Alluvium (OA) and Tertiary Formation based on remote sensing, hydrogeology and field observations.

Geographic Information System (GIS) platform was used to study the lateral and vertical extensions of the aquifer and to delineate aquifers. Three aquifer disposition sections are prepared using Rockworks software for the three valleys in the region. Critical analyses of data obtained from the groundwater exploration programme by Central Ground Water Board helped in identifying two distinct aquifer groups in the area: Aquifer Group I (AG-I, depth 0 to 30 mbgl) and Aquifer Group II (AG-II, from 30-50mbgl upto 300 m bgl). Groundwater samples were collected from different aquifers to study the difference in chemical quality. Each sample was analyzed for a range of physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, Na^+, K^+, Ca^{2+}, Mg^{2+}, total hardness, bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), total alkalinity, sulfate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-) and heavy metals such as iron(Fe) and arsenic(As) using standard methodology. The principal component analysis (PCA) technique was used to interpret the relationships with specific processes influencing water quality.

There is a striking difference between the hydrochemistry of groundwater from Tertiary Formation and the Alluvium. The groundwater of YA and OA are classified as magnesium-bi-carbonate type facies, while the groundwater of Tertiary Formation is classified to be of mixed type facies. The groundwater from the YA exhibits a higher concentration of iron than the OA and Tertiary formations. Chemically, the groundwater in YA and OA has HCO_3^- of 143.49 mg/L and 123.28mg/L respectively. The groundwater of YA is characterized by high HCO_3^-. The iron concentration in the groundwater of YA, OA and Tertiary Formation is 7.68 mg/L,

5.05mg/L and 3.7mg/L respectively. High Arsenic concentrations (12-97 µg/L) have been detected in the groundwater of the region. Approximately 24% of the groundwater samples from YA show arsenic concentrations above the permissible limit of 10 µg/L set by BIS. In contrast, the average arsenic concentrations in groundwater from the OA and Tertiary formations are 6.58 µg/L and 9.03 µg/L, respectively. The OA sediments have a relatively lower arsenic load compared to the YA and Tertiary formations, indicating that groundwater in the YA area is more susceptible to arsenic contamination (>10 µg/L) than that in the OA and Tertiary formations. PCA was applied using ten components, viz., HCO_3^-, Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, *Fe* and *As*. The analysis rendered four significant PCs (PC1, PC2, PC3 and PC4), explaining 72.99% of the total variance of the data set. PC1 explains the contribution of rainfall infiltration and seepage from surface water bodies. High loadings of *As* and *Fe* in PC2 indicate a similar geochemical origin. PC3 is indicative of the dissolution of silicate minerals. The cross plot of Arsenic versus depth suggests that the tube wells tapping AG-II have comparatively less As load, possibly indicating that the contamination is confined in the upper part under the influence of the local-scale groundwater flow regime. As and Fe show a strong positive correlation in the samples of YA. The region beneath YA is characterized by numerous swamps, cutoff channels, oxbow lakes, and other waterlogged areas, which act as locations for biomass accumulation. Infiltration from these water bodies carrying organic carbon contributes to vertical groundwater percolation. The shallow aquifer in this region is prone to elevated arsenic levels when organic matter is introduced, likely promoting microbial respiration and the reductive dissolution of iron oxyhydroxides. This process releases arsenic adsorbed in oxyhydroxides and Fe^{2+}, resulting in a positive correlation between *As* and *Fe* in groundwater. Additionally, HCO_3^- ions are released into the groundwater during this process, establishing a relationship between arsenic and HCO_3^- in the shallow aquifers of YA. The present study indicates that the geomorphology, hydrogeology, hydrochemistry, organic matter and the depth of the aquifer play a significant role in the mobilization of arsenic in groundwater.

Keywords: *Geology, geomorphology, arsenic contamination, Cachar fold belt, Barak valley, groundwater quality, younger alluvium*

HYDRO-CHEMICAL CHARACTERIZATION OF GROUNDWATER AND ASSESSMENT OF WATER QUALITY FOR DRINKING AND AGRICULTURAL USE IN AND AROUND URANIUM-CONTAMINATED AREAS OF GWALIOR, CENTRAL INDIA

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This study investigates elevated uranium levels in groundwater in specific areas of the Gwalior district, Madhya Pradesh, within the context of broader occurrences across India, particularly in the Indo-Gangetic Basin and central and southern regions. It offers a comprehensive analysis of groundwater quality for drinking and agricultural use, comparing findings with established safety standards. The study examines potential sources of uranium contamination, linking its presence to factors such as fertilizer application, nitrate pollution, climate, and local geology. Additionally, it explores uranium's correlation with bicarbonate levels. Addressing immediate water quality concerns, the study suggests that natural geological and petrological processes may be primary sources of uranium, emphasizing the need for sustainable groundwater management strategies in the affected areas.

The study region is located within Gwalior district, Madhya Pradesh, and is covered by Survey of India topographical sheets 54-J/3, 54-J/4, 54-J/7, and 54-J/8. Physiographically, it falls under the Central Highland division, specifically the Central India Plateau subdivision. Groundwater quality, including key parameters and trace metals like uranium, was evaluated in both pre-monsoon and post-monsoon seasons across 99 locations, with a grid size of 5 x 5 sq. km. Basic parameter analysis was conducted at CGWB's Regional Chemical Laboratory in Bhopal, and trace metal analysis at the Chandigarh lab using ICP-MS. Data accuracy for ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, NO_3^-, SO_4^{2-}, and F^-) was within a 5% margin, verified by the charge balance error. Hydrochemical characteristics, water chemistry mechanisms, hydrochemical facies, and ion sources were analyzed using various graphical and statistical tools, including ionic ratios, Piper, and Gibbs diagrams. Hydrochemical facies were used to classify water types and dominant ions. Water suitability for drinking was assessed through the NSF-WQI, focusing on 12 primary parameters (e.g., pH, TDS, TH, Ca^{2+}, and Mg^{2+}), grading water from excellent to poor quality. For agricultural suitability, indices like SAR, RSC, SSP, MH, and KI were applied.

To examine spatial and temporal variations, ion concentration datasets (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, NO_3^-, SO_4^{2-}, F^-, Mn, Ni, Pb, Fe, and U) for both pre-monsoon and post-monsoon seasons were analyzed using systematic techniques and to assess drinking water quality, the study applied BIS standards to groundwater parameters across the study area. Basic analysis indicated that no location exceeded the BIS pH limit of 8.5. Electrical conductivity (EC) ranged from 751 to 1500 µS/cm in most samples, with some areas showing EC < 3000 µS/cm. Exceeding nitrate levels (>45 mg/l) were observed at 19.19% of locations in the pre-monsoon season and 45.45% in the post-monsoon season. Fluoride concentrations surpassed the BIS limit (1.5 mg/l) at 16.16% of locations in pre-monsoon and 8.8% in post-monsoon, while one site recorded phosphate beyond the WHO limit (1.0 mg/l) in the pre-monsoon

only. Additionally, total hardness (TH) exceeded 600 mg/l at 4.44% of locations in the post-monsoon season. Results showed elevated post-monsoon concentrations for nitrate, silica, TH, calcium, and potassium, with minimal seasonal variations in pH, EC, alkalinity, chloride, sulfate, fluoride, phosphate, and sodium.

Trace metal analysis found no chromium, copper, selenium, or arsenic pollution but identified partial contamination from manganese, nickel, lead, and iron. Uranium concentrations exceeded the BIS limit (30 µg/l) at 29.29% of locations in pre-monsoon (max 944.9 µg/l) and 27.27% in post-monsoon (max 207.8 µg/l), with 11 sites above the AREB limit (60 µg/l). Factors for uranium mobilization included hydrogeological, geological, climatic, nitrate pollution, and fertilizer use, showing a positive correlation with bicarbonate.

The Piper trilinear diagram categorized the region's water as Ca-Mg-HCO_3 type, with Na^+ and HCO_3^- dominating at most sites. Temporary hardness was found in about 50% of samples, with mixed-type waters in the remainder. Gibbs' model indicated that groundwater chemistry is influenced by rock-weathering, increasing salinity and reducing quality. The assessment of agricultural indices for groundwater in the study area showed that nearly all samples fall under the S_1 category for SAR, indicating an excellent sodicity index. Over half of the samples had Residual Sodium Carbonate (RSC) values below 1.25, making them safe for irrigation. Most samples also had a Soluble Sodium Percentage (SSP) under 60%, supporting their suitability for irrigation. Additionally, the majority of samples fell into the 'Permissible' range based on % Na and had a Permeability Index between 25-75%, which is favorable for irrigation. However, samples were unsuitable according to the Magnesium Hazard (MH) and Kelly Index (KI). The USSL Staff diagram placed most samples in the C_3-S_1 class, denoting high salinity but low sodium. Water Quality Index (WQI) analysis classified 60% of the locations as good for drinking and 32.32% as fair.

In summary, the magnesium levels were found to be higher in the pre-monsoon season, while nitrate, silica, total hardness, calcium, and potassium concentrations increased post-monsoon. Parameters like pH, EC, alkalinity, chloride, sulfate, fluoride, phosphate, and sodium showed minimal seasonal variation. Concentrations of chromium, copper, arsenic, and selenium remained within safe limits, indicating minimal pollution impact. However, uranium concentrations exceeded BIS limits in some samples, with no significant seasonal difference, and were correlated with nitrate and bicarbonate levels. The Piper trilinear diagram identified the water type as Alkaline Earth-Bicarbonate (Ca-Mg-HCO_3) in both seasons, with sodium (Na^+) and bicarbonate (HCO_3^-) as the dominant ions in most locations. About 50% of samples showed temporary hardness, while others had mixed water types. According to Gibb's model, rock-weathering processes influence groundwater chemistry year-round, increasing salinity and lowering water quality.

Keywords -*Uranium, Gwalior, NSF-WQI, agricultural quality indices, Gibb's model*

APPLICATION OF RICE HUSK MODIFIED BIOCHAR FOR GROUNDWATER REMEDIATION

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The utilization of surface-modified biochar composites in hydrological applications represents a growing area of scientific inquiry. Preliminary investigations indicate that rice husk-derived biochar exhibits effective bio-sorbent efficiency for heavy metals and micro-pollutants, while also contributing to carbon sequestration in both soil strata as well as groundwater sources. Furthermore, the integration of acid-modified biochar composites shows remediation potentials for environmental contaminants, along with low cost, high carbon content, and enhancement of overall density of treated biochar. The price of modified biochar is also known to be almost half of activated carbon, and its adsorption capacity is much higher compared with other cheap adsorbents such as Zeolites and modified clay composites. This makes the chemical-modified biochar suitable as a promising material for large-scale environmental remediation projects. Despite existing studies on biochar's application in groundwater remediation, there remains a significant gap in understanding the long-term stability and regeneration potential of modified biochar composites. Moreover, the interaction mechanisms between these composites and diverse groundwater contaminants under varying environmental conditions have been inadequately explored. Addressing these gaps is crucial to optimize the application of modified biochar in real-world remediation scenarios. Further, the success of field trials to evaluate the performance of modified biochar under real-world conditions should consider the influence of varying environmental factors, such as temperature, pH, presence of multiple contaminants, adsorption capacity, and stability of biochar. Understanding these interactions will provide valuable insights for optimizing biochar-based remediation technologies. An additional factor of environmental viability and regeneration, the modified biochar stands out using desorption models and usage of certain chemicals which introduces effective cationic concentration displacing the sorbed metal ions proving as a reusable adsorbent option inside a filtration setup for groundwater remediation. The acid modification of pristine biochar results in a significant increase in specific surface area, expansion of pore size, polarity, charge characteristics, O/C ratio, and total acidity, particularly due to the introduction of various oxygen-containing functional groups, including C=C, C=O, C–O, and phenol-alcoholic –OH bonds. These functional group introduce more binding sites on the biochar surface which is effective for adsorbate attachment through chemisorption interactions, confirmed through functional groups on the surfaces of the biochar determined qualitatively and quantitatively following different sorption isotherm models. Moreover, functional groups are also crucial for the immobilization of heavy metals and other contaminants through mechanisms such as electrostatic attraction, ion exchange, and surface complexation. To address the reduced carbon ratio, the usage of a dual acid mixture is an effective solution resulting in a balanced biochar composition. Additionally, the capability of heavy metal immobilization or sorption efficiency are explainable by the unique characteristics of surface-modified biochar and the experimental conditions followed for the regeneration of surface properties. The chemical modification conditions of using optimized pyrolysis temperature and pyrolytic cycle duration depends on the biochar's characteristics and the acid's ionic strength used in the treatment. Further theories of metal availability or the dissolved state of the metal also govern the sorption kinetics and isotherm, redefining the adsorption equilibrium in groundwater or natural conditions for modified biochar samples. The morphology and surface chemical composition of biochar were analyzed using methods such as XRD (X-ray diffractometry), SEM (Scanning Electron Microscope), BET (Brunauer-Emmett-Teller method), and FTIR (Fourier-Transform Infrared Spectroscopy). The chemical modification using HCl, NaOH, and HNO_3 : H_2SO_4 acid admixture improved the physical and chemical properties of biochar, enhancing the adsorption of Cd(II) as an effective adsorbent in comparison to pristine biochar. Primarily, the lignin structure inside the biochar expands while hindering the stabilization of soluble metal salts, and the chemical modification majorly liberates the metal ions in the feedstock before pyrolysis and other impurities adhering to the surface of biochar, thereby increasing the overall hydrophilic or hydrophobic nature. The hydrophilic nature introduction on surface increases the aromatic nature on the surface due to the upsurge of nitrogen and oxygen containing groups leading to crosslinking reaction in presence of alkaline modifying agents. The results for different surface modifications, from single-factor experiments demonstrated the effectiveness of pH variation for studying the adsorption of Cd(II) ions onto the pristine and modified biochar surfaces, initial concentration of Cd(II), and biochar dosage using different modified biochar samples for significant adsorption of Cadmium nitrate ($CdNO_3$). Out of all the biochar modifications the dual acid-modified biochar provided maximum surface area, and pore volume, with an increasing number of oxygen-containing groups on the surface, thus more adsorption sites were enhanced for cadmium ions, resulting in coordinated adsorption with cadmium (II) ions, due to interaction of negative-positive charge interaction on the surface. At 25°C and pH = 8, the acid-modified biochar exhibited a maximum adsorption capacity of 143.69 mg/liters for Cd(II) after 24 hours, representing a significant enhancement in adsorption. Additionally, a conclusion was drawn with increase of pH promoted the dissociation of carboxyl functional groups and simultaneously increased the negative charge on the surfaces, leading with enhanced electrostatic attraction and hydrolysis of Cd(II) by the biochar, which was conducive to the adsorption reaction.

Keywords: *Biochar, water remediation, cadmium removal, surface modification, adsorption efficiency*

CONSTRUCTED WETLANDS FOR REMOVING PESTICIDES AND ANTIBIOTICS FROM CONTAMINATED WATER

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Around the world, groundwater is an essential resource for industrial operations, agriculture, and drinking water. It sustains over 2 billion people worldwide and contributes to about 30% of freshwater resources. However, a number of pollutants have seriously compromised its quality, with pesticides and antibiotics emerging as the most significant contaminants. Pesticides are widely employed in agriculture, are poisonous to humans and aquatic life, and pose major health concerns to the public when they leak into groundwater through surface runoff, leaching, and inappropriate disposal. Similarly, antibiotics are extensively used for treating microbial infections, and 30-90% of the antibiotics that are consumed are excreted which ends up in the wastewater discharge. The release of antibiotics into the environment fuels the worrying increase in antimicrobial resistance (AMR), a developing global public health emergency. These pollutants are persistent in the environment and are not removed by traditional wastewater treatment systems. Therefore, the development of innovative and long-lasting remediation techniques for contaminated water is urgently needed. Among the promising methods, constructed wetlands (CWs) have drawn interest as a practical, economical, and sustainable way to remove antibiotics and pesticides from water.

This review presents the mechanisms underlying CWs and their efficacy in cleaning up pesticide and antibiotic contamination in water. To remove contaminants from wastewater, CWs—artificial wetland systems—use physical, chemical, and biological processes. A thorough assessment of the many CW designs, including hybrid CW systems is part of the review. To remove contaminants from contaminated water, each CW design makes use of special properties such as plant uptake, adsorption, microbial degradation, and photolytic processes. Data was collected from a wide range of peer-reviewed publications, based on field trials and laboratory experiments, published over the last decade, offering a thorough understanding of CWs' performance in the removal of pesticides and antibiotics. This review also examines a number of design factors that have a huge impact on the efficiency of CWs in removing pollutants, including substrate type, water depth, hydraulic retention time (HRT), and plant species selection. To improve CWs' capacity to eliminate a variety of pollutants from water, the significance of combining them with other treatment technologies is being examined. With an emphasis on water as the treatment medium, the data in this study is based on multiple studies that assessed CWs' capacity to treat a range of pesticides (including atrazine, chlorpyrifos, and glyphosate) and antibiotics (including tetracycline, ciprofloxacin, and ampicillin).

Although the effectiveness of CWs varies depending on the kind of pollutant and the design of the CW system, the review finds that CWs can dramatically lower the quantities of pesticides and antibiotics in contaminated water. The vertical flow systems, which encourage aerobic conditions and microbial breakdown in the root zone, demonstrates high removal efficiencies for hydrophobic pesticides. On the other hand, anaerobic microbes that can degrade more persistent pollutants thrive in horizontal flow CWs. Hybrid CW systems have been shown to offer the best performance, combining both vertical and horizontal flow to take advantage of the benefits of both systems, improving the removal of a wide range of contaminants, including pesticides and antibiotics. Enhanced removal rates is mostly dependent on the plant species utilized in CWs. It has been observed that aquatic plants like *Typha*, *Phragmites australis*, and *Canna indica* are efficient at both removing pollutants from the water and creating an atmosphere that encourages microbial breakdown in the rhizosphere. The researchers also emphasize how different substrate types, such as sand, gravel, and organic matter, have an impact on the filtering and adsorption procedures that help in removing pollutants. Furthermore, the biodegradation of antibiotics and pesticides depends on the microbial communities in CWs, especially those in the rhizosphere. In CWs, microorganisms including bacteria, fungi, and actinomycetes have the ability to break down harmful compounds into less harmful biodegradable compounds, increasing the removal efficiency overall. The efficiency of CWs in eliminating pesticides and antibiotics from water varies across investigations, despite the encouraging findings. There are still several issues, such as shifting removal efficiencies in response to changes in temperature, flow rate, and nutrient availability. Furthermore, whereas CWs have proven effective at eliminating single pollutants, little is known about how well they work in situations involving multiple pollutants.

The removal of pesticides and antibiotics from contaminated water can be accomplished effectively and sustainably with constructed wetlands. Because CWs combine physical, chemical, and biological processes, they are a flexible and environmentally responsible substitute for mechanized wastewater treatment techniques. CWs can be made more efficient by incorporating hybrid CW systems, choosing the right plant species, and structuring the system to guarantee the ideal hydraulic retention time. However, there are still a number of unanswered questions, especially about the long-term efficacy of CWs in practical settings and their capacity to eliminate numerous pollutants at once. Additionally, further studies are required to understand the fate and transformation of contaminants within CWs and to develop strategies for improving their performance under varying environmental conditions. The use of CWs for water remediation, particularly for treating complex mixtures of pesticides and antibiotics, is not well documented in the literature. There is little study on the field-scale application of CWs; the majority of the investigations are laboratory size scale. Future studies should fill this knowledge vacuum by concentrating on long-term monitoring and field testing to confirm lab results and enhance the scalability of CWs for groundwater remediation. Additionally, CWs may be more effective at treating contaminated water when combined with other cutting-edge treatment methods like membrane filtration or advanced oxidation processes. Overall, CWs represent a promising and sustainable technology for water remediation, but continued research is essential to fully understand their potential and limitations in diverse environmental conditions.

Keywords*: Constructed wetlands, groundwater contamination, pesticide removal, antibiotic degradation, sustainable remediation*

IMPACT OF LAND-USE AND LAND -COVER CHANGE ON GROUNDWATER QUALITY IN NORTHERN PART OF ODISHA, INDIA: A HYDROGEOCHEMICAL AND GIS APPROACH

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Water is one of the most valuable resources that is widely distributed all over the world and is available to mankind for sustenance and survival. Groundwater is the most important resource for almost all sectors globally: residential, agricultural, and industrial applications. About 40% and 70% of global water resources are used for household and irrigation purposes, respectively. The proposed study carried out in the Urban and its surrounding area of Keonjhar District, which is one of the popular tourist destinations in Northern part of Odisha. Since it is one of the regions of large-scale mining activities, leading to pollution of water resources and the degradation of groundwater. Further, rapid urbanization and increasing number of tourists has increased dependency on water resources, resulting in over-extraction of groundwater and increasing the risk of contamination. Even though there are several reports on variation in groundwater quality and suitability of groundwater for various purposes, but still there is not much significant work has been attempted to link change in LULC patterns to groundwater quality fluctuation yet. Thus, in this study a hydrogeochemical and GIS based approach has been attempted to evaluate the groundwater quality and linking it to change in LULC patterns. The study area experiences tropical to sub-tropical climate with hot summer, high and well-distributed rainfall during the monsoon and a cold winter. The district is mainly drained by the river Baitarani and its tributaries barring a very small patch in the extreme south-western part, falling in Brahmani, the Singhbhum Granites cover 50% of the district's land, while the Iron Ore Group covers the western and south western limit. The study area's groundwater is divided into fractured, fissured, and consolidated basement rock formations, with shallow levels during pre and post monsoon periods. A total of 56 groundwater samples were collected from different locations during PRM period (April 2024), maintaining its spatial distribution and based upon lithological and LULC variance. The physical parameters like pH, EC and TDS were measured in-situ and samples were brought to Laboratory for further analysis. The major cation and anion analysis were done following standard procedure and each parameter were measured thrice to maintain the accuracy with an error percentage of 5 to 10%. Landsat 8 satellite imagery was processed using Arc GIS tools to create an LULC map of the study area 2014 & 2024, using supervised classification. Study categorized land cover types into five classes urban areas, agricultural land, barren land, forests, and water bodies. Using GIS software, the samples with higher nitrate concentration on the LULC map 2024, enabling spatial analysis of contamination patterns in relation to land use categories. Cations shows dominance of Na>Ca>Mg>K and Anion dominance in order of HCO_3^->Cl^->NO^{3-}>$SO^{4}{}_{2-}$ All ions are under permissible limit except nitrate, about 19 samples show higher concentrations prescribed both by WHO (2011) and BIS (2012). This could be attributed to an increase in agricultural activity to meet the crop demand of the rising population. The groundwater samples are plotted in the Piper (1944) Trilinear Diagram. The plot shows four fields where groundwater samples are reported. Most of samples are falling in Field F which is Mixed Ca-Mg-Cl type

while one sample is falling in A field which is Ca-HCO^3type and three samples are falling in B field which indicates Na-Cl type.

Two sets of LULC Maps for year 2014 and 2024 were compared to evaluate the changes in land use over the decade and an assessment was made of their impact on groundwater quality for the year 2024. It is inferred from the study that there is increase of urbanization from 32.09sq km to 40.04sq km (24.77%) and agricultural land from 66.1 sq km to 70.82sq km (7.14%) from 2014 to 2024. It may be predicted through LULC maps that increased urbanization has led to anthropogenic activities, intensive farming, and improper disposal of residential wastewater, all of which may have been linked to elevated nitrate contamination. Thus the study infers that the groundwater quality of the area is safe for various purposed except the locations having high nitrate concentration. The high nitrate concentrations in these locations are mainly due to the change in LULC patters i.e. increasing urbanization and agricultural activity. This initial phase of contamination requires immediate attention, with the implementation of rigorous management policies and strategies essential to ensure the sustainable use and protection of resources. Thus, it is imperative for better land use planning and the adoption of sustainable farming practices in the study area to address groundwater contamination and protect the resources.

***Keywords*: *LULC, groundwater quality, hydrogeochemistry, urbanization, agriculture*

EVALUATION OF GROUNDWATER SUITABILITY FOR DRINKING AND IRRIGATION PURPOSES IN PULLAMAPATTI WATERSHED USING CCME-WQI WITH SPECIAL EMPHASIS ON HEALTH RISK IN FLUORIDE AND NITRATE CONTAMINATION

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Assessing groundwater quality is essential for ecosystem health and human well-being. Quality is impacted by lithology, geochemistry, and human activities, with contaminants like fluoride and nitrate posing health risks, particularly in regions like Dharmapuri. Fluoride contamination is a major concern in many parts of India, including the various hamlets of Dharmapuri district. The objective of the present study aims to: (1) assess groundwater quality for drinking and irrigation, (2) investigate fluoride contamination origins and geogenic sources in Pullamapatti watershed, Dharmapuri District, and (3) calculate the CCME- Water Quality Index and assess health risks for various age groups due to fluoride-nitrate exposure. The findings will support effective drinking water management strategies in Pullamapatti, Northern Tamil Nadu, India.

The Pullampatti watershed in Dharmapuri district, Northern Tamil Nadu, has an area of 1701.69 km^2, located between 78°00' to 78°35'E longitude and 12°00' to 12°31'N latitude. The terrain consists of Charnockites and gneissic rocks from the Archaean crystalline formations, with undulating plains and upland plateaus in a semi-arid, hot, dry climate. Groundwater is found in phreatic to semi-confined conditions within crystalline rocks and alluvial formations. There were 51 dug well samples and 18 bore well samples of each season (pre and post monsoon period 2022), representing the entire watershed collected. Water samples were analyzed for pH, EC, TDS, hardness, alkalinity, and major cations and anions, following BIS and WHO standards. In situ measurements of pH, EC, and TDS were conducted using a Horibba LAQUA multi-parameter analyzer. Titrimetric methods were used for Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^-; flame photometry (Model 1385) for Na^+ and K^+; colorimetry for SO_4^{2-}; and a Continuous Flow Analyzer for F^- and NO_3^-. Spatial distribution of physicochemical parameters was mapped in ArcGIS 10.3 using IDW interpolation. Analytical values for parameters like EC, pH, total hardness, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, Na^+, K^+, CO_3^{2-}, HCO_3^-, NO_3^-, and F^- determined groundwater quality from dug wells. Indicators such as SAR, RSC, Na%, Kelly’s ratio, and magnesium hazard ratio were evaluated for irrigation suitability. Drinking water quality was assessed using the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI). Health risk assessment (HRA) followed USEPA guidelines to evaluate potential health risks from contaminants like fluoride and nitrate.

In the pre-monsoon period, groundwater in the Pullamapatti watershed showed EC levels from 758 to 6780 µS/cm, indicating high dissolved ions. Sodium, potassium, sulfate, and nitrate ions were found in the ranges of 37–730 mg/l, 1.2–43 mg/l26–270 mg/l, and 3.16–106 mg/l, respectively. Groundwater samples showed hardness ranging from 65 to 1865 ppm, averaging 654 ppm. Calcium levels varied between 10 and 365 ppm, while magnesium ranged from 13.37 to 266.3 ppm. Bicarbonate (HCO_3^-) was the dominant anion, with

concentrations between 119 and 585 ppm, though some samples had chloride (Cl^-) as the primary anion. Carbonate (CO_3^{2-}) levels were lower, ranging from 0 to 50 ppm, indicating varied chemical composition in the groundwater. In the post-monsoon period, groundwater samples have TDS between 288 and 3391mg/l reflecting a slight mineral increase from pre-monsoon. Electrical conductivity (EC) ranged from 576 to 6760 µS/cm, indicating high ion presence. Cl^- concentrations varied from 56.8 to 900.9 mg/l, averaging 322.93 mg/l. Sodium and potassium levels ranged between 11–368mg/l and 1–20mg/l, respectively. Sulfate concentrations were between 3.6 and 617.98 mg/l, while nitrate ranged from 0.01 to 216.84mg/l. Hardness spanned from 100 to 1590 mg/l, with an average of 528.85 ppm, reflecting higher calcium (16–310 mg/l) and magnesium (19.44–360.13 ppm) levels. Bicarbonate was the dominant anion (70–390mg/l), with carbonate between 0 and 150mg/l. pH values remained within the permissible range (6.94–8.29). Fluoride ranged from 0.13 to 2.84mg/l, with an average of 1.11mg/l, sometimes exceeding the WHO limit of 1.5mg/l. Phosphate levels were minimal, between 0 and 0.2496 ppm. For irrigation, sodium percentage (Na%), SAR, Kelly's ratio, RSC, PI, MHR, and potential salinity indicated that most samples were suitable. Agriculture indices are as follows: Na% was found between ranges (10.32 - 91.62) & (2.85 - 82.3), sodium absorption ratio varies from (0.66 – 19.45) & (0.15 – 10.6), Kelly's ratio (KR) varies from (0.11 - 10.87) & (0.02 to 4.64), residual sodium carbonate varies from(-27.43 – 7.84) & (−28.12 to 6.14), permeability index (PI) varies from (17 – 107.02) & (2.60 to 86.65), magnesium hazard varies from (18.46 – 80.02) & (16.90 to 90.99), potential salinity varies from (10.16 – 91.58) & (2.49 – 82.29) during pre and post monsoon respectively; results shown that the majority of the groundwater samples were suitable for irrigation uses. The CCME-WQI for drinking showed values from 34.9 to 77.15 (average 55.59), indicating marginal to poor quality. Health risk assessment (HRA) showed that over 34% of samples exceeded safe limits for fluoride and nitrate, with higher risks for infants and children compared to adults.

The hydrochemical parameters of the dug well water samples of the study area are compared with the standards of BIS & WHO, which shows that the values are within the permissible limit. Higher values of EC indicate the presence of inland salinity along the watershed. Analysis showed that dug wells are mostly affected by fluoride contamination, 34.61% and 25% of samples during pre- and post-monsoon respectively have fluoride concentration >1.5mg/l, particularly in areas including Dharmapuri, Karimangalam, Manicknoor, Mittanahalli, Timmanapuram, Nallampalli, Bandarahalli, and Kongarapatti. The CCME-WQI for drinking purpose showed that 26.92% of samples are fair, 61.53% samples are marginal and 11.53% are poor. The present study indicates that the groundwater chemistry is mostly controlled by geogenic processes (weathering, dissolution and ion exchange) as the dominant factor affecting groundwater chemistry to some extent of anthropogenic activities. The health risk assessment revealed that 37% of the samples exceeded safe fluoride levels for infants, children, and adults. Oral ingestion of nitrates poses significant health risks, particularly for children, who are the most vulnerable across all age groups. The Total Hazard Index indicates that nitrate levels in several groundwater samples exceed safe limits (HI > 1), especially for children. Although 80% of the groundwater remains appropriate for agriculture, the study stresses the need for targeted groundwater management to tackle contamination issues and mitigate health risks from elevated fluoride and nitrate ingestion, particularly for vulnerable populations of infants and children.

Keywords: *Health risk assessment, WQI, hazard quotient, hazard index, groundwater*

REMOVAL OF INORGANIC CONTAMINANTS FROM GROUNDWATER USING LATERITE SOIL IN MIDDLE WESTERN GHATS, INDIA

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Groundwater contamination by inorganic pollutants, particularly fluoride and arsenic, is a major environmental and public health issue in many parts of India. These contaminants lead to severe health problems, including skeletal and dental fluorosis, various cancers, and neurological disorders. The demand for clean groundwater is especially high in rural regions, where 85% of drinking water is supplied by groundwater. Addressing these contaminants is crucial for ensuring safe water access in India. Given the high treatment costs associated with traditional methods, there is a growing interest in finding affordable, sustainable, and regionally appropriate treatment alternatives. This study explores the potential of using typical laterite soil of Middle-Western Ghats, a naturally occurring material rich in many minerals especially iron and aluminum oxides and abundant in the region, as a low-cost adsorbent for removing fluoride and arsenic from groundwater. Laterite soil's specific adsorption properties, natural abundance, and low environmental impact make it a promising material for sustainable water purification. The choice of laterite soil for this study is based on its composition and widespread availability in the Middle Western Ghats. Iron and aluminum oxide minerals create a porous structure with a large surface area, enabling the soil to adsorb contaminants through multiple mechanisms, including electrostatic attraction, ion exchange, and ligand exchange. These mechanisms make laterite soil particularly effective in removing anionic contaminants like fluoride and arsenic, which tend to bond with the positively charged sites on iron and aluminum oxides. This adsorption potential, combined with the soil's natural abundance, suggests that laterite soil could serve as a sustainable and locally viable solution for groundwater purification in remote areas.

The methodology involved sample collection, soil preparation, and batch adsorption experiments. Laterite soil samples were collected from NITK campus. The collected soil samples were then cleaned, air-dried, and sieved to create a uniform particle size, which improves adsorption efficiency. The XRD results revealed significant peaks for iron oxides (hematite and goethite) and aluminum oxides (gibbsite), confirming the soil's composition and supporting its high potential for adsorbing fluoride and arsenic. In the laboratory, synthetic fluoride and arsenic solutions will be prepared in simple ultra-pure water, allowing for controlled testing of the soil's adsorption capabilities. The adsorption experiments will involve immersing the laterite soil in these solutions under varying conditions of contact time, pH, and contaminant concentration. Arsenic and fluoride concentration will be measured using spectrophotometric analysis and ion selective electrode meter, respectively. Parameters such as pH and contact time will be adjusted to identify the optimal conditions for contaminant removal. The efficiency of arsenic and fluoride removal under acidic and alkaline conditions will be checked. The time taken to reach the adsorption equilibrium will also be checked which will tell the rate of arsenic and fluoride adsorption. Further, pH at point-of-zero-charge and arsenic and fluoride adsorption isotherm of the soil will be determined.

The use of laterite soil as a low-cost adsorbent presents several advantages for sustainable water treatment, particularly in rural and semi-urban areas. Laterite's widespread availability in the Middle Western Ghats and minimal processing requirements make it a cost-effective alternative to synthetic adsorbents, which are often expensive and difficult to implement on a large scale. Additionally, laterite soil is biodegradable and poses little environmental risk, making it a safe option for rural communities that lack advanced waste disposal facilities. Utilizing laterite soil aligns with principles of sustainability by reducing the need for synthetic chemicals, lowering costs, and supporting a local supply chain that benefits regional economic development. Moreover, the use of a locally available resource minimizes environmental impact, reduces transportation costs, and enhances the feasibility of community-level groundwater treatment projects.

This study evaluates laterite soil as an effective, sustainable, and locally available adsorbent for removing fluoride and arsenic from groundwater. Its natural composition, particularly its high iron and aluminum oxide content, may enables strong adsorption, making it a feasible alternative to conventional treatment methods. The Middle Western Ghats' abundant laterite deposits offer a readily accessible solution for communities facing challenges with groundwater quality. By providing an affordable and environmentally responsible solution, this approach has the potential to become a cornerstone of decentralized water purification efforts, improving groundwater safety and public health while fostering sustainability and regional resource utilization across India. Further research will focus on optimizing the adsorption process, investigating potential for soil regeneration and reuse, and conducting field trials to validate laboratory results in real-world conditions.

Keywords*: *Adsorption, sustainability, laterite soil, inorganic contaminants, arsenic, fluoride, adsorption-isotherm

EFFECT OF MICROPLASTICS ON THE DYNAMICS OF EMERGING CONTAMINANTS IN GROUNDWATER

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Microplastics (MPs) are defined as plastic particles having sizes less than 5 mm and have emerged as a serious threat to public health. MPs are found in all the environmental matrices: surface water, groundwater, sediments and WWTPs. One more important problem with MPs is that they are now found in almost all the food items as well as in the blood samples of newborn babies and found in copious quantities of them. In previous literature MPs have been linked to pharmaceutical and personal care products (PPCPs) and heavy metals. Some studies have also explored the potential of MPs in the transportation of antibiotic-resistant genes (ARGs) in surface waters. The level up to which the MPs are acting as a reservoir for ARGs, and other co-selectors is little understood, especially in groundwater. The current study focuses on the impact of MPs found in groundwater on its antibiotic resistance potential, to minimize the susceptible microbes from becoming resistant. The study sheds light on the type of MPs found in the area and its abundance in the studied samples.

Groundwater samples were collected from 6 locations in Roorkee and nearby villages. These samples were pre-processed for different analysis. For antibiotic analysis, one litre of groundwater sample was collected in amber glass bottle. After the SPE procedure the samples were loaded on the LC-MS/MS (Shimadzu, Japan) and analysed for the target compounds: ciprofloxacin and triclosan. 100 mL groundwater sample was collected in PVC bottles for heavy metal analysis. The samples for heavy metal (copper, chromium and zinc) analysis were filtered using 0.45µm cellulose nitrate filter papers (Axiva, India). Samples were digested using aqua regia (3:1 ratio for $HCL:HNO_3$) at 103°C following APHA protocol for heavy metal analysis. The heavy metals were analysed using inductively coupled plasma mass spectrometry (Agilent 8900; ICP-MS: triple quad, Agilent Technologies, Inc., USA). 100 litres of groundwater filtered from 63µ sieve was reconstituted using one litre Milli Q water and was utilized for MP analysis. Micro–Raman spectroscopy was utilised for characterization of the microplastics. A 20x, 50x and 100x objective lens (NA 0.55) and 532 and 785nm laser source (5 mW; grating 1800 lines/mm) were used as the method conditions for the Raman Spectroscopy. The spectra generated from the Raman` Spectroscopy was identified manually using origin software. Four litres of groundwater sample was collected in sterilized PVC bottles and was filtered using 0.22µ cellulose acetate filter paper. For analysis of resistant genes (16 S rRNA, *ycc*T, *tet*A, *sul*1, *mcr*5) DNA was extracted using MO BIO kit for sediments (MOBIO) following manufactures protocol. Each qPCR was performed in thermal cycler of Applied Biosystems with assay that included 2µl DNA insert (normalized to 5ng/µl), 1ul each forward primer and reverse primer (5mM), 5µL SYBR green master mix, 1µl DNA free molecular biology water. The cycle conditions for qPCR included initial denaturation at 95°C for 3 min, followed by 40 cycles of: denaturation 95°C for 10 secs; annealing at 60°C for 30 secs and extension at 72°C for 30 secs. The melt curve analysis was performed using temperature 60°C – 95°C with 5°C increment, each step for 30 secs. The absolute abundance of the ARGs was calculated in gene copies per liter (GCL) in MS excel after incorporating all the dilutions; and for further analysis the relative abundance

was calculated by dividing absolute abundance by 16S rRNA gene copies per liter (the resulting number was unitless). Shapiro Wilk test was used to test the normality of the dataset and non-parametric tests were used. The Wilcoxon rank sum test was utilized to ascertain the relation of the target ARGs with the co-selectors. Principal component analysis (PCA) was utilized to understand the behavior of ARGs in the co-selector stress. Statistical tests were performed using R (version 4.3.2) and R-Studio (version 3.2.1).

All the samples showed ARGs and the co-selectors. The relative abundance of *sul*1 gene was highest in all the samples while the levels of *mcr*5 were minimum. There was a correlation between the levels of *ycc*T and zinc in L1 and L4 (L: location). Also, there was correlation between the levels of *tet*A and ciprofloxacin in L1, L2 and L6. MPs found were in blue, black, red and transparent colour. MP fibres and films were the shapes of the MPs studied. L3 sample had the highest concentration of MP fibres while L4 had high MP films concentration. The study concludes that MPs may be acting as carriers for ARGs and heavy metals into the groundwater. The study also concludes that there is a cross resistance is occurring in groundwater, and this might cause various pathogens to become resistant. The authors suggest that various measures should be taken by the local people and the government to stop the dissemination of the pollution in the studied areas.

Keywords: *Emerging contaminants, ARGs, antibiotics, heavy metals, microplastics, groundwater*

EMERGING POLLUTANTS IN WATER, SOURCES, HEALTH IMPACTS AND MANAGEMENT

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Water is very important resource for surviving of human beings on the Earth, used for drinking as well as irrigation and industrial works provided by the surface and groundwater sources. Water resources played important role in the developments and established socio-economic balance in a country also but nowadays anthropogenic and natural activities introduced the Emerging Pollutants (EPs) and toxic contaminants into the water resources globally. These newly introduced chemicals are not in the regulatory guidelines & standards and have the potential of toxicity to humans and ecosystems. Recently, the chemicals, personal care products and fragrances, micro plastic, pharmaceuticals waste, medicines, Bisphenole A (BPA), house hold cleaning product, fertilizers, disinfectants-bi-products (DBPs), pesticides, plasticizers, hormones and endocrine–disrupting compounds, persistent, organic pollutants and industrial by-products, rare & trace elements and pathogens were observed in the water. The concentration of the emerging pollutants increases day by day as a result of increasing urbanization, industrialization, and agriculture activities. The concentration of the EPs in water depends on the its properties like solubility, degree of persistent, volatility, polarity, adsorption and degradations. These EPs analysed in water by use of advanced instruments such as the HPLC (High-Performance Liquid Chromatography), GC-MS (Gas Chromatography-Mass Spectroscopy), ICP-MS (Inductively Coupled Plasma-Mass Spectrometry), therefore, increases the cost of analysing, monitoring and characterization of EPs in the water. The sources of the emerging pollutants in groundwater as well as surface water include disposal of domestic, industrial, hospital, agriculture waste and landfill leachate and runoff. These pollutants are an emerging concern due to the negative impact on the health of the human beings and ecosystems, accumulated in the food chain, and then the body organs of the human beings and aquatic animals. The adverse impact to human health of EPs includes genotoxic and mutagenic, endocrine disruption, acute and chronic toxicity, resistance of micro-organisms to antibiotics, bladder tumours, carcinogenic effects, fetal loss anomalies, long gestational duration etc. Studies revealed that the EPs lead to liver and central nerves system disorders, skin allergy, otitis, and neuro-psychological disorders. EPs are toxic for the ecosystem directly and indirectly, affecting the plant's growth and health of aquatic animal. Therefore, there is a need to control the EPs in water. However, there are some challenges to control the EPs such as identification, lack of guidelines and standards limits and protocol, accurate techniques for analysis and measurement, and its removal. Generally, management and removal of the EPs from the water is done by use of physico-chemical and biological processes such as filtration by sand and media filtration, advanced oxidation processes, chlorination, use of zeolite, adsorption using granular activated carbon, constructed wetland (CW), hydrolysis processes, bio-sorption, bio-char, adsorption by carbon nanotube and clay minerals, decomposition by micro-organism, membranes, bio-reactors and phytoremediation. The integrated treatments or combination of treatment systems such as constructed wetlands and activated carbon with oxidation process are very effective and low energy consumption treatments for removal of EPs from water.

Some of the important aspects in control and management of EPs in water are effluent quality monitoring and characterization for the identification, stabilization of waste disposal system, and setting the limits by the pollution control agencies. A proper environmental management plan is required to be implemented including the green technology with emphasis on organic farming. Use of natural and non-toxic personal care products, bio-degradable products can help in minimizing the EPs in effluents, thereby helping to reduce he adverse impacts on health of humans and ecosystems.

Keyword: *Emerging pollutants, water, health impacts, sources, management*

REVOLUTIONIZING SMART WATER SAFETY: A FAST, LOW-COST PAPER STRIP DIP TEST FOR ON-SITE BACTERIAL CONTAMINATION DETECTION

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Safe water drinking is an important criterion to maintain public health, requiring effective monitoring to prevent bacterial contamination. In this study, we developed a novel colorimetric paper strip dip (PSD) test for quantification of bacterial contamination. This test utilizes dye-coated paper strips that undergo Fenton reaction when immersed in a mixed solution of DI water and hydrogen peroxide (H_2O_2). The bacterial catalase in contaminated water competes with the Fenton catalyst for H_2O_2, resulting in a visually observable color change in both the strip and solution. The intensity of the decolorization on the strip/solution determines the bacterial contamination level in the water sample. The method offers a lower detection limit of 50 CFU/ml for catalase positive bacteria (*Escherichia coli)* within 5 min at room temperature (25 °C). Moreover, the test exhibited minimum interference for bacterial detection in the presence of potential contaminants present in natural water sources. The test is integrated with a mobile app for effortless and reliable quantification of bacterial contamination. In addition, the app recommends the chlorination requirement for disinfection of contaminated water sample. Thus, the PSD test is rapid, precise, specific, economical (~0.060 USD per test), and user-friendly for on-site bacterial monitoring of drinking water sources.

Water-borne diseases are primarily caused by bacterial presence in water that infect millions of people in developing countries. Diseases caused by water contamination result in 3.4 million deaths yearly. Therefore, it is imperative to devise efficient tools for water quality monitoring. Among the pivotal parameters for gauging water quality, coliforms and other catalase-positive bacteria are paramount, serving as vital indicators of water contamination. According to the World Health Organization (WHO), the concentration of viable bacteria and coliforms in drinking water should not be more than 10 CFU/100 ml and 1 CFU/100 ml, respectively. Therefore, reliable bacteria monitoring methods for precise, convenient, and rapid on-site detection are essential for alleviating waterborne diseases.

The PSD test developed for monitoring bacterial contamination in water is based on the classic Fenton reaction, where the dye on the paper strip gets decolorized via the action of OH· radicals when the water sample is contamination-free. In the presence of bacteria, the reagent responsible for $OH^{\cdot}$ radical production, i.e., H_2O_2 is broken down into water and oxygen by the action of the catalase enzyme, and the dye on paper stays intact. Thus, the color intensity on the strips in a PSD test decreases with reducing bacterial concentrations in water. The dip test paper strips were prepared using Whatman filter paper immersed in a solution containing optimized concentrations of $FeSO_4$ and MB dye. The paper was soaked in the solution for 30 min, followed by air drying at room temperature. The dried dye-coated paper was cut into 2 cm × 0.7 cm strips. The working of strips was validated by immersing the coated paper strips into a solution containing H_2O_2 (optimized concentration) and an equal volume of catalase/catalase-positive bacterial sample (known concentration). After incubation, the strips were removed from the solution and dried at room temperature.

The test was conducted with controls, including distilled water and a water sample. The bacteria-spiked test solutions and the control solutions were incubated for 30 s. Subsequently, the dye-coated paper strips were immersed in the solution for 5 min at room temperature to quantify the catalase/microbial activity of the sample. After that, an optimized concentration of $NaNO_2$ was added and mixed with the test solution for 30 s to quench the Fenton reaction, stabilizing the color. The strips were then removed from the mixture and air-dried. The strip and solution color were analyzed visually. The results were further corroborated by measuring the absorbance of MB remaining in the solution after the PSD test at 665 nm. The color of the dye on the strips recedes from blue to grey and further to darker grey as the bacterial concentration decreases, which was quantified by a mobile app, "Color Grab". The ΔE^* values are inversely correlated with the color gradient on the paper strip. The ΔE^* values of the colorimetric PSD test showed higher LOD values of *E. coli* was 50.06 CFU/ml. The PSD test shows high sensitivity for *E. coli*, 0.477, ΔE^*/dec. For b^* measurement, the sensitivity for *E. coli*, *C* 0.800, b*/dec. In the case of solution absorbance measurement (OD_{665}), the sensitivity for *E. coli*, was 0.034 per dec. The disinfection of the bacterial solutions was further verified by conducting a PSD test before and after chlorination. For all the bacterial solutions, the dye color on the strip faded from their respective blue (prior chlorination) to grey (after chlorination) indicating a decrease in bacterial concentration after disinfection.

Rapid contamination of water bodies necessitates the development of quick, reliable, and low-cost monitoring systems, which can indicate bacterial contamination to ensure the consumption of clean drinking water. In this study, a rapid, accurate, and user-friendly PSD test has been developed for on-site bacterial detection in water, which is a function of Fenton chemistry and catalase action on dye-coated strips. The degree of decolorization of the paper strip indicates the level of bacterial contamination in the water. Integration with mobile apps further enhances the applicability of tests for smart water management. Moreover, initiatives can be taken to collaborate with water management authorities and regulatory bodies to integrate the developed test into existing water quality monitoring frameworks.

Keywords: *Colorimetric paper strip, coliform, Fenton reaction, catalase-positive bacteria, chlorination*

MICROPLASTIC DETECTION IN UNCONFINED GROUNDWATER AQUIFER SPOTS OF HARIDWAR, INDIA

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The water sample collection and microplastics study in Uttarakhand's Haridwar sector involved an organised evaluation of groundwater from six different locations: Dhanori, Karanpur Mafi, Bhagwanpur, Kawad Marg, Sitapur, and Piran Kaliyar. The selected locations were chosen based on their use of handpump groundwater stations in the district, situated in the southwestern section of the state. The groundwater extraction focused on unconfined aquifers, with samples collected every 10 days over a three-month period This extensive sampling technique was developed to provide a full understanding of microplastic (MP) pollution in groundwater sources, which remains relatively unexplored compared to marine environments. The aquifers in this area form a three-tier system typical of Indo-Gangetic belt. This system is characterized by three distinct zones, each separated by thick restricting clay layers of varying thicknesses. The complex character of these alluvial sediments, with frequent alternations between fine and coarse textures, has a considerable impact on the behaviour of water and possible contaminants like microplastics in the subsurface environment.

Microplastics, tiny plastic particles that may survive in the environment for long periods of time, are common in a variety of habitats, including marine ecosystems, where their abundance is well documented. However, their presence and behaviour in groundwater systems remain poorly understood. Identifying this knowledge gap, the study aimed to identify and quantify microplastic pollution in groundwater in Haridwar district, with a focus on eight of the most regularly found microplastics in the environment. These included polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polycarbonate (PC), polymethylmethacrylate (PMMA), and polyamide. To guarantee rigorous examination, groundwater samples were taken in triplicate from six capped monitoring bores in the Roorkee district.

The sampling and analysis process for microplastics was meticulously conducted to minimize contamination and ensure reliable results. Groundwater was taken from the handpump stations with a 10-liter steel bucket. For each sample session, 100 liters of groundwater were acquired by passing the water through the process ten times, with each iteration resulting in the collection of ten liters. The collected volume was then treated to a pre-filtration procedure to remove debris and bigger particles. For this aim, a 63-micron sieve was used, which successfully captures microplastics while allowing smaller particulates to pass through. To ensure that microplastics stuck to the sieve mesh were not missed, the sieve was jet-sprayed with deionized water.

The microplastics released during this stage were transferred to a 1000-liter glass bottle for further investigation. The next step in the technique was to transport the collected water to IIT Roorkee's laboratory facilities. The water samples were vacuum filtered using an assembly equipped with 0.2-micron filter paper. This method guaranteed the retention of even the smallest microplastic particles. The filtrate, which contained microplastic particles trapped on the filter paper, was then subjected to characterization. These investigations used

micro-Raman spectroscopy for polymer identification, which is particularly useful for determining the chemical composition of individual microplastic particles. Furthermore, SEM provided detailed imaging that revealed the size, shape, and surface morphology of the collected particles, providing useful information about their likely sources and environmental behaviour.

Given that the groundwater samples in this investigation were collected from capped bores, microplastics most likely entered these unconfined aquifers via porous media or soil layers. The alternation of fine and coarse sediments in the research area's alluvial deposits lends credence to this concept, as these heterogeneous substrates can facilitate the movement and accumulation of microplastics. This work emphasizes the need to broaden the scope of microplastic research to encompass groundwater systems on a larger geographical scale. The samples tested via the Micro-Raman facility at IIT campus indicated the presence of PET, PTFE, PP and PE in the groundwater samples.

While the findings from the Haridwar area give useful baseline data, more research is needed in other parts of India and around the world to acquire a more complete knowledge of microplastic pollution in groundwater. Such research would help to discover the variation in microplastic occurrence across different hydrogeological settings, as well as the factors that influence their transport and persistence. Finally, the detection of microplastics in Haridwar's Indo-Gangetic aquifers emphasizes the significance of monitoring and managing this increasing pollutant. The systematic collection and analysis of samples using advanced characterization techniques such as micro-Raman spectroscopy and SEM are crucial for better understanding microplastic dynamics in subsurface water systems. Further research into varied aquifer systems around the world is required to provide a global perspective on microplastic contamination and its implications for human health and the ecosystem.

Keywords: *Microplastics, groundwater, unconfined aquifer, soil, porous media*

DESIGN OF Ag-MODIFIED 3D-GRAPHENE-BASED ELECTROCHEMICAL SENSOR FOR DETECTION OF MERCURY IONS IN WATER AND SOIL SAMPLES

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The mercury ion (Hg^{2+}) is considered one of the most dangerous heavy metal pollutants, posing a high risk to human health and to various organisms. Therefore, detecting Hg^{2+} ions is essential in water and other environmental samples. Various methods have been developed to identify Hg^{2+} ions, including atomic absorption spectrometry (AAS), microwave-induced plasma atomic emission spectroscopy (MIP-AES), inductively coupled plasma mass spectrometry (ICP-MS), and atomic fluorescence spectrometry (AFS). Voltammetry has always been an important alternative to several spectroscopic instruments-based techniques that can measure Hg^{2+} ions at ultra-trace levels in complex matrices. Graphene is a sp^2-hybridized carbon allotrope with a 2D honeycomb lattice with remarkable electron mobility, a large theoretical surface area, and good electric conductivity. However, the conventionally synthesized graphene is generally in 2D, which is prone to clumping and aggregating, thus losing the surface area and the electron transport property. It's exciting to report that new research has shown 3D graphene can offer larger surface area, conductivity, and mass transfer efficiency than 2D graphene because of their porous architectures and it's generally anticipated that this technology will be employed to create high-performance electrochemical sensors. In the present investigation, a low-cost freeze-casting approach has been adopted for the preparation of AgNPs/3D-graphene nanocomposite. The obtained detection limit of 0.39nM is significantly lower than in prior publications when compared to the methods using nanocomposite materials. This AgNPs/3D-graphene/GCE sensor has been used successfully to monitor Hg^{2+} in actual samples, such as soil and borewell samples. Overall, this work demonstrated the great potential of using AgNPs/3D-graphene nanocomposite to create a new class of electrochemical sensors that will enable accurate and dependable measurement in real systems. Ag nanoparticles modified with 3-D graphene (AgNPs/3D-graphene) nanocomposite have been synthesized through a simple, cost-efficient, one-step freeze-casting route. XRD was used to explain the phases and structural properties of the as-synthesized graphene oxide (GO), bare 3D-graphene and AgNPs/3D-graphene nanocomposite. AgNPs/3D-graphene nanocomposite. The strong peaks at $2\theta = 37.9°$, 44.1°, 64.1°, 77.2°, and 81.1° can be indexed to the (111), (200), (220), (311), and (222) planes of face-centered cubic (fcc) Ag crystals. Scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HRTEM) were used to examine the surface morphology of the as-prepared AgNPs/3D-graphene nanocomposite and bare 3D-graphene. A 3D porous cellular structure, composed of interconnected graphene sheets with pore sizes ranging from sub-micrometers to micrometers, is observed in both the AgNPs/3D-graphene nanocomposite and bare 3D-graphene. In the HRTEM study, the Ag nanoparticles, which have an average size of 30 nm, are evenly distributed across the graphene sheet surfaces and do not exhibit any evidence of aggregation. Also, the loading content of Ag in the AgNPs/3D-graphene nanocomposite was evaluated by ICP-AES analysis, and the findings verify that 12% of the Ag is loaded in the nanocomposite.

The cyclic voltammetry (CV) experiment was performed using the AgNPs/3D-graphene/GCE at a scan rate of 30 mV/s in a 0.1 M KCl solution containing 10 mM $K_4[Fe(CN)_6]$ as a redox probe to explore the electron transfer mechanism at the catalyst-modified surface.The AgNPs/3D-graphene/GCE was shown to have a greater current responsiveness when compared to the bare GCE and the bare 3D graphene-modified GCE. The fast increase in the redox probe's current over the modified electrode suggests that the AgNPs/3D-graphene nanocomposite modified electrode has an enhanced charge transfer property. To further verify the specific roles of 3D-graphene and AgNPs, the interfacial charge transfers properties of the bare GCE, 3D-graphene-modified GCE, and AgNPs/3D-graphene/GCE at the electrode-electrolyte interface were investigated using electrochemical impedance spectroscopy. Compared to the bare GCE and 3D-graphene-modified GCE electrodes, the AgNPs/3D-graphene/GCE showed lower charge transfer resistance due to the decreasing radius of the semicircles. In electrochemical experiments, the sensitivity is mainly determined by the pH, accumulation potential, and accumulation duration. The optimal electrochemical parameters used in the current investigation include a deposition potential of -0.5 V, a deposition time of 50 s, a potential scan range from 0.2 to 0.6 V, a step potential of 0.05 V, and a modulation amplitude of 0.025 V. Differential pulse anodic stripping voltammetry (DPASV) measurements were employed to assess the Hg^{2+} in solutions. The experiments were conducted in 0.1M KCl and 0.1M KNO_3 supporting electrolyte medium (pH 5) at the applied voltage of -0.5V for the 50s, and the potential scan was carried out in a range of 0 V to + 0.6 V. The DPASV responses of Hg^{2+} using a modified AgNPs/3D-graphene/GCE electrode was recorded in the concentration range of 0.1 to 40 μg/L. The responses showed a linear increase in the stripping peak current. A detection limit of 0.08 μg/L (0.39 nM) was achieved based on a signal-to-noise ratio (S/N) of 3. With an accumulation time of 50 seconds and an $R^2 = 0.999$ in Fig. 6(e), the manufactured sensor demonstrated good sensitivity of $1.9x10^{-8}$ A per μg L^{-1} of Hg^{2+}. There was no significant variation of the stripping current of Hg^{2+} was observed using five different modified electrodes. Among the five examined electrodes, the current response variation from these electrodes varies by only 5.58%. Sensor's stability was observed for 28 days, and the relative standard deviation was 1.57%. It has been used to measure Hg^{2+} in soil and underground water samples to evaluate the practicability of fabricated sensors further. Three soil samples were taken from a synthetic bed received by the Analytical Chemistry Division, BARC, for analysis, and two borewell water samples were collected from the 24 Pargana area of West Bengal. The cold vapor atomic absorption spectroscopy (CVAAS) technique was used to validate the values. The results of the analysis agree well with the two methods of determination. AgNPs/3D-graphene/GCE utilized as the working electrode for detecting Hg with high sensitivity and selectivity. The AgNPs/3D-graphene/GCE exhibited a wide linear range for Hg^{2+} detection, spanning from 0.2 to 50 μg/L, with a low detection limit of 0.08 μg/L, indicating high sensitivity. The analytical method was validated using the certified reference material (CRM), and the Z score was reported to be 0.64. After being stored in the ambient environment for 28 days, the AgNPs/3D-graphene/GCE exhibited electrocatalytic current towards Hg (II) at 95.8%, demonstrating good long-term stability. Very good results were obtained when the AgNPs/3D-graphene/GCE sensor was applied to detect Hg^{2+} in soil and borewell real samples. The method would provide new insight into the sensible design and use of AgNPs/3D-graphene/GCE for precise and reliable Hg (II) sensing in real samples.

Keywords: *Electrochemical sensor, Hg^{2+}, 3D-graphene, Ag nanoparticles, Stripping voltammetry*

EXPLORING ELECTROCHEMICAL OXIDATION FOR THE REMOVAL OF BISPHENOL-A FROM CONTAMINATED GROUNDWATER

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Groundwater is essential for maintaining the long-term viability of ecosystems, since it serves as a crucial supply of potable water for people, sustains agricultural activities, and plays a significant role in maintaining a global water cycle balance. In recent decades, concerns regarding the presence of various organic pollutants in water bodies have intensified, with Bisphenol A (BPA) emerging as a prominent target of environmental scrutiny. As an endocrine-disrupting compound commonly found in plastics, BPA has been linked to adverse health effects, making its removal from water sources a severe environmental challenge. The release of BPA into the environment is a critical issue with diverse sources, encompassing both industrial and consumer-related activities. The pathways through which BPA is released include not only the direct release from production facilities but also indirect routes, such as the discharge of wastewater and wash water from BPA production facilities or consumer product manufacturing facilities utilizing BPA. Moreover, the effluent from wastewater treatment plants contributes to the environmental release of BPA, and leaching from discarded consumer products at hazardous waste landfill sites adds to the complexity.

To address this issue, innovative technologies have been explored, and one such promising way is the application of electrooxidation (EO) technology with graphite electrodes. Recently, there has been a growing emphasis on advanced oxidation processes (AOPs), particularly the electro-oxidation process and photocatalytic processes. Consequently, there is a vital need to develop and popularize new methods that enhance emerging contaminant degradation while minimizing their environmental impact. In EO process, contaminants undergo oxidation either by the oxidizing radical species generated on the anode surface or through direct electron transfer from organics to the electrode surface. RSM is a statistical approach which can be used to model experiments, evaluate the effects of multivariable on response values and optimise the process parameters. The degradation of BPA was designed and optimised by central composite design of RSM. In this regard, the removal efficiency of BPA was chosen as the response value. Based on the results of some preliminary studies, acceptable input variables were investigated to get the optimum response using CCD.

To investigate the effect of current density, a series of experiments were conducted at 1, 3, 5.5, 10 mA cm^{-2} using graphite electrodes. In the presence of ROS, the degradation efficiency of BPA was determined by scavenging experiments using different conventional quenchers: KI, Ethyl alcohol, and TBA. The scavenger-induced inhibitory effect on BPA degradation followed the order of Synthetic water>groundwater>KI>Ethanol>TBA. The degradation efficiency reached 98.59 ± 0.81% under 120 min of electrolysis when no radical scavengers were present. After the addition of 10 mM KI in the reactor, the degradation efficiency declined to 31.67 ± 1.3%. However, after the addition of 10 mM EtOH and TBA in the reactor, the degradation efficiency declined to 61.68 ± 1.3% and 63.77 ± 0.4%, respectively.

This study confirmed that anodic oxidation, facilitated by the generation of hydroxyl radicals, is an effective method for BPA mineralization in aqueous environments. The research shows the critical role of applied current density in the BPA degradation efficiency and highlighted the need for nuanced strategies in water treatment. The use of MALDI-TOF mass spectrometry enabled detailed analysis of the byproducts resulting from BPA degradation, revealing a complex degradation pathway involving aromatic ring cleavage and subsequent oxidation reactions. Scavenger studies demonstrated that the addition of radical quenchers significantly reduced BPA degradation efficiency. The EPR studies, using DMPO further confirmed the primary role of hydroxyl radicals (surface and free) and singlet oxygen in BPA degradation.The study also revealed a significant reduction in bacterial colony formation with increasing BPA concentrations, indicating potential disruption to biological wastewater treatment processes in the presence of BPA. These findings not only highlight the importance of addressing BPA contamination for human health but also underscore the need for maintaining the integrity of drinking water treatment systems.

Keywords: *Emerging contaminants, Groundwater treatment, Electrooxidation, By-products, Solar energy*

OCCURRENCE AND EXTENT OF ELEVATED URANIUM CONTAMINATION IN THE GROUND WATER SOURCES, KRISHNAGIRI DISTRICT, TAMIL NADU, INDIA

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India is the largest ground water user in the Earth and ground water is the backbone of India's agriculture and drinking water security. Groundwater contributes nearly 62% in irrigation, 85% in rural water supply and more than 50% in urban water supply. The occurrence and availability of the ground water in the crystalline basement complex of the Southern India, including Tamil Nadu is highly complex due to its heterogeneity nature. Further, the minerals present in the rock formation get dissolved in the ground water and make enriched with minerals. In certain places, the mineral enriched ground water become harmful to the human consumption. Uranium (U) as a potential drinking water health hazard is brought to the notice after the provisional guideline given by World Health Organization (WHO). One such contamination was investigated in the parts of Krishnagiri District of Tamil Nadu. Groundwater being crucial source of water in the region, this study was carried out with an objective to identify the distribution and spatial extent of Uranium in ground water source. This study provides a strong database for better understanding the source of uranium in the aquifer system of Krishnagiri region and the results would be useful for further studies in semi-arid regions

Based on the recommendations of the parliamentary standing committee in 2019, CGWB was entrusted to carry out baseline survey for Uranium in groundwater throughout the country for the first time. Accordingly, 1208 samples were collected from all districts in Tamil Nadu during NHS Monitoring in May 2019. Uranium analysis has been performed using ICPMS. Perusal of the results showed that nineteen samples had Uranium concentrations above the BIS permissible limit of 30ppb**.** Of which, 5 samples (26%) were from locations in Krishnagiri District with the highest value being 302 ppb at a bore well in Megalachinnapalli.Based on the baseline study, CGWB, SECR had taken up a special study to identify the occurrence of Uranium in ground water of Krishnagiri and Palepalli firkas of Krishnagiri District. A total of 40 ground water samples including dug wells, bore wells, hand pumps have been collected during pre-monsoon season (September 2022) and it has been found that the Uranium concentration varied from 0.34 to 485 ppb with average value of 79 ppb and standard deviation of 105 ppb (68% data falls within plus or minus 1 standard deviation). Out of 40 samples, 22 (55%) of samples have Uranium concentration more that the BIS permissible limit. During postmonsoon, the Uranium value ranged between 1.7 and 351 ppb with an average of 72 ppb and standard deviation of 82 ppb. Out of 48 samples, 29 (60%) of samples have Uranium more than the BIS permissible limit.

A total of 998 km^2 area has been identified in Krishnagiri district comprising six firkas namely Krishnagiri, Barugur, Alapatty, Pallepalli, Guruparapalli and Periyamutur of Bargur, Veppenapalli, Kaveripattinam, and Krishnagiri Blocks for the present study area based on the precious studies by the CGWB. A total of 110 nos. of ground water samples have been collected during May 2024, out which 41 samples from phreatic aquifer and rest are from the

confined aquifer of the study area. All the samples were analysed for basic parameters using standard methodology and Uranium using Fluorometric analysis.

Out of 110 nos. of ground water samples collected from 110 gram panchayats, 18 (16.4%) samples showed Uranium concentration more than the BIS permissible limit for Drinking Purposes (0.03 mg/l). Groundwater from shallow aquifer unit and deep aquifer have high concentration of Uranium. 3 gram panchayats viz. Narlapalli, Chennasandiram and Achchamangalam showed Uranium concentration in shallow aquifer. 15 samples showed Uranium concertation beyond permissible limit for deep aquifer (Bore Wells), gram Panchayats viz. Pedatalapalli, M.C.Palli, Kammampalli, Agaram, Kurubarapalli, Beemandapalli, Kuppachiparai, Chennasandiram, Marasandiram, Madhepalli (Gurubarapalli) Kodiapalli, Palepalli, Guruvinayanapalli, Madhepalli (Palepalli). In dug wells, the electrical conductivity ranges between 649- 4610 µS/cm at 25° C with mean value of 1974 µS/cm. The concentration of nitrate ranges from 3 to 74 mg/l with a mean value of 30 mg/l. The concentration of Uranium ranges from 1 to 68 µg/l with an average of 12 µg/l. Whereas in Bore Wells, the electrical conductivity ranges between 860 - 5140 µS/cm at 25° C with mean value of 1883 µS/cm. The concentration of nitrate ranges from 2 to 78 mg/l with a mean value of 32 mg/l. The concentration of Uranium ranges from 1 to 156 µg/l with an average of 23 µg/l.

The present study reveals that the Uranium concentration in ground water in 18 Gram Panchayats from the part of the Krishnagiri district of Tamil Nadu is more than the BIS for drinking water. The village people of 18 GPs are vulnerable to Uranium contamination. Further, it is observed that the higher concentration of the Uranium in ground water is from Northern, North East and North Western part of the study area which is basically Grantic Gnesis complex. The Uranium concentration in ground water collected from the Migmatic Complex is within BIS for drinking water. Study shows that uranium distribution is not homogenous throughout the region, however, spatial distribution graphs reveal that concentration increases towards Northern, North East and North Western direction.

Keywords: *Groundwater, uranium, Krishnagiri district, water chemistry*

DRIP IRRIGATION PROMOTED MIGRATION OF MICROPLASTIC PARTICLES ACROSS VERTICAL SOIL COLUMNS

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The widespread use of plastics has undeniably brought numerous advantages to society**,** facilitating countless advancements in technology, industry, and daily life. However, the proliferation of plastic debris in various environmental systems has become an escalating concern. Among the most insidious forms of plastic pollution are microplastics, which have garnered significant attention due to their ubiquity and potential to harm ecosystems and human health. While research on microplastic contamination has been extensively conducted in aquatic environments, there remains a notable gap in studies focused on terrestrial ecosystems, particularly soils. This disparity is concerning, as microplastic pollution is an increasingly severe issue with far-reaching implications, including its presence in the human body, where it has been linked to adverse health effects such as immune response dysregulation and neurotoxicity.

Recognizing this pressing issue, our research has undertaken an experimental investigation to study the transport behavior of microplastics within soil matrices. Specifically, we focus on Nile red-stained microplastic particles, sized between 35 to 40 microns, as tracers to understand their migration patterns. This study employs vertical soil columns as experimental setups, designed to mimic natural subsurface conditions. Each soil column has a depth of 30.5 cm and is packed with carefully prepared soil types to replicate varying real-world scenarios. By using artificial drip irrigation systems to simulate rainfall or water infiltration, we aim to elucidate the mechanisms by which microplastics are transported through soil systems, potentially leaching into underlying groundwater reservoirs.The primary objective of the study is to systematically investigate the factors influencing the downward movement of microplastics in different soil types. The influence of several variables on microplastic transport was examined, including variations in soil pH, organic matter content, fulvic acid concentration, and drip irrigation intensity. These parameters were chosen because of their potential to alter the physicochemical properties of the soil environment, thereby affecting the mobility of microplastics.

To begin the experiments, vertical soil columns were packed with either fluvial sand or gravel soil. The soil was pre-conditioned to achieve specific pH levels and organic matter contents, ensuring controlled and reproducible conditions across trials. Microplastic particles stained with Nile red dye were introduced at the top of the soil column along with water droplets, mimicking natural infiltration processes under varying drip irrigation intensities. The simulated irrigation allowed for precise control over water volume and flow rate, enabling us to observe how the changes in hydrodynamic conditions affect the transport and retention of microplastics within the soil matrix.The effluent from the outlet at the bottom of the soil column was collected at regular intervals to quantify the number of microplastic particles that had traversed the column. These collected samples were then subjected to analysis under a fluorescent microscope, which enabled accurate detection and quantification of the microplastic particles. By examining the concentration and distribution of particles in the effluent, we developed correlations to determine how factors such as soil composition, chemical properties, and water flow influence the movement of these contaminants through porous media.

Our findings suggest that the transport behavior of microplastics is strongly influenced by the interplay between soil properties and hydrological conditions. For instance, soils with higher organic matter content exhibited increased retention of microplastics, likely due to enhanced adsorption facilitated by the interaction between the microplastics and organic molecules. Similarly, variations in pH were observed to affect the surface charge of both the soil particles and the microplastics, thereby influencing their mobility. Fulvic acid, a naturally occurring component of soil organic matter, played a critical role in altering the transport dynamics by potentially modifying the soil's porosity and particle aggregation characteristics. The study also highlighted the impact of drip irrigation intensity on microplastic migration. Higher flow rates were found to promote greater transport of microplastics, as the increased water velocity reduced the residence time of particles within the soil and minimized opportunities for retention or adsorption. Conversely, lower flow rates allowed for more pronounced interactions between the microplastics and the soil matrix, leading to increased retention. These insights provide a clearer understanding of the factors that govern the movement of microplastics in terrestrial environments. Importantly, they underscore the potential risks associated with microplastic contamination in soil, as these particles could migrate downward and contaminate groundwater resources—a critical concern for both environmental and human health. The results of this research also have broader implications for the development of mitigation strategies aimed at minimizing microplastic pollution in soils. By identifying the key parameters that influence microplastic mobility, it may be possible to design interventions or soil amendments that enhance the retention of these particles, preventing their further spread into the subsurface environment.

In conclusion, our experimental study represents a significant step forward in understanding the transport phenomena of microplastics in soil systems. By using Nile red-stained microplastics as tracers and employing meticulously designed soil column experiments, we have been able to systematically investigate the effects of various soil properties and hydrological conditions on the movement of these particles. The findings provide valuable insights into the complex interactions between microplastics and soil environments, paving the way for future research and practical applications aimed at addressing the growing challenge of microplastic pollution in terrestrial ecosystems. As the threat of microplastic contamination continues to rise, studies like ours are critical to advancing scientific knowledge and informing policies that promote sustainable environmental management.

Keywords: *Microplastics, soil column transport, drip irrigation, contaminant transport, porous media*

FLUORESCENCE-BASED DETECTION OF MICROPLASTICS: ADVANCING RAPID AND RELIABLE WATER QUALITY MONITORING

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Microplastics are small plastic particles less than 5 mm in size, that have caused significant environmental concern, due to their widespread presence and persistence in different ecosystems. This study aims to optimize methodologies for the detection and quantification of microplastics using Nile Red as a fluorescent dye. Nile Red is a lipophilic stain that is widely used in the detection of microplastics. The principle behind this detection technique is to fix the stain onto the microplastics, followed by extraction and destaining to analyze the fluorescence intensity using a fluorescence spectrophotometer. The rapid detection of contaminants, including microplastics, in aquatic environments is crucial for effective water quality monitoring and public health and hygiene. Conventional analytical methods are often tedious and demand complex sample extraction and isolation. Such conditions limit their feasibility for large-scale and real-time applications. Rapid detection methods like fluorescence spectroscopy, provide significant precedence over conventional methods, by allowing quick response times. This enables faster decision-making and implementation of mitigation strategies. Contaminant hotspots can be identified and water quality trends can be actively monitored with the aid of such rapid detection. Thus, ensuring that interventions can be carried out before contaminants impose greater risk to the environment and human health. This study compares the effectiveness of detection methods for microplastics like Fourier Transform Infrared Spectroscopy (FTIR), Raman spectroscopy, Scanning Electron Microscopy (SEM), Pyrolytic gas chromatography/ mass spectroscopy (Py GC/MS), with fluorescence spectroscopy. While each technique has its advantages, fluorescence microscopy stands out for its rapid and cost-effective screening capabilities. However, challenges such as potential staining of organic particles and required sample preparation were noted as limitations.

Our research detected several types of microplastics namely, polyethylene terephthalate (PET), polystyrene (PS), polypropylene (PP), and polyvinyl chloride (PVC). Stain fixation tests were conducted to assess the binding efficacy of Nile red over different durations (1, 5, and 10 days). The results indicated that the dye adhered effectively to the microplastic surface for extended periods. This enabled robust visualization and analysis of the microplastic particles. Images with the fluorescence microscope reproduced distinct images which confirmed the stability dye-plastic interaction. The control set included staining without microplastics. The dissipation of the fluorescence was also analysed by exposing the samples to UV light under various conditions.

Fluorescence spectroscopic analysis was conducted after de-staining, at excitation wavelength 560 nm, while the emission intensity was recorded. The quantum yield of the setup was also assayed to understand the photophysical properties. Principal Component Analysis (PCA) was used to analyse the correlation between microplastic type and concentration. Inference from the biplot suggests that PE and PET were closely associated, as were PP and PVC. Thus, similarities in fluorescence intensity and concentration profiles were established. Concentration was positively correlated with the type of plastic, affirming the reproducibility of fluorescence spectrophotometry for quantitative analysis.Visual images were acquired with a Scanning Electron Microscope, for gaining additional insights into the surface characteristics of different microplastics. PP displayed a smooth surface with sharp edges and a hard texture, while PE exhibited a rough surface with uneven edges and a softer texture. These observations align with the fluorescence intensity data, where variations in surface morphology possibly influenced the dye absorption and emission pattern.This study highlights the effectiveness of Nile Red as a multifaceted fluorescent dye for the rapid detection of microplastics. This feature hence enables enhanced water quality monitoring. The strong correlation between concentration and fluorescence intensity strengthens the reliability of the method. The PCA analysis corroborated with the consistency of fluorescence data across different microplastic types, confirming the reproducibility for rapid screening and detection.

The future scope involves exploring different factors, like the influence of various environmental matrices and microplastic shapes on dye fixation and detection. Method standardization for different size ranges and optimizing conditions like time, temperature, and concentration will be crucial for wider application. Currently, this method supports the detection of particle sizes greater than 75 microns. Further research can enhance this method for the detection of smaller microplastics and reduce sample preparation efforts. This study contributes to the development of efficient, scalable methodologies for the detection and analysis of microplastics using fluorescence spectrophotometry. It paves the way for more extensive environmental monitoring and a deeper understanding of microplastic distribution and behaviour in various ecosystems.

Keywords: *Nile Red, polyvinyl chloride, polyethylene, polypropylene, polystyrene, principal component analysis*

GEOCHEMICAL AND HYDROCHEMICAL EVALUATION OF GROUNDWATER IN SEMI-ARID PHALTAN AREA, SATARA DISTRICT, MAHARASHTRA, INDIA: IMPLICATIONS FOR POTABLE WATER AND AGRICULTURAL USE

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This study examines the hydrochemical characteristics of groundwater in the Phaltan area of Satara district, Maharashtra, and evaluates its suitability for drinking and irrigation. The region, situated on basaltic lava flows, experiences a semi-arid climate with limited water resources. Groundwater, as the primary source of potable water, is heavily reliant on irregular and sparse rainfall. Factors such as recharge, atmospheric precipitation, surface water, and subsurface geochemical processes significantly influence groundwater quality. Ninety-one groundwater samples from dug and bore wells were collected and analyzed to assess geochemical variations and overall water quality.

Hydrochemical analysis was combined with GIS-based Inverse Distance Weighting (IDW) to study spatial variations in groundwater quality. The chemical analysis followed standard procedures outlined by the American Public Health Association (2002) and Trivedi and Goel (1984). Key chemical parameters analyzed include pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA) as $CaCO_3$, total hardness (TH) as $CaCO_3$, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^-), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), and fluoride (F^-). On-site measurements for pH, EC, and TDS were conducted using handheld analysis kits. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations were determined through acid titration, while total hardness, calcium, and magnesium were analyzed using standard EDTA titration methods. Chloride (Cl^-) was measured by $AgNO_3$ titration, and sodium and potassium were determined using a flame photometer. Sulfate was analyzed using the $BaCl_3$ method with a spectrophotometer, while nitrate levels were assessed using the cadmium column reduction method. All chemical parameters, except for pH and EC, are expressed in milligrams per liter (mg/L), milliequivalents per liter (meq/L), and millimoles per liter (mol/L). The pH is expressed in units, and EC is in micromhos per centimeter (μS/cm) at 25°C. Ion balance errors were within the acceptable range of ±5%, as recommended by Domenico and Schwartz (1990).

Geochemical data were presented using graphical charts such as the US Salinity diagram and Wilcox salinity diagram to assess groundwater suitability for irrigation. Groundwater samples were classified based on sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and sodium percentage. Graphical representations including the US Salinity, Durov, Piper trilinear, Wilcox, and Gibbs plots were utilized to understand factors influencing groundwater chemistry. The study revealed that some groundwater samples exceeded the desirable limits for total dissolved solids (40%), total hardness (80%), calcium (15%), magnesium (31%), Fluoride (14%), and Iron (7%). However, all samples remained within permissible limits except for EC. Chloride, sodium, calcium, and bicarbonate were identified as the dominant ions in the groundwater. From the Piper trilinear diagram, it is apparent that majority of the samples (60%) belong to Ca2+-Mg2+-Cl--SO42- demonstrating the

dominance of alkaline earths over alkali (viz., Ca+Mg > Na+K) and weak acidic anions over strong acidic anions (i.e., HCO3 > Cl+SO4). The hydrochemical facies were primarily of mixed Ca-HCO$_3$, Na-HCO$_3$ and Mg-HCO$_3$ types, with some samples representing Ca-Cl and Na-Cl types, indicating fresh recharged water. Hydrochemical facies predominantly belonged to mixed Ca-Mg-Cl and Na-Cl types, with some samples showing fresh recharged Ca-HCO$_3$ type groundwater. The US Salinity Laboratory and Wilcox diagrams also suggested that some samples fell into irrigation zones (C4S2) that may not be ideal for crop growth. In terms of drinking water suitability, 31.9 % of samples were found to be excellent while 6.6% of samples were found to be unsuitable according to the Water Quality Index (WQI), with some exceeding the permissible limits set by WHO and ISI standards. The Gibbs diagram indicated that rock-water interactions were the dominant factor affecting water quality in the region. The chemistry of groundwater is largely rock dominated. The suitability of groundwater for irrigation was assessed using agricultural indices, including Sodium Adsorption Ratio (SAR), Sodium Percent (Na%), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Residual Sodium Bicarbonate (RSBC), Magnesium Hazard (MH), Corrosivity Ratio (CR), and Permeability Index (PI). The results indicated that most samples were suitable for irrigation, although 37% were classified as potentially harmful due to high magnesium content, and 35% were deemed unsuitable based on Kelly's ratio due to excess sodium. Overall, the study suggests that groundwater quality in study area is generally good, suitable for both drinking and irrigation, with a few exceptions. To ensure sustainable water quality, it is critical to manage groundwater use, reduce over-exploitation, enhance rainwater harvesting, and monitor the impact of urbanization. Further research in other basaltic regions of Maharashtra is recommended to provide a comprehensive assessment of groundwater quality across the southeast Deccan Volcanic Province. This study offers valuable insights into groundwater quality management and supports the development of strategies for sustainable water use in the region.

Keywords: *Hydrochemical characterization, hydrochemical facies, groundwater suitability, rock-water interactions, Kelly's ratio*

POLYCYCLIC AROMATIC HYDROCARBONS IN SURFACE AND GROUNDWATER: DISTRIBUTION, HEALTH RISK AND MANAGEMENT

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Polycyclic Aromatic Hydrocarbons (PAHs) are persistent organic pollutants characterized by multiple fused aromatic rings, known for their persistence, toxicity, and hydrophobic nature. Their occurrence in surface and groundwater systems has raised global concerns due to their toxic, mutagenic, and carcinogenic properties. Rapid industrialization, urbanization, and an increase in vehicular emissions have intensified PAH contamination, posing significant risks to environmental and public health. PAHs enter water bodies primarily through atmospheric deposition, wildfires, industrial discharges, urban runoff, and improper waste management. Their distribution in surface and groundwater is influenced by factors such as the source of contamination, hydrological conditions, seasonal variations, and the physicochemical properties of the water body. The hydrophobic nature of PAHs leads to their strong affinity for sediments, resulting in long-term contamination of aquatic systems, particularly in regions with inadequate wastewater treatment infrastructure, leading to widespread ecological and public health concerns. This review paper presents a comprehensive analysis of PAH distribution, estimation, health effects, and management. Furthermore, the paper aligns with the United Nations Sustainable Development Goals (SDGs), particularly Goal 6: Clean Water and Sanitation and Goal 3: Good Health and Well-being.

The levels of PAH contamination, with urban and industrial zones exhibiting significantly higher concentrations than rural or remote areas. Major river systems, including the Ganges and Yamuna, have been identified as hotspots for PAH pollution due to extensive anthropogenic activities. Groundwater contamination is a growing concern in regions where PAHs leach into aquifers from contaminated soils and surface sources. Seasonal variations, particularly during monsoons, exacerbate the problem by increasing runoff and sediment transport, leading to elevated PAH levels in water bodies. Advanced analytical techniques such as Gas Chromatography-Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC) are widely employed for PAH detection due to their high sensitivity and selectivity. These methods are often complemented by sample preparation techniques like solid-phase extraction (SPE) and liquid-liquid extraction to enhance accuracy. Recent developments in sensor technology and nanomaterials have improved the real-time detection of PAHs at ultra-low concentrations, making them promising tools for environmental monitoring.

The toxic effects of PAHs on human health are well-documented, with chronic exposure linked to cancer, respiratory ailments, immune dysfunction, cardiovascular diseases, endocrine disruption, and developmental disorders. PAHs such as benzo[a]pyrene, is a potent carcinogen. Human exposure occurs through direct consumption of contaminated water, dermal contact, and bioaccumulation in the food chain. Aquatic organisms exposed to PAHs accumulate these compounds in their tissues, leading to biomagnification across the food chain. This not only disrupts aquatic ecosystems but also increases human exposure through the consumption of contaminated water and seafood. Epidemiological studies in India have highlighted the prevalence of waterborne diseases and health disorders in communities

exposed to polluted water sources, emphasizing the urgent need for effective PAH management and mitigation measures.

Effective management of PAHs in aquatic environments requires integrated strategies combining prevention, remediation, and policy interventions. Preventive measures include adopting cleaner combustion technologies, implementing stricter regulations for industrial discharges, and promoting sustainable agricultural practices to reduce runoff contamination. Remediation techniques have advanced significantly in recent years, ranging from physical removal methods to chemical treatments such as advanced oxidation processes (AOPs) and biological approaches like bioremediation. The use of PAH-degrading microorganisms offers a cost-effective and environmentally friendly solution, particularly for large-scale contamination in resource-limited settings. Monitoring programs play a crucial role in tracking PAH distribution and assessing risks, with geographic information systems (GIS) and remote sensing technologies enabling real-time data analysis. Effective collaboration among government, academia, and industry is crucial for developing sustainable water management practices that will protect water resources, and public health, ensuring a cleaner, healthier, and sustainable environment for present and future generations.

Keywords: *PAHs, groundwater, health risks, environmental pollution, water quality, sustainable water management*

COMPARATIVE HYDRO-GEOCHEMICAL ASSESSMENT OF SHALLOW TUBEWELL IN PARTS OF NORTH AND SOUTH BANK PLAIN OF BRAHMAPUTRA

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This study evaluates the suitability of groundwater for drinking as well as irrigation in two regions of Assam: Dalgaon-Sialmari block in Darrang district and the Mayong block in Morigaon district. In these areas, groundwater is the primary source for drinking and irrigation, especially in regions where vegetable cultivation relies heavily on agrochemicals, In Dalgaon-Sialmari, 40 groundwater samples were randomly collected from 10 Gaon Panchayats, while in Mayong, 48 samples were collected during the pre-monsoon season in 2024.For drinking water, parameters such as pH, total dissolved solids (TDS), and heavy metal concentrations were assessed against BIS 10500:2012 and WHO. For irrigation, considerations included Sodium Absorption Ratio (SAR), Sodium Ratio (Na%), Residual Sodium Carbonate (RSC), Kelly's Index (KI) and Permeability Index (PI) to determine the water's potential impact on soil structure and crop health. These were assessed against standards such as Food and Agriculture Organization (FAO) standards. The hydrogeochemical characterization of groundwater was conducted using multiple graphical representations such as Piper, Schoeller, Durov, Radial plots, Wilcox and Gibb’s diagram. These tools facilitated the identification of dominant hydrogeochemical facies and inter- ionic relationships, offering insights into the underlying geochemical processes influencing water quality variability. Spatial distribution maps were developed using Geographic Information System (GIS) technology, provide a visual representation of groundwater quality variations across the study area. These maps help in illustrating the variation in groundwater quality across the study area. The findings reveal localized contamination in certain areas of the study region, where specific parameters exceed permissible limits set for safe human consumption and agricultural use. This underscores the necessity for continuous monitoring to effectively manage and enhance groundwater quality in these identified zones. There was no significant nitrate contaminations observed in both the study areas, despite increased use of nitrogenous fertilizers which may be due to high dilution effect of rainwater, surface runoff, soil compaction, etc. This study concluded by evaluating groundwater quality against standards, highlighting its suitability for intended uses and identifying potential concerns.

Keywords: *Groundwater contamination, water qualiy index, physiochemical parameters, hydrogeochemical processes*

HYDRO-GEOCHEMICAL APPRAISAL OF GROUNDWATER IN BOLOGARH BLOCK OF KHURDA DISTRICT, ODISHA, INDIA

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Bologarh Block of Khurda District located in the central-eastern region of Odisha comprising of 234 sq.km of area. The major part of the block occupied by hard rock formation with moderate to very low yield. This block is categorized as semi-critical from ground water extraction point of view, with an extraction rate exceeding 70% and characterized by water scarcity, which significantly impacts the quality of life of local population. Additionally, there are areas within these blocks that suffer from fluoride contamination in groundwater. The blocks are geologically underlain by hard rock formations of the Eastern Ghats, including Khondalite, Charnockite, and Granites/Granite gneiss with limited ground water potential. The problem of groundwater in this block has a substantial impact on the inhabitants of the area. This work is, therefore, designed to recognize various hydrogeochemical processes responsible for the modification of water chemistry and to assess the drinking and irrigational water quality with a view to establishing its safety in the Bologarh Block of Khurda district, Odisha.

The ground water samples collected from 59 nos. of dug wells and 30 nos. of tubewells from different locations throughout entire Bologarh Block in two seasons i.e. premonsoon and postmonsoon. To understand the various geochemical processes and suitability for various purposes, the groundwater quality is examined by the physico chemical parameters during the both seasons (pre & post monsoon). The major cation and anion content, changes in the cation and anion composition of groundwater, as well as their shifts, are used to identify variations in hydro chemical characteristics. The analyzed results are plotted in the Piper Diagram which illustrates the variations in hydro chemical characteristics during the pre and post monsoon seasons. The variation in the ground water chemistry is affected by the different natural processes like rock–water interaction, evaporation, and precipitation. Also, the plot of the analyzed data on Gibbs diagram is used to explaining the natural mechanism affecting the groundwater chemistry in the study area, identifying rock weathering (rock–water interaction) as the predominant process responsible for changes in groundwater chemistry. The impact of the weathering processes on groundwater chemistry and identification of possible sources of major ions in groundwater depend on the correlation between cation and anions. Scatter plots of different cation and anion like $Na+$ and Cl^-, Ca^{2+} and SO_4^{2-}, and $Ca^{2+} + Mg^{2+}$ and HCO^{3-} can indicate whether carbonate or silicate weathering is the primary factor affecting groundwater quality. The scatter plot of $Ca^{2+} + Mg^{2+}$ and $SO_4^{2-} + HCO^{3-}$ can indicate whether ion exchange or mineral dissolution is the primary factor affecting groundwater quality.

The results of the physicochemical parameters during in the both seasons suggest changes in hydrochemical characteristics, with major cations being sodium and calcium, and bicarbonate as the dominant anion. These changes are influenced by rock–water interactions, including carbonate and silicate weathering processes, along with cation exchange processes. The groundwater quality for drinking purpose compare with drinking water standards IS 10200:2012. The primary parameters affecting drinking water quality in this study area are fluoride contamination, followed by hardness. To further asses the drinking groundwater quality suitability, the water quality index (WQI) is calculated. The WQI classification for drinking water quality for the both seasons assigned with to the excellent to poor water classes. This study was performed to understand the impact of groundwater quality on the crop yields and its suitability for the irrigation. The values of, SSP, PI, RSC, KR and TDS show that most of the samples fall under good to suitable category. Wilcox Plot shows groundwater to be within excellent to a good class.

The study reveals that groundwater quality in Bologarh Block is significantly affected by geochemical processes, particularly weathering of minerals in the hard rock formations. Fluoride contamination and hardness are the key challenges for drinking water, while groundwater quality for irrigation is largely within acceptable limits. The seasonal variations in water chemistry emphasize the importance of monitoring both pre- and post-monsoon conditions to manage water resources effectively. The dilution in fluoride contamination is observed in some of the groundwater samples from few locations during post monsoon. These findings are crucial for developing strategies to address water scarcity and contamination issues, ensuring sustainable water use in the region for both domestic and agricultural needs. Thus, a sustainable management plan is prepared to mitigate the vulnerability zone of ground water. Alternate source for drinking water supply has also been suggested. The different measures of intervention such as nala-bandh on the ephemeral stream, percolation tank and check dam have also been suggested for sustainability of Ground water resources of the Block.

Keyword: Groundwater, contamination, cation exchange, rock weathering, sustainability

COMPREHENSIVE GROUNDWATER QUALITY ANALYSIS IN PUNJAB STATE, INDIA

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The analysis draws upon data from 242 groundwater monitoring stations (GWMS) across Punjab, consisting of 85 bore wells and 157 dug wells, collected during the pre-monsoon period of May 2022. These monitoring stations are strategically distributed across the state, which is known for its extensive dependence on groundwater for agricultural irrigation, industrial activities, and drinking water. The groundwater samples were collected with careful consideration of local hydrogeological conditions, and the samples underwent comprehensive chemical analysis using standard methods. The parameters analyzed included pH, temperature, electrical conductivity (EC), TDS, hardness, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, and other elements that are critical for understanding groundwater chemistry. Sodium Adsorption Ratio (SAR) was also calculated to assess the suitability of water for irrigation purposes.

The results indicate significant spatial variability in groundwater quality across the state, highlighting both areas of concern and regions with acceptable water quality. The pH values of groundwater in most regions are found to be slightly to moderately alkaline, which is suitable for most uses. However, salinity levels, measured by electrical conductivity (EC), show considerable variation, with some areas exhibiting high salinity, rendering the water unsuitable for drinking and irrigation. Groundwater in the northern parts of Punjab is generally of desirable quality, whereas the central parts of the state exhibit mostly permissible quality water. The southern and southwestern regions, however, are characterized by predominantly saline groundwater, making it unfit for consumption and agricultural use. Calcium levels across the state are typically low, while magnesium concentrations are elevated in certain areas, affecting the water's hardness and quality. Sodium concentrations, in particular, are high in several districts, impacting both water and soil health. Potassium concentrations tend to be low in most regions, although they may be elevated in specific areas. The chloride and sulphate levels also exhibit considerable variation, with certain regions showing values above the permissible limits, which compromises the water quality. Additionally, arsenic contamination, although localized, exceeds the permissible limits in parts of Ferozepur, posing significant health risks to local populations. Nitrate contamination is particularly problematic in the southern and southwestern districts, with nitrate levels often surpassing acceptable limits, primarily due to the overuse of fertilizers and agricultural runoff. Fluoride levels, while mostly within acceptable limits, show localized exceedances, which require attention in specific regions.

The primary sources of groundwater contamination in Punjab can be attributed to both anthropogenic activities and natural factors. The over-extraction of groundwater for agricultural irrigation and industrial use has led to significant depletion of aquifers, exacerbating the challenges of maintaining water quality. The intensive use of fertilizers and pesticides in agriculture has contributed to the increase in nitrate levels, making the groundwater unsuitable for drinking and irrigation. In addition, untreated or inadequately treated industrial discharges are a significant source of contamination, contributing to the presence of harmful chemicals in groundwater. Poor waste management practices, including improper disposal of solid and liquid wastes, further exacerbate the contamination of groundwater resources. Over-extraction has also caused saline water intrusion in certain regions, especially in the southern parts of the state, where the aquifers are more prone to salinization. Natural factors, such as geological conditions, contribute to elevated levels of arsenic and fluoride in certain pockets of Punjab. Inefficient irrigation practices, including flood irrigation, lead to excessive runoff and waterlogging, which further exacerbates salinity issues. Moreover, inadequate drainage systems result in waterlogging, which increases the risks of contamination and further deteriorates water quality. Climate change, with its potential to alter rainfall patterns and affect groundwater recharge, adds an additional layer of complexity to groundwater quality management. Reduced rainfall and erratic monsoon patterns may impact groundwater recharge, leading to lower water levels and a greater concentration of contaminants. This highlights the urgent need for proactive and sustainable water management practices to safeguard the quality of groundwater resources in the region.

The findings of this study underscore the importance of implementing targeted measures to address groundwater quality issues in Punjab. Based on the analysis, several key recommendations are proposed. First, there is an urgent need to enhance groundwater monitoring systems by establishing a continuous and robust framework for monitoring key water quality parameters. This would allow for early detection of contamination trends and enable timely interventions. Second, improving waste management practices, especially in industrial and agricultural sectors, is essential to minimize the impact of agricultural runoff and industrial discharges on groundwater. Regulating the use of fertilizers and pesticides will help control the levels of nitrates and salinity in groundwater, thus reducing the adverse effects on water quality. Upgrading irrigation methods, such as adopting drip irrigation and sprinkler systems, can minimize water wastage and help prevent salinity buildup. Public awareness campaigns aimed at educating local communities on the importance of groundwater conservation and sustainable water practices are essential for promoting long-term water quality improvements.

To mitigate the adverse effects of contamination, the development of groundwater recharge strategies, including rainwater harvesting and artificial recharge, should be prioritized to replenish aquifers and enhance water quality. Addressing specific contaminants such as arsenic and fluoride will require the establishment of treatment facilities in affected regions. Additionally, research on advanced water treatment technologies and sustainable water management practices should be promoted to address emerging challenges. Finally, comprehensive policies and regulations should be developed and enforced to ensure the sustainable use and management of groundwater resources for future generations.

Keywords: *Groundwater quality, chemical parameters, pH, TDS, nitrates, heavy metals, salinity, contamination, sustainable management*

HYDRO-FRACTURING THE UNCONVENTIONAL HYDROCARBON RESERVOIR ROCKS LIKE SHALE AND ITS IMPACT ON GROUND WATER

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The demand of conventional hydrocarbon (HC) is steadily decreasing in recent years as the oil-gas production rate, due to overall worldwide depletion of reserves, falling reservoir pressure and hydrocarbon recovery factor, has become less in most of the existing reservoirs. Hence, the industry slowly but steadily started leaning towards unconventional energy sources such as shale and similar tight rocks. Exploitation of shale gas & oil started in USA in 1821 and the development began in 1914. However, the ventures were not economically viable till Mitchell Energy introduced dual technology of horizontal drilling (HD) of wells followed by hydro-fracturing (HF) in order to enhance production considerably and economically in 2007-'08. HF became the key factor in this Shale Revolution which made US, world's highest producer of oil & gas wherein shale oil contributed 65% and shale gas 78% of the total production. HF is water intensive, as every well requires an average 6-7 million (MM) of freshwater. The post HF flowback and produced water (FPW), is highly toxic (may be carcinogenic too) and should not be allowed to contaminate groundwater and environment. Another issue is water should be efficiently used for HF so that the neighourhood aquifers need to be safeguarded from overuse.

Although during oil-gas exploration earlier, many wells were drilled in Shale, they were never economically viable because shale being a poorly permeable to impermeable rock, always had very poor production rate. It was only 2007-08 onwards when Mitchell energy came out with a unique dual technology which was proved to become successful of enhancing production with economic viability. This combined methodology included HD followed by HF and instantly became a game changer with a cheaper lifting cost. With the advent of dual technology, drilling of shale oil-gas wells started increasing in USA and in many other countries, including Canada, India, China, Russia. Every well started enhancing their production by applying HF technology. USA has become the highest producer of oil and gas in the whole world, six years in a row, because of substantial contribution from shale oil (about 2/3rd of total oil production) and gas (about 3/4th of overall gas production). However, HD and HF applications involve two challenges, one is requirement of huge quantity of freshwater of about 2-16 million gallons of water with an average being 6 million gallons for a HF well. The average for India is also 6 MM gallons. Use of so much freshwater causes a depletion of groundwater resource in the area around the oil-gas field which becomes very challenging in arid or semi-arid area. Research and field applications are on as to how to prevent this colossal wastage or overuse of so much freshwater and whether a true replacement of freshwater can be found.

It can easily be imagined that if so, much freshwater is required to HF a well, the postfrac return, which is nearly 75-80% of water used in making the fracturing fluid or slickwater, contributes a huge volume of Flowback and Produced water (FPW), that needs to be taken care of. Remaining volume of 15-20% is consumed by the bedrock or formation. The other challenge is how to safely deal or dispose of the postfrac FPW which includes toxic

chemicals. The chemicals are of undisclosed composition as well-operators or HF-companies do not mention most of them under an agreement between companies and the government.

In the last 15-16 years, the success stories of shale gas/oil have been reported and published in many documents, including books, scientific papers from journals, government reports, monographs, policy documents. They originated from USA, Canada, India and many other countries. All such documents are downloaded and critically studied. Moreover, the 1st author has worked for nearly 20 years in many unconventional oil/gas fields out of his 43 years of experience in overall oil/gas upstream industry. Also, he has been dealing with unconventional energy sector on behalf of the Government of India as Senior Advisor and as Geological Coordinator in a principal National Oil Company of India in between 2005-2006 and 2015-2016. Literature survey and discussion amongst all the authors and interactions were done with the industry people to prepare this paper. During literature survey the following highlighting points have come forward: a) In HD, initially the well is drilled vertically/directionally, and then horizontally (for 1-2 km), followed by HF from the furthest end of the hole and progressed inwards towards the well bore, after getting separated by a number or set of packers. HF is done with slick water or frac-gel, consisting of water, sand and chemicals and hit the formation mostly radially around the bedding plane under very high pressure ranging in between 350-700kg/cm^2, so that the effect becomes maximum; b) LPG (Liquefied Petroleum Gas) fracturing is waterless fracturing, but the method is found to be very costly and unsafe, as there is chance of fire and explosion and so, LPG has to be handled very cautiously; A good number of researches have contributed significantly in the direction of the various methodologies of recycling post HF FPW and reusing them in various sectors including HC industry; d) Recycling process needs to be techno-economically viable as the treatment process and costs vary.

Various applications by the industries and research could not indicate any techno-economically viable substitution of hydro-fracturing the shale without water to safeguard the freshwater overuse and wastage. Also, the effluents including the post frac FPW are to be disposed of in effluent disposal wells which are generally going upto a depth of 1000-1200 m. In USA, through research it has been found that the effluents, injected into deep wells create cracks and fractures due to low scale seismicity induced by the effluents under high pressure and contaminate groundwater by leaking and leaching into formation or bedrocks. So, no deep disposal as per current US regulations for the effluent water including FPW in deep wells. These effluents need to be handed over to a government approved third party who will do recycling of the effluents at designated plants after collection from the operators and return the treated water after Recycling for Reuse as a replacement of freshwater in drilling, water injection or HF job in the nearby wells and fields. The surplus water is made available for irrigation, transportation and general cleaning in many sectors. Based upon the present status of knowledge and practice, it is recommended that similar steps are to be taken in India and other countries as practiced in USA. Sufficient Research & Field application are required, so that the FPW/effluents with bad chemicals needs to be de-toxified, neutralized and softened. This way, the FPW/effluent water after recycling if used in the oil/gas upstream industry can minimize or completely replace the huge volume of freshwater requirement and the need of effluent disposal will also not arise.

Keywords: *Shale-oil/gas, hydro-fracturing, horizontal drilling, FPW-Effluents, recycle-reuse*

FRESHWATER RESOURCES UNDER MICROPLASTICS SIEGE: A GLANCE AT ASIA

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Global plastic production has experienced a dramatic increase since the beginning of the 21st century, reaching approximately 413.8 million tons (MT) in 2023. Despite the staggering production volume, only 36 MT was derived from post-consumer recycling, highlighting significant inefficiencies in global waste management and recycling practices. Asia, with a population of 4.8 billion, is responsible for nearly 60% of the world's plastic production, underscoring the region's critical role in plastic consumption and waste generation. More than half of ocean plastic dumps are contributed by 5 Asian countries: China, Indonesia, Philippines, Thailand, and Vietnam. Plastics have become integral to modern life due to their durability, flexibility, and weight. They have largely replaced traditional materials such as metals and wood across various applications, driven by their functionality, versatility, and cost-effectiveness. However, the rapid urbanization and population growth in many regions have increased plastic usage. Most of the used plastic ends up in the environment as waste due to improper and decentralized waste management practices and human behavior. This accumulation poses significant environmental concerns, contributing to various social and ecological issues.

Plastics undergo further disintegration and degradation due to various physical, chemical, and biological processes in the environment and small-size (<5mm) particles are formed, which are popularly known as micro-plastics. These particles are called secondary microplastics, while primary microplastics are manufactured for various applications. As per the literature survey, it is being reported that microplastics (MPs) are being detected in the environment, but their versatility and omnipresence make source identification very challenging. MPs are present in the air, water and soil. Microplastics are particularly problematic in aquatic environments. According to a study of 2017, globally rivers transport around 1.15 to 2.41 million tons of plastic waste to oceans every year. MPs are frequently found in oceans and landfills where larger plastic debris disintegrates into smaller particles. The landfills and wastewater contain both primary and secondary MPs. The use of plastic equipment and materials, fertilizers, and pesticides in agriculture contributes to the MPs in the agricultural soil, which are subsequently mobilized by surface runoff during rainy season and irrigation period while some particles find their way to deeper soil layers due to infiltration. MPs in surface water bodies are well known and are being reported by various workers in surface water, including lakes, ponds and flowing rivers and sea water. The highest concentration of MPs in river water is about 5,00,000 particles/m^3, reported in the Saigon River of Vietnam. This river passes through Ho Chi Minh City, which is the most populous city in Vietnam. In addition to surface water, MPs are now being reported and identified in the groundwater at various water levels in different geological environs.

It is found that MPs concentration is more in and around highly populated city centers where high numbers of anthropogenic activities are reported. The comparison and analysis of data from different studies pose a challenge due to variations in the methods and protocols of sampling, sample volume, their pretreatment, handling, the observed size range of MPs, and tools used for quantitative and qualitative analysis. Quality control practices during the procedure also affect their concentration, which is missing in some studies. Microplastics variation in size, shape, composition, density, attachment and detachment tendency, interaction with other organic and inorganic pollutants, and heterogeneous subsurface properties make them a complex entity to model their transport. This leads to a challenge for scientists and academicians involved in developing suitable transport models for microplastics in the groundwater in different geological environs.

Among Asian countries, China is at the forefront of research into microplastics in groundwater systems, followed by India and South Korea. However, comprehensive data on microplastics concentrations from countries like Thailand and Indonesia remain less reported despite their significant contributions to global plastic pollution. China reported an alarming concentration of MPs in groundwater, 6832 particles/L. It is reported around Rizhao City of Shandong Province, located in the northeast coastal area of North China. The concentration of MPs in groundwater India reported 0-80 particles/L, Indonesia about 236 particles/L from groundwater wells of Jakarta Megacity While, South Korea, Thailand, and Iran reported relatively lesser concentrations. Despite growing awareness of microplastic pollution's implications for environmental health and human safety, significant research gaps open the opportunity to carry out study on MPs in GW. The migration of MPs in groundwater from surface water and soil/rock interactions needs to be studied. The escalating issue of microplastics pollution necessitates urgent action from governments and researchers. Enhanced waste management strategies are crucial to mitigate plastic pollution's impact on ecosystems and human health. Furthermore, establishing standardized research protocols will facilitate a better understanding and comparison of microplastics contamination across different geological environs. As the global community grapples with the consequences of rampant plastic production and waste mismanagement, addressing the challenges posed by microplastics must be prioritized to safeguard environmental integrity and public health moving forward.

Keywords: *Waste management, pollution, microplastics, freshwater, groundwater, transport modelling*

Cr(VI) TRANSPORT MODELING IN MODIFIED TOTHIAN BASIN IN A TWO-LAYERED AQUIFER SYSTEM

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Groundwater is an extremely vital resource of drinking water in developing countries like India. Therefore, a proper understanding of the relationship between regional groundwater flow and natural subsurface phenomena is extremely vital to analyze several geological processes like contaminant transport, groundwater aging, and groundwater interaction in the hyporheic zone. This research focuses on the impact of hydraulic head distribution developed by analytical and numerical models on the transport characteristics of hexavalent Chromium [Cr(VI)] in the Tothian basin comprising a two-layered aquifer system. Toth (1962) represented the Tothian basin which is basically located in central Alberta of Canada. The tributary of the Red Deer River creates a series of parallel and equally spaced valleys, and water divides over most of the area (Toth 1962).

For estimating hydraulic head distribution, the two-dimensional rectangular flow domain is considered with a steady water table at the top. The water table is assumed to be topography-controlled. Therefore, the water table is a subdued replica of the topography. The water table is considered the regional as well as the local undulation of the topography. The groundwater flow basin is modified with two-layered, anisotropic aquifer systems. The right boundary of the flow domain is the midpoint of the highest water divide of the region, and theoretically, no horizontal flow is involved through this boundary. Therefore, the right boundary of the flow domain is considered as the no flow boundary. The left boundary of the domain is the midpoint of the lowest valley of the basin. Therefore, it is also considered as no flow boundary for the same reason as the right-hand side boundary. The bottom boundary of the domain is impervious rock and therefore, it is also considered as the no flow boundary. At the interface of the two strata in the computational domain, the hydraulic head and the water flux are identical for both layers. The separation of variables method and Fourier series have been used to develop the analytical groundwater model. The proposed analytical solution has been validated with a previously proposed analytical solution for a simplified flow system. Analytical solutions provide a deeper understanding of groundwater flow behavior in comparison to numerical models. Moreover, they conventionally aid in the mathematical representation of water movement in the hydrological system.

This study represents the effect of estimated hydraulic head distribution (analytical and numerical) on the transport characteristics of contaminants. The numerical model is simulated utilizing the COMSOL software, incorporating identical boundary conditions that have been considered in the analytical model. Cr(VI) has been used as a contaminant in this regional transport modeling as Chromium (Cr) has been used extensively in numerous industrial processes, mining, plumbing, gasoline, and tannery industries. Excessive concentration of carcinogenic Cr(VI) poses significant concern in the quality degradation of subsurface groundwater resources in the regional scale. In addition, consumption of groundwater contaminated by excessive concentration of Cr(VI) leads to skin irritation, DNA

damage, and the development of cancer, depending on exposure dose, exposure level, and duration. Several mechanisms, including molecular diffusion, advection, and hydrodynamic dispersion, are incorporated into the regional contaminant transport model to investigate the mobilization and retention characteristics of Cr(VI) in the fully saturated aquifer system. The two-dimensional advective dispersive equation incorporating adsorption is utilized in the research work to interpret the transport characteristics of Cr(VI) in the two-layered aquifer system. The contaminant transport model evaluates the impact of anisotropic hydraulic conductivity in the two-layered soil system. The result of the transient Cr(VI) transport model reveals that the contaminant plume reaches the interface of the two layers for the case of the isotropic medium. In addition, the contaminant transport model is simulated for both conditions when the hydraulic conductivity is higher in the top layer and that is higher in the bottom layer. The simulated spatial distribution of Cr(VI) interprets that the advection mechanism plays a crucial role in the migration of Cr(VI) in the zone of low hydraulic conductivity. The retention of carcinogenic Cr(VI) significantly enhances at the interface of two layers where the hydraulic conductivity alters notably.

The simulation result revealed that the chance of quality degradation of groundwater is higher if the source of contaminants exists near the valley bottom of the domain. This study helps to understand the plume migration characteristics of Cr(VI) in the Tothian basin. The simulation result can offer vital information regarding the amount of eluted contaminant mass and the average residence time of the contaminant in the computational domain. Furthermore, a probabilistic human health risk assessment utilizing Monte-Carlo simulation can be performed to provide a realistic scenario of risk assessment for adults and children through the ingestion and dermal exposure of groundwater resources contaminated by Cr(VI). Both carcinogenic and non-carcinogenic risk quotients can be estimated from the breakthrough curves of Cr(VI) using statistical measures. This information is crucial to establish remediation strategies for contaminated groundwater resources in the regional scale to oppose the harmful effects of carcinogenic Cr(VI) on human health.

Keywords: *Regional groundwater flow, Tothian basin, analytical model, carcinogenic Cr(VI)*

HEALTH RISK ASSESSMENT OF FLUORIDE CONTAMINATION IN GROUNDWATER: A CASE STUDY OF ALWAR DISTRICT, RAJASTHAN, INDIA

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Globally, groundwater is a crucial resource for sustaining human life, agricultural production, and industrial requirements. However, the current trends in its utilization are causing a significant decline in both its quality and quantity, posing a serious threat to long-term water security. Furthermore, over-extraction of groundwater due to increasing demand lowers water tables, concentrating geogenic elements and worsening water quality. Additionally, anthropogenic activities like mining and industrial activities worsen the problem by releasing effluents into the environment. These challenges highlight the urgent need for regular monitoring and effective management to protect this vital resource. In view of this, the present study is to assess the groundwater quality and associated health risks in the Alwar District of Rajasthan, focusing on the fluoride contamination that poses significant health challenges. The study aims to evaluate fluoride levels in groundwater across different villages and analyze their impact on various age groups of the local population, who heavily rely on groundwater resources for domestic and agricultural needs. Groundwater quality data from CGWB wells, collected between 2016 and 2021, were analyzed to determine the extent of contamination and identify villages where fluoride concentrations exceed the Health Quotient threshold for safe consumption.

Alwar District, situated in Eastern Rajasthan, is geographically characterized by the presence of the Pre-Cambrian Aravalli hills, which is the dominating topography of the region. The plains in the district are primarily composed of Quaternary alluvium, forming the main aquifer system that supports groundwater availability. The hydrology of the study area is significantly influenced by seasonal rivers i.e., Sabi, Ruparail, Chuhar Sidh, and Landoha originating from Aravalli hills flow in the north-east direction. Since 2019, 9285 habitations across India have been identified as affected by fluoride, out of them 4,349 are in Rajasthan. The National Fluorosis Prevention and Control Programme (NPPCF, 2014) has been implemented in 30 districts of Rajasthan, including Alwar, to tackle this widespread issue (Directorate of Economics and Statistics, 2023-2024). These factors highlight the critical significance of Alwar District as a priority region for addressing the pressing issue of fluoride contamination in groundwater.

The study analyzed groundwater quality data from CGWB borewells across villages in Alwar District, Rajasthan, for the period 2016 to 2021. The number of wells sampled varied each year for the study area. In 2016, data from 42 wells were collected, followed by 32 wells in 2017, 24 in 2018, 19 in 2019, 10 in 2020, and 26 in 2021. These data were analyzed to assess groundwater quality trends. The key health parameter, Health Quotient (HQ) with considering standard Reference Dose (RfD = 0.06 mg/kg/day), was calculated based on the United States Environmental Protection Agency (USEPA, 1993) recommendations. Daily

Water Intake (DWI), Average Lifespan (AL), Exposure Frequency (EF), Mean Body Weight (MBW), and Mean Age Exposure Duration (MEAD) were factored into the risk calculations for each demographic group. The study used standard values for health risk assessment parameters. Daily Water Intake (DWI) was set at 1, 3, and 4 liters per day for children, women, and men, respectively. Average Lifespan (AL) was considered as 12 years for children, 67 years for women, and 64 years for men. Exposure Frequency (EF) was uniformly set at 365 days per year for all groups. Mean Body Weight (MBW) was taken as 15 kg for children, 55 kg for women, and 65 kg for men, while Mean Age Exposure Duration (MEAD) was 4380 days for children, 24455 days for women, and 23360 days for men. A Health Quotient greater than 1 indicates a significant risk of severe health effects, such as dental and skeletal fluorosis. Conversely, an less than 1 is considered within the acceptable limit for non-carcinogenic risk from fluoride in groundwater, as per USEPA (1993) guidelines.

The study revealed significant variations in fluoride concentrations across well locations over the study period. In 2016, out of 42 wells, 37 wells had fluoride concentrations within the desirable limit (≤1 ppm), while 5 wells exceeded the permissible limit (≥1.5 ppm). For 2017, among 32 wells, 27 were within the desirable limit, 2 wells had fluoride levels between 1–1.5 ppm (safe limit), and 3 exceeded 1.5 ppm. In 2018, 22 out of 24 wells fell within the desirable limit, with 2 wells in the 1–1.5 ppm range. For 2019, 16 out of 19 wells were within the desirable limit, 1 well had fluoride levels between 1–1.5 ppm, and 2 exceeded 1.5 ppm. In 2020, 7 out of 10 wells had fluoride concentrations ≤1 ppm, 2 were in the 1–1.5 ppm range, and 1 exceeded 1.5 ppm. For 2021, among 26 wells, 21 had fluoride concentrations ≤1 ppm, 3 were in the 1–1.5 ppm range, and 2 exceeded 1.5 ppm.

The Health Quotient values for children indicated severe health risks (HQ ≥ 1) at 6, 7, 3, 4, 3, and 8 places for the years 2016, 2017, 2018, 2019, 2020, and 2021, respectively. For males, values ≥1 was observed at 5, 4, 2, 2, 3, and 3 places for the respective years, while for females, such values were found at 5, 6, 2, 3, 3, and 7 places for the respective years. The maximum HQ value for children was 3 at Ramgarh in 2021. For women, the highest value was 3.3 in Govindgarh in 2017, and for men, it was 3.7 at the same location and year. The study also indicated that fluoride concentrations tended to increase toward the plain areas, likely due to transport via runoff. Groundwater in the study area was found to be alkaline in nature, dominated by Ca^{2+} and Mg^{2+} ions over SO_4^{2-} and Cl^-. The analysis of the Piper diagram revealed that the groundwater is predominantly of the Ca-Mg-Cl-SO_4 type, typically associated with mineral dissolution from carbonate rocks or agricultural activities that contribute to increased sulfate and chloride levels in soil and groundwater. These findings underscore the need for targeted interventions to mitigate fluoride contamination and protect public health.

Keywords: *Alwar, fluoride, groundwater, health risk assessment, health quotient*

INFLUENCE OF MINERAL WEATHERING SEQUENCE AND ORGANO-MINERAL COMPLEXES ON FATE AND TRANSPORT OF NANOPLASTICS IN RIVERINE AND GROUNDWATER SYSTEMS

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Globally growing plastic production and its mismanagement are significant concerns due to its high durability, versatility, and robustness, leading to massive plastic accumulation in the riverine and subsurface environments. The majority of discarded plastic products in the environment undergo degradation into smaller fragments, i.e., microplastics (MPs, size < 5 mm) and nanoplastics (NPs, size < 1 µm) due to various environmental factors, and find their way across multiple water bodies. NPs, owing to their smaller size, exert a more significant adverse effect on human health and the environment. Surface water carrying NPs can percolate into the subsurface and ultimately reach the aquifer, which might cause groundwater contamination with NPs. Further, NPs can dominantly facilitate the co-transport of other contaminants due to their greater adsorption capacity, posing greater threats to subsurface ecosystems and endangering groundwater resources.

NPs fate and transport in the environment is significantly influenced by existing particulate matter and aqueous chemistry. Detailed investigation of NPs interaction with environmental colloids is of extreme scientific and societal significance. Colloidal mineral particles are omnipresent and often associated with organic matter and form organo-mineral complexes (OMCs) exhibiting different reactivity than their pure mineral phase. Mimicking the natural scenario, we investigated NPs interaction with abundantly occurring ferrihydrite its weathered product i.e., goethite and their corresponding OMCs i.e., organo ferrihydrite (O-Fh) and organo goethite (O-Goe). Our study provides insight into environmentally relevant mineral phases and OMCs impact on the fate and transport of NPs in aqueous and terrestrial environments.

Ferrihydrite, goethite, O-Fh, and O-Goe were synthesized and characterized. Polystyrene latex beads (100 nm, fluorescently labeled) were procured for this study, as a proxy of naturally occurring NPs in the environment. All experiments were performed at pH = 6 and 25°C. Stability studies of NPs (10 mg/L) have been carried out in order to investigate the potential role of minerals/OMCs on aggregation and sedimentation of NPs in suspension using the dynamic light scattering (DLS) technique and UV-Visible spectroscopy. Batch sorption experiments were performed to delineate the kinetics and adsorption capacity of respective minerals/OMCs for NPs. The unidentified concentration of remaining NPs in the supernatant was quantified using a fluorimeter. Further, systematic experiments involving column transport were conducted to understand the transport of NPs in subsurface porous media. Quartz sand was used to mimic the subsurface media, however, in real scenario, granular particles are usually coated with minerals and OMC, which can significantly impact NPs transport in the saturated porous media. Therefore, we performed the comparative transport experiments with bare, mineral, and OMC coated quartz sand and also estimated the role of pore water chemistry on the NPs retention in the column. XRD data revealed that ferrihydrite and O-Fh particles were amorphous and matches with the XRD pattern of two-line ferrihydrite exhibiting two characteristic broad peaks at 2θ of ~ 34° and ~ 63°. While, typical peaks at 2θ = 18°, 21°, 33.2°, 36.7°, 53.2°, and 59.1° corresponds to goethite, with similar peaks observed in O-Goe, suggesting that association of organic matter with minerals couldn't change the overall crystal structure of OMCs. The achievement of the point of zero charge in the presence of goethite at 35 mg/L, however in the presence of Fh, O-Fh, and O-Goe results suggested that overall zeta potential of respective NPs-mineral bimodal system remains negative, suggesting enhanced stability of NPs. Sedimentation kinetics results correlated well with the obtained zeta potential results, suggesting larger hetero-aggregation of goethite+NPs followed by their sedimentation.

Ionic strength (IS) and pH are significant factors influencing NPs interaction with minerals/OMCs in the aqueous system. We found that in all varying IS conditions goethite has shown almost similar maximum NPs adsorption, however, with increasing IS concentrations, O-Goe shown increased NPs adsorption. Similarly, we have seen insignificant change in obtained q_e values for ferrihydrite-NPs at different IS concentrations, however, O-Fh shows increasing NPs adsorption with increasing IS concentrations. In case of OMCs, at lower IS, there was a competition between ions and NPs to bind on the OMCs surface, which could result in partial attachment of NPs. Whereas, at higher IS, self-aggregation of NPs leads to enhanced adsorption on OMCs. Further, results revealed that increasing pH (5-9) of the solution has drastically decreased ferrihydrite sorption capacity with NPs. Whereas, goethite has shown moderate decreased in NPs adsorption with increasing pH of the solution, suggesting goethite-NPs interactions are less susceptible to pH variation of the aqueous systems. Further, OMCs have also exhibited similar trend of decreased NPs adsorption with increasing pH. Hence, acidic and alkaline conditions of aqueous systems can highly impact NPs interactions with minerals/OMCs, and ultimately dictate NPs fate. To represent the real scenario, we conducted sorption experiments in river water. Results revealed that in river water also goethite has shown significantly higher NPs sorption. However, ferrihydrite and OMCs have shown similar limited interaction with NPs in river water, attributing to combined effect of interfering ions and dissolved organic matter. Our experiments in controlled conditions shows good alignment with result in natural water matrices, suggesting this study could be useful to predict fate of NPs in aqueous systems.

Ferrihydrite, goethite and OMCs are abundantly present in subsurface media, they often occur as patches over sand grains which can significantly impact the fate and transport of NPs. Results in RW revealed that, NPs retention in ferrihydrite and goethite-coated quartz sand was higher than their respective OMCs-coated sand, suggesting that pure mineral phase is efficient than OMCs to restrict NPs mobility in subsurface media, and acting as natural filter to protect groundwater aquifer from plastic contamination. This study provides insightful details on the role of pure mineral phase and their respective organo-mineral complexes on NPs fate and transport in aqueous and subsurface environments, emphasizing the mobility of NPs in riverine and groundwater systems.

Keywords: *Nanoplastics, mineral-organic complex, sorption, transport, groundwater*

EVALUATION OF IMPACT OF MINING ON GROUNDWATER QUALITY IN AND AROUND SINGRAULI COALFIELD, INDIA

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The study area, Singrauli coal field region is located in the Singrauli district of Madhya Pradesh and in the Sonbhadra district of Uttar Pradesh state in central India. Singrauli (NCL) is one of the largest coal fields and power complexes (Mini Ratna, Category I) in the world, presently contributing about 16% of India's coal production by large mechanized opencast mines. At present, Indian coal is the most abundant fuel resource, the principal source of energy, and most significant contributor to the country's industrial success. Geologically study area is composed of Gneissic complex, metamorphic rocks and sandstone with clay, ferruginous sandstone, sandstone shale with clay of Lower Gondwana group. Barakar is the only coal bearing formation in which all the coal mines are operating. The Major River draining the area is Rihand, which is a tributary of river Son. Open-cast coal mining processes generate a substantial quantity of solid wastes, such as waste rock debris, heap leach materials caused by overburden disposal, tailings, and liquid wastes from the washing facilities. Coal mining have impacted the natural water quality, quantity, its flow direction and produce environmental, ecological, and geological imbalance.

Acid mine drainage is a serious issue in coal mining area where sulfide-enriched coal is present. Among the various contaminants affecting groundwater quality in which fluoride and nitrate have emerged as two of the most concerning. High levels of fluoride in groundwater can lead to dental and skeletal fluorosis, and Nitrate contamination in groundwater can cause methemoglobinemia in infants (a condition known as "blue baby syndrome") and other health problems in humans. The contamination of groundwater by these substances is a growing public health concern, especially in rural areas where people heavily rely on untreated well water. This study focuses on assessing the groundwater quality in and around the Singrauli coalfield, with a specific emphasis on fluoride and nitrate contamination. By analyzing groundwater samples from various sources across the region, this research aims to understand the extent of contamination and its potential implications for public health.

During Pre-monsoon season 2022, a total 54 grid-wise water samples were collected from Northern coalfield of Singrauli district, M.P. and adjoining district of Sonbhadra, Uttar Pradesh and analyzed by the National Institute of Hydrology (NIH), Roorkee Uttarakhand. At every sampling site, wells were perched for a few minutes before collecting the representative water sample. Our study focused exclusively on 31 groundwater (GW) samples collected from boreholes, hand pumps, and dug wells. All the water samples were collected in the pre-washed HDPE bottles APHA (2005) and filter through Micro Separation Filter Paper Nylon Springe (0.45-µm) filters for major ion chemistry. In-situ parameters such as pH, EC, ORP and temperature were measured using portable waterproof Hanna Instrument. Alkalinity such as concentration of HCO_3^-, CO_3^{2-} of the water samples were identified by Titrimetric method, using suitable reagent such as methyl alcohol, phenolphthalein and Measure ions were determined by Ions Chromatograph method using Standard Cations, Anions mobile phase and silica is analyzed by UV Spectrophotometer respectively. Before analysis of the sample, the instrument was calibrated as per standard norms. The minimum detection limit (MDL) of various ions is about 1 mg/L, except fluoride which is 0.2 mg/L.

The measured physicochemical parameters of the groundwater samples are compared with the drinking water standards established by Bureau of Indian Standards (BIS, 2012) World Health Organization standards (WHO, 2011). The pH of the groundwater in the study area varies from 5.5 to 7.3 with an average of 6.4, which is indicating acidic to alkaline nature of the water samples. Out of total sample, 32% of groundwater samples pH values are lesser than the desirable limit of 6.5 for drinking water. The TDS value for groundwater varied from 160 mg/L to 947 mg/L (avg: 493 mg/L). TDS value in AMD water is exceeding the permissible limit. Sulphate concertation in groundwater samples are varies between 3.28 to 212.48 mg/l with an average of 65.29 mg/l, and $NH4^{+}$ in the groundwater are varies between 0 to 1.21 mg/l with an average of 0.36. The $NH4^{+}$ concentration in 29% groundwater samples is exceeding the permissible limit. The cation and anion abundance in the groundwater samples are in order of $Ca^{+2}>Na^{+}>Mg^{+2}>K^{+}$ and $HCO3^{-}> SO4^{+2}>Cl^{-}>NO3^{-}>F^{-}$. Majority of the groundwater samples are having water facies of Ca^{+2}- Mg^{+2}-$HCO3^{-}$, Ca^{+2}-Mg^{+2}-$SO4^{-2}$-Cl^{-} and mixed type. The result of WAWQI given in suggests that 31% and 22% of groundwater samples respectively are excellent to good type for drinking, irrigation purposes, while 22% and 3% of samples are poor to very poor water type and 9% of the samples are unfit for any purpose. The concentration Nitrate range from 0.06 to 153.87 mg/l with an average of 26.81 mg/l. The Nitrate concentration exceeds permissible limit in 16% in the groundwater. The fluoride values in the groundwater vary between 0.06 to 4.27 mg/l with an average of 0.86 mg/l. The fluoride concentration exceeds prescribed limit in 13% of the groundwater. The K^{+} in the groundwater 2.40 to 28.64 mg/l with an average of 8.30 mg/l and K^{+} values are exceeding 29% in the groundwater sample. The Ca^{2+} in the groundwater vary between 5.65 to 119.76 mg/l with an average of 63.68 mg/l, respectively.

The present study reveals that the Fluoride and Nitrate concentration in ground water is more than the BIS for drinking water. Nitrate contamination in groundwater due to human induced and contamination from industrial effluents while fluoride contamination in groundwater due to both geogenic and anthropogenic activities. Anthropogenically, high fluoride concentration in groundwater near fly ash ponds (rich in fluoride) may result due to leaching & percolating water near the mine area. Geogenic fluoride mobilization may occurs due to presence of apatite, biotite and hornblende bearing rocks such as Granitic Gneissic Complex present in the study area. The weighted average water quality index (WAWQI) indicates 34% of the groundwater samples were unfit for drinking purpose in the coal mine area. The major water facies of the water system were found to shift from fresh water type Ca-HCO3 to (Na+K)-SO4, Ca-SO4 and mixed type shows dominance of alkaline earth metals over alkalis and dominance of weak acid ($HCO3^{-}$ + $CO3^{-2}$) over strong acid suggestive of $HCO3^{-}$ driven silicate weathering in the area. Silicate weathering, and ion exchange are major Hydrogeochemical processes operating in study area.

Keywords: *Groundwater, water quality, impact of coal mining, fluoride contamination, groundwater depletion, WAWQI*

HYDRO-GEOCHEMISTRY AND ISOTOPIC CHARACTERIZATION OF PHREATIC GROUNDWATER IN PART OF CENTRAL GANGA PLAIN, INDIA

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Groundwater constitutes 97% of the planet's freshwater resources and is indispensable for drinking water, agriculture, and industrial activities. It serves as the primary source of drinking water for approximately half of the world's population, with 2.5 billion people relying solely on it to meet their daily needs. The quality and availability of this resource, however, are increasingly compromised by industrialization and modern agricultural practices. This degradation is driven by the excessive withdrawal of groundwater and uncontrolled use of fertilizers, pesticides and insecticides, a challenge further exacerbated by population growth and the escalating impacts of climate change. Aquifer water chemistry is the result of both geological factors and anthropogenic processes. The alluvial aquifer of the Central Ganga Plain (CGP) is crucial for the livelihoods of residents providing water for irrigation, drinking and household use. The increasing overexploitation of groundwater driven by high demand and intensive agricultural activities resulting in deteriorating water quality and declining water level in the area.

Present study was carried out in the part of CGP, comprising of two districts (Azamgarh, and Jaunpur) of state Uttar Pradesh which covers an area of 7,932 km^2. The study area is characterized by alluvial sediments, which are classified into two distinct units: younger alluvium, limited to the active floodplain, and older alluvium, occupying higher elevations. The unconsolidated nature of these sediments, exhibiting both porosity and permeability, which results in a potential groundwater aquifer. Gomti, Sai, and Tamsa are the major rivers flowing in the area. Groundwater samples (n=48) were collected from handpumps, and tubewells in March 2021. In situ measurement of spatial data, pH, EC, ORP, and temperature were carried out in the field. Groundwater samples were analyzed for major ions and stable isotopes (^{18}O and ^{2}H) at the National Institute of Hydrology, Roorkee. The groundwater samples are near neutral to slightly basic in nature and EC values vary from 510-2890 µS/cm indicate groundwater mineralization. Na^+ is the dominating cation followed by Ca^{2+} and HCO_3^- is the most abundant anion followed by Cl^-. NO_3^- (n=3) and SO_4^{2-} (n=3) ions exceed the permissible limit of BIS. The Mg-Ca-HCO_3 (32%) is the major water facies followed by Na-HCO_3 (14%). The Gibbs plot for cations and anions suggest the rock water interaction is the key process for the mineralization, which is in agreement with the result of Na/Cl vs EC plot. Hydrogeochemical analysis, using different bivariate plots suggest silicate weathering is the major process operating in the area followed by ion exchange.

The δ^{18}O values vary from -8.95‰ to -3.92‰ and δ^{2}H values vary from -61.24‰ to -29.7‰. The groundwater line (GWL) has been developed using 41 samples which is given as: $\delta^2H = 5.6\times\delta^{18}O - 10.5$. The lesser slope of 5.6 and intercept of GWL in comparison to Global Meteoric Water Line (GMWL) and Local Meteoric Water Line (LMWL) suggest the effect of evaporative enrichment. The d-excess value varies from -1.8‰ to 14.3‰. The d-excess of the majority of the samples confirm the evaporative enrichment of groundwater. Two

samples with $\delta^{18}O$ values of -8.95‰ and -8.57‰, are close to the canal isotopic values (mean -9.96‰) which suggest to recharge of phreatic aquifer through canal. The hydrochemical and isotopic study indicate that local rain is main source of recharge to phreatic aquifer and geogenic processes are the main controlling factor of the hydrochemical characteristic of the groundwater.

Keywords: *Silicate weathering, stable isotope, middle ganga plain, geogenic contamination*

PRINCIPAL COMPONENT ANALYSIS AND MODIFIED GROUND WATER QUALITY INDEX AS POWERFUL ACTIONABLE TOOLS FOR GROUND WATER QUALITY ASSESSMENT AND POLICY INTERVENTION: A CASE STUDY IN PART OF THE GANGETIC RIVER BASIN OF GORAKHPUR DISTRICT, INDIA

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Groundwater serves as a crucial source of drinking water in India. Regions like Gorakhpur District, Uttar Pradesh, India, having population >4.4 million (2011) with decadal growth rate of 17.81%. The district has nearly 100% groundwater-based drinking water supply. Indian Government's vision to achieve piped water supply to each household in sufficient, safe and affordable manner is largely dependent upon the groundwater resources. Hence, determination of groundwater quality for stakeholders becomes paramount considering public health concerns. The present study uses the Principal Component Analysis (PCA) to reveal the factors controlling ground water quality and proposes a modified version of the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) to provide actionable index assessment. This modification incorporates the BIS guidelines for drinking water quality, ensuring alignment with national regulatory standards and public health needs.

The study area is Gorakhpur Administrative District having 3484 km^2 geographical area. The study area, lies in the Gangetic Plains and is drained by structurally controlled Rapti River. The plains consist of Quaternary alluvial deposits. Sandy and Silty-sandy layers form the unconfined aquifers which are underlined by the clayey layer acting as confining layer. Ground water samples were collected from 32 locations from the study area during pre-monsoon of year 2023 in such a manner that whole area is covered evenly. Samples were collected from the ground water sources tapping phreatic aquifer. Standard procedures and guidelines of sampling, storing, and transferring were followed as prescribed by APHA. 14 basic physio-chemical parameters (pH, TDS, Chloride, Carbonate, Bi-carbonate, Sodium, Potassium, Magnesium, Total Hardness, Calcium, Fluoride, Sulphate, Silica, Nitrate) and 6 Heavy Metals (Manganese, Iron, Arsenic, Lead, Zinc and Uranium) were analysed for this study. PCA is a powerful tool for multivariate statistical analysis. PCA can provide information about hidden relationships among original variables. For present dataset, Principal Components (PCs) were calculated and loading factors for top contributing PCs were also determined. The analysis was performed using Python 3.9 on Google Colab using the scikit-learn library.

GWQI is calculated using CCME-WQI. This method gives the values in range of 0 to 100 and scale divides water in 5 categories (95-100 Excellent, 80-94 Good, 65-79 Fair, 45-64 Marginal, 0-44 Poor). The issue with this index is that when the fewer number of variables are above the recommended values it may fail to appropriately incorporate their effect on drinking water quality. There might be cases when a heavy metal or carcinogenic variable is present above prescribed maximum limit but CCME-WQI might classify the water sample in higher categories. Since, drinking water supply is directly linked to the public health aspects, decision makers and stakeholders need to have a tool which can clearly point out the contaminated water source for timely and effective policy interventions and remedial measures. To address these challenges a simplified method has been proposed which takes into account the CCME-WQI and the standards set by the regulatory agencies. The Indian Standard for Drinking Water prescribed by BIS provides a range of concentration for various physio-chemical parameters. It defines as Acceptable limit and Permissible limit. The standard recommends the Acceptable limit to be adopted for the drinking water purposes. Values above this limit renders water unsuitable for human consumption and may cause health risk. But in case of absence of alternate water source, up to permissible limit of water can be used. The prescribed classification is Permissible (CCME-WQI>90 and no failed parameters), Acceptable (CCME-WQI>65 and One or More Parameters Beyond Acceptable but under Permissible Limit) and Unacceptable (CCME-WQI<65 or One or More Parameters beyond Permissible Limit). The basic statistical analysis was performed for all the 20 physio-chemical constituents of 32 sampling locations. Mean, Median, Mode and Standard deviation for each parameter were calculated. The maximum values in case of TDS, Total Hardness, Bi-carbonate, Calcium, Magnesium, Manganese, Iron, Arsenic are above acceptable limits recommended by Indian Drinking Water Quality Standards.

The PCA reveals that the first four principal components explain 71.27% of dataset variation as shown in Table 2. PC1 contributes 35.28% of total variation in the data set. Loading factor analysis reveals that the TDS (0.3778, Cl (0.3425), TH (0.3408), Mg (0.3184), Na (0.3190), and HCO3 (0.2944) are the important constituents of PC1. Whereas, PC2 contributes to the 17.34% variation with Zn (0.3589), As (0.3578), Mn (0.3405), Fe (0.3324), and Ca (0.3641) as the main contributors for PC2. As per original CCME-WQI, 08 sampling locations have ‘Excellent’ category of groundwater for drinking and domestic purpose, while 15 locations have ‘Good’ and 9 have ‘Fair’ category. Our proposed Modified CCME-WQI shows that only 05 locations have ‘Permissible’ quality of water, whereas 09 locations have ‘Acceptable’ quality and 18 locations have ‘Unacceptable’ quality of ground water. PCA analysis suggests that PC1 component likely represents the overall mineralization of groundwater, driven by natural geological processes or anthropogenic factors while PC2 is primarily associated with heavy metals (Zn, As, Mn, Fe). This component might indicate geochemical processes and reactions such as dissolution of minerals. PC3 highlights lead (Pb) and fluoride (F), which are significant contaminants in groundwater. PC4 captures the trends associated with arsenic contamination, a critical concern in groundwater, particularly in regions with natural arsenic mobilization from sediments. The modified CCME-WQI, incorporating Indian drinking water standards, provides a clear and actionable assessment of groundwater quality. Out of 32 locations analysed, 18 were classified as "Unacceptable," indicating significant challenges in water quality management, and urgent mitigation measures to be adapted. 9 locations have “Acceptable” type of quality, where remedial steps should be adopted to minimize the long-term health risks. Only 5 locations met "Permissible" standards. Hence modified CCME-WQI provides targeted locations for positive interventions by decision makers and stakeholders. This study underscores the utility of modified CCME-WQI type indices in guiding informed policymaking for sustainable, safe drinking water management.

Keywords: *Water quality index, principal component analysis, ground water contamination, public health risks, drinking water, Gangetic Plains*

HYDRO-GEOCHEMICAL INVESTIGATION OF GROUNDWATER AND SURFACE WATER QUALITY IN THE MINING-IMPACTED REGIONS OF NORTHERN COAL FIELD SINGRAULI, CENTRAL INDIA

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Coal mining is an important global operation, which drive to energy production and economic development of a nation. However, it also has a negative impact on environmental, especially on water resources. Both open-pit and underground coal mining operations have been linked to surface water contamination, groundwater depletion, and disruption of natural hydrological systems worldwide. Acid Mine Drainage (AMD), causes the leaching of heavy metals and sulphates, causing severe pollution in water bodies and affecting ecosystems and human health. In India, coal mining plays a pivotal role in meeting the nation's energy demands, with coal contributing over 70% of the total energy generation. The country's coal-rich regions, especially in states like Jharkhand, Chhattisgarh, Odisha, and Madhya Pradesh, are hotspots for extensive mining activities. The Northern Coal Field (NCL), Singrauli region in central India is experiencing significant water contamination challenges due to extensive mining operations, thermal power plants (TPPs), ash ponds, and industrial activities. This factor contributes to environmental degradation adversely impacting ecosystem and human health while raising concerns about the portability of water resources in the region. The study focuses on mines of NCL Singrauli and its surrounding areas aiming to establish a comprehensive baseline dataset on water quality. By analyzing hydro-geochemical attributes of collected water samples, the research seeks to identify key factor influencing water quality and contamination in the area. Understanding groundwater hydro-chemistry in coal mining regions is crucial for assessing water-rock interactions and identifying water sources. In this study, the effects of coal mining, TPPs, and industrial activities on the quality of groundwater and surface water in and around NCL Singrauli have been systematically evaluated. The findings provide critical insights into the hydrogeochemical processes and contamination pathways shaping the region's water resources.

To obtain a hydro-geochemical characterization of groundwater and surface water in the study area, water sampling surveys were carried out during pre-monsoon 2022, Grid-based sampling for 1525 sq. km area has been done (10km×10km grid) during summer 32 water samples (21 groundwater samples, 7 mines water samples, 4 surface water) samples were collected from check dams, flowing water, industrial/mine effluents and from shallow and deeper sources (i.e., dug wells, hand pumps, and bore wells), in mines of NCL Singrauli and the surrounding areas as per the standard procedures of APHA (2012). Separate samples have been collected for major ions, trace metals, stable isotopes, and radiogenic isotopes. The physical and chemical parameters that were measured during the sampling survey are listed, including the pH, ORP, electrical conductivity (EC), sample location, and water temperature (T). The water samples were filtered using 0.45-µm filter paper and preserved by adding concentrated nitric acid (HNO_3) (2 ml) to maintain the pH of 2. Alkalinity was also measured by titrating with H_2SO_4 (0.1 N) and methyl orange as an indicator in the Hydrology Laboratory of the Department of Geology at Banaras Hindu University. Major anions Ca^{2+},

Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, F-, HCO_3^{-} , NO_3^{-} and Cl^{-} were analyzed by using an ion chromatograph at NIH Roorkee. The ion balance error is found below 10% for the analyzed samples. After being acidified with HNO_3 (pH<2), samples were kept cold until they were transported to the lab to be analyzed for trace metals like Cu^{2+}, Ni, Fe^{2+}, Co^{2+}, Mn^{2+}, Zn^{2+}, Cr, Pb, Cd, Al^{3+}, B, Se and As by using ICPMS at NIH Roorkee.

The pH of water samples varies from 2.5 to 8.2 (average value of 6.3) i.e. acidic to alkaline in nature. From the total samples, 44% of the groundwater and 31% of surface water samples had lower pH values than the permissible limit of pH and showed an acidic nature. TDS values ranging from 154 to 1570 (average of 560) mg/L in water samples were mainly within the freshwater category, except 4 samples from acid mine drainage which had TDS values> 1000 mg/L. The Piper diagram (Piper, 1944) plotted for hydrochemical facies in the study area shows that the dominating facies are Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^{-} (41%), followed by Ca^{2+}-Mg^{2+}-HCO_3^{-} (37%), Mixed (Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^{-}) (16%), (Na^{+}+K^{+})-SO_4^{2-}-Cl^{-} type (6%). All the MW and AMD samples fall in Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^{-} water facies and the majority of GW samples fall in Ca^{2+}-Mg^{2+}-HCO_3^{-} water facies. In Gibb's diagram sub-surface water chemistry was controlled by rock-weathering along with the influence of evaporation dominance. Out of the total groundwater samples analyzed, 13% exceeded the permissible limit for nitrate, 19% for fluoride, and 38% for ammonium. In surface water samples, 6% exceeded the permissible limit for fluoride, 6% for calcium, 25% for electrical conductivity (EC), and 44% for ammonium. The Gibbs plot indicates that the groundwater samples are influenced by rock-water interactions. However, all Acid Mine Drainage (AMD) and one Mine Water (MW) sample show a trend towards evaporation. Among the groundwater samples, the low Mg^{2+}/Na^{+} and Ca^{2+}/Na^{+} ratios observed in two samples suggest an additional source of Na^{+}. Furthermore, silicate weathering and its associated minerals have left a distinct signature on the groundwater chemistry. For the groundwater samples, 19% exceeded the permissible limit for aluminium (Al), while 6% exceeded the limits for boron (B) and manganese (Mn). In surface water, 38% exceeded the limit for aluminium, 19% for manganese, 25% for nickel (Ni), and 6% for selenium (Se).

The pH of (44%) groundwater samples and (31%) surface water samples are acidic in nature and have pH below the permissible limit of BIS (2012), i.e. (6.5 – 8.5). Major hydrochemical facies in AMD and mine water samples are characterized by Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^{-}, and groundwater samples are characterized by Ca^{2+}-Mg^{2+}-HCO_3^{-}. The major ions like F^{-}, NO_3^{-}, and NH_4^{+} in the groundwater and Ca^{+2}, F^{-}, NH_4^{+}, NO_3^{-}, and SO_4^{2-} in surface water samples exceeded the permissible limit of BIS (2012). The source of fluoride contamination in the study area is due to coal burning in a thermal power plant and pink granite formation of the area; both anthropogenic and geogenic sources are implied. High nitrate and ammonium concentrations are observed in mine water sump samples and the samples that are near rural areas. Trace metals like Al, B, and Mn in the groundwater Al, Mn, Ni, and Se in surface water samples exceeded the prescribed limit of BIS (2012). Silicate weathering and ion exchange are the major hydrogeochemical processes observed to control the groundwater chemistry in the study area. The reason for this unusually high concentration of some of the major ions and trace metals in the groundwater of Singrauli may be due to both geogenic and anthropogenic activities like coal mining and leaching from the waste generated from the various power plants, ash ponds, industries, etc.

Keywords: *NCL, AMD, hydrochemistry, water chemistry, hydrogeochemical*

SYNTHESIS OF BAMBOO-DERIVED ACTIVATED CARBON FOR GROUNDWATER TREATMENT: TURBIDITY AND HARDNESS REDUCTION

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Activated carbon has emerged as a promising adsorbent for water purification due to its high surface area and porosity. Bamboo charcoal, characterized by its high porosity and exceptional adsorption capacity, presents an economical and non-toxic alternative to conventional adsorbents. Furthermore, bamboo-derived carbon materials exhibit unique properties such as electromagnetic shielding and infrared radiation absorption. Therefore, we concentrated our efforts on the appropriate engineering and development of materials based on bamboo-derived activated carbon discovering practical and efficient ways to utilize this abundant supply of adsorbents material for groundwater treatment, with a focus on turbidity and hardness reduction. In this work we synthesis, characterization, and application of bamboo carbon (BC) and activated bamboo carbon (ABC) for water treatment. This study evaluates the efficacy of bamboo-derived activated carbon for groundwater treatment as well with a focus on turbidity and hardness reduction.

The research methodology encompassed the synthesis, characterization, and application of BC and ABC for water treatment. Waste bamboo chunks were carbonized to produce BC, which was subsequently activated using HNO_3 to enhance its adsorption properties and facilitate reuse. The structural, morphological, and functional properties of BC and ABC were comprehensively characterized using various analytical techniques. XRD analysis was employed to determine the crystalline structure and sizes of BC and ABC. X-ray photoelectron spectroscopy (XPS) provided insights into the surface chemical composition and bonding states of the carbon materials. SEM was utilized to examine the surface morphology and pore structure of the adsorbents. Zeta potential analysis was conducted to assess the surface charge characteristics of BC and ABC. FTIR spectroscopy was performed to identify the functional groups present on the adsorbent surfaces. Comparative adsorption studies were carried out to evaluate the effectiveness of BC and ABC in removing turbidity and hardness from various water samples. The water samples included groundwater and river water collected from New Dari village, Dali, Siang, Aalo, Pasighat and Leparada districts as well as from different regions of Jonai in Assam. Batch adsorption experiments were conducted under varying conditions to optimize the treatment process. The experimental parameters investigated included adsorbent doses (ranging from 0.01 to 0.04 g/L), temperatures (25°C to 45°C), and agitation times (10 to 60 min).

The results revealed significant differences between BC and ABC, highlighting the impact of chemical activation on the adsorbent properties. XRD analysis showed that the crystalline sizes of BC and ABC were 57.41 nm and 24.71 nm, respectively, indicating a reduction in crystallite size upon activation. This decrease in crystallite size suggests an increase in the surface area and porosity of ABC compared to BC, potentially enhancing its adsorption capacity. Zeta potential measurements provided insights into the surface charge characteristics of the adsorbents. BC exhibited a surface charge of -36.2 mV, while ABC showed a slightly more negative charge of -39.6 mV. The increased negative surface charge of ABC may contribute to enhanced electrostatic interactions with positively charged contaminants, improving its adsorption performance. According to the SEM pictures, bamboo fibres and parenchyma cells, among other structural characteristics, were preserved when carbonized BC was pyrolyzed at 400°C. Additionally, the longitudinal section of the BC revealed well-built, big, regular, and cleanly ordered pores that measured less than 5 mm. Large macropores oriented parallel to the fibres were retained after BC was activated using an HNO_3 at 400°C. Additionally, a number of nanosized pores may have formed on the surface of the AC as a result of internal bonding breaking. The activated carbon's SEM pictures reveal a slightly expanded view of numerous thick, circular pores that may be macropores, resulting in branching micropores inside the carbon. The adsorption studies demonstrated the superior performance of ABC compared to BC in removing turbidity and hardness from water samples. Under optimal conditions, ABC achieved up to 100% removal of both turbidity and hardness. The enhanced adsorption capacity of ABC can be attributed to its increased surface area, improved pore structure, and modified surface chemistry resulting from the chemical activation process. The effects of various experimental parameters on the adsorption performance were investigated. Increasing the adsorbent dose from 0.01 to 0.04 g/L led to improved removal efficiencies for both turbidity and hardness, likely due to the increased availability of adsorption sites. Temperature variations between 25°C and 45°C showed a moderate impact on adsorption performance, with slightly higher removal efficiencies observed at elevated temperatures. This suggests that the adsorption process is endothermic in nature. The agitation time study revealed that the adsorption process reached equilibrium within 60 minutes, with the majority of contaminant removal occurring within the first 30 minutes.

This study demonstrates successful synthesis and application of bamboo-derived activated carbon for groundwater treatment, specifically targeting turbidity and hardness reduction. The use of waste bamboo as a precursor for activated carbon production aligns with sustainable development goals by utilizing abundant and renewable resources. Furthermore, the study showcases the role of nanotechnology in enhancing the efficiency of water treatment processes, as demonstrated by the nanoscale crystallite sizes of the synthesized adsorbents. Future research directions may include investigating the adsorption mechanisms in greater detail, exploring the removal of other water contaminants, and scaling up the production and application of bamboo-derived activated carbon for large-scale water treatment operations. Further, studies on the regeneration and reuse of the adsorbent would be valuable in assessing its long-term economic viability and environmental sustainability. This study contributes to the growing body of knowledge on sustainable water treatment technologies and underscores the importance of utilizing renewable resources in addressing global water pollution challenges. The successful application of bamboo-derived activated carbon for turbidity and hardness reduction in groundwater treatment opens up new avenues for the development of efficient, cost-effective, and environmentally friendly water purification solutions.

Keywords: *Bamboo charcoal, bamboo activated carbon, water treatment*

EXAMINING THE CHARACTERISTICS OF GROUNDWATER QUALITY IN FLUORIDE-ENRICHED HARD ROCK REGION IN VELLORE DISTRICT TAMILNADU, INDIA USING HYDRO-GEOCHEMICAL AND MULTIVARIATE STATISTICAL TECHNIQUES

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Groundwater is an essential resource that sustains human life, agricultural activities, industrial processes, and ecosystems. It serves as a critical source of drinking water for millions worldwide, emphasizing the importance of its protection and sustainable management. However, groundwater faces growing threats from over-extraction and contamination, endangering its availability for future generations. Among various contaminants, fluoride is a naturally occurring geogenic pollutant at presents a significant challenge, impacting groundwater quality more profoundly than industrial pollutants. Geogenic fluoride pollution, particularly in arid and semi-arid regions, is a growing concern. Fluoride contamination in groundwater has far-reaching implications, often surpassing the impact of industrial pollutants. Excessive fluoride concentrations pose serious health risks, such as dental and skeletal fluorosis, necessitating stringent monitoring and management to ensure the sustainable use of this invaluable resource. This study focuses on investigating groundwater quality in a fluoride-enriched region of Vellore district, Tamil Nadu, India.

Groundwater quality data from 30 wells were obtained from the Central Ground Water Board (CGWB) between 2022 and 2023. The data obtained was categorized into two seasons, pre monsoon and post monsoon. On analysis it revealed that 60% of the samples exceeds the permissible fluoride limit of 1 mg/L according to World health organization (WHO). The study also examines the hydro-geochemical processes and mechanisms influencing groundwater chemistry and employs advanced exploratory data analysis techniques, including structural equation modeling (SEM), to validate the findings. Hydrogeochemical analyses indicate that groundwater in the region is predominantly of the $NaHCO_3$ (sodium bicarbonate) and NaCl (sodium chloride) types, attributed to rock-water interactions and anthropogenic sources, respectively. These interactions result in most groundwater samples exhibiting alkaline characteristics. Further to provide a comprehensive understanding of groundwater quality, the study utilized advanced multivariate statistical methods, including Cluster Analysis (CA), Factor Analysis (FA), Multiple Linear Regression (MLR), and Structural Equation Modeling (SEM). These methods enabled the categorization, identification, and modeling of factors contributing to groundwater quality and fluoride contamination. Cluster Analysis (CA) classified the sampling locations based on water quality and physico-chemical parameters, grouping them according to similar characteristics. This method proved effective in identifying regional variations and provided a clearer understanding of the underlying factors influencing groundwater quality. It also facilitated the linking of physicochemical attributes to their sources, distinguishing between natural processes, such as rock-water interactions, and anthropogenic influences, such as agricultural runoff or urban activities.

Cluster of TDS, TH, Ca, Mg, Cl, and SO_4, indicates water with higher hardness and salinity. Additionally, a cluster of F, Na, and HCO_3 reflects natural weathering activities, while another cluster, consisting of pH, K, and NO_3, highlights the influence of agricultural activities in the region. The classification enabled the targeted identification of areas in need of intervention, helping to prioritize regions that require focused attention for remediation or further study. Factor Analysis (FA) simplified the dataset by transforming correlated variables into a smaller set of uncorrelated factors, thereby reducing the dimensionality of the data while retaining essential information. The factor loadings revealed distinct influences on groundwater quality: Factor 1 showed strong associations with chloride (Cl), calcium (Ca), and magnesium (Mg), indicating contributions from mineral dissolution and rock-water interactions. Factor 2, on the other hand, was characterized by high loadings for sodium (Na), bicarbonate (HCO_3), and sulfate (SO_4), suggesting influences from anthropogenic sources, such as agricultural activities or industrial processes, as well as evaporation.

These findings highlight the different hydro-geochemical processes that contribute to the quality of groundwater in the region. The Multiple Linear Regression (MLR) model provided further insights into the factors contributing to contamination, offering a highly accurate method for identifying both environmental and geogenic sources of fluoride enrichment. The model highlighted the complex interplay between natural processes and human activities in shaping groundwater chemistry, demonstrating how these factors together influence fluoride levels. Structural Equation Modelling (SEM), a robust multivariate statistical technique, was employed to construct and validate models linking observed and latent variables. This approach facilitated the direct analysis of relationships between independent and dependent variables, offering a comprehensive understanding of the mechanisms influencing groundwater quality. The SEM results demonstrated excellent goodness-of-fit indices, with values of 0.98 for the pre-monsoon period and 0.97 for the post-monsoon period. These high indices highlight the reliability and effectiveness of SEM in modeling the complex dynamics of groundwater quality across seasons. The study also highlights seasonal variations in fluoride concentrations and identifies the key factors influencing groundwater quality in the Vellore district. The use of an integrated approach combining CA, MLR, and SEM to assess the groundwater quality in the study area reveals that the water chemistry is primarily influenced by rock-water interactions and the dissolution of evaporites. This study enhances our understanding of groundwater chemistry and highlights the urgent need for regular monitoring of fluoride contamination and its flow patterns in affected regions. Additionally, it provides valuable insights into preventive measures that should be implemented for wells impacted by fluoride dispersion from the source rock.

Keywords: *Fluoride, Hydro-geochemistry, Factor Analysis, Multiple Linear Regression, Structural Equation Modeling*

INTEGRATED ASSESSMENT OF GROUNDWATER QUALITY USING EWQI AND VARIANCE DECOMPOSITION METHOD TO EVALUATE FLUORIDE-INDUCED HEALTH RISKS

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Groundwater (GW) is an invaluable resource that provides a reliable source of freshwater for multiple activities such as agriculture, industry, and domestic use. The World Health Organization (WHO) reports that over 750 million people worldwide struggle to access safe drinking water. In emerging economies like India, groundwater is a primary source of potable water. Contamination affects one-quarter of India's groundwater sources, impacting approximately 200 million people. Therefore, understanding the quality of drinking water is crucial for sustainable development in both urban and rural areas. GW contamination from both natural and man-made sources is currently posing a serious threat to India's Gangetic plains. Growing GW withdrawals, water scarcity, fast development, widespread industrialization, and urbanization are all contributing factors to the GW quality decrease. Numerous contaminants and trace elements, including fluoride and nitrate, are introduced as a result of these operations, and they pose a major risk to human health. Therefore, a thorough evaluation is required to quantify the level of GW pollution.

To fill this gap, 59 groundwater samples were gathered from tube wells and hand pumps of various depths in the Sirdala block in the Nawada district of Bihar during the pre-monsoon season A portable digital meter (PSCTestr35) was used to test physical parameters including pH, EC, and TDS as soon as the sample was collected. Ion chromatography was used to investigate the principal cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and anions (F^-, Cl^-, HCO_3^-, NO_3^-, and SO_4^{2-}). An entropy-based water quality index (EWQI) was used to evaluate the groundwater's suitability for human use. The entropy-weighted water quality index (EWQI) provides a comprehensive measure by integrating all physicochemical data into a single representative value that reflects overall water quality. This study assesses human health risk assessment (HHRA) related to fluoride and two distinct age groups: adults and children. Additionally, for oral health risk models, the relative contribution and interaction of input factors were evaluated using a variance decomposition-based Sobol sensitivity technique. Three distinct scores such as FOE (first order effect), SOE (second order effect), and TE (total impact) were assessed for various demographic age groups. Also, to understand the spatial variation and dynamics of groundwater quality, groundwater contamination, and its associated health risk the spatial maps were depicted using ArcGIS.

Ionic dominance in groundwater was shown to follow the following sequence: cations: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and anions: $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$, according to a descriptive examination of the hydrochemistry of groundwater samples. The nature of groundwater is slightly alkaline in nature and the concentration of fluoride exceeded the permissible limit of 1.5 mg/l in 42.37% of the total groundwater samples. The Entropy Weighted Water Quality Index (EWQI) is used in this study to measure the drinking water quality. The study region's groundwater samples had EWQI values ranging from 23.70 to 453.38. According to these findings, one of the study's groundwater samples was classified as having extremely poor

quality (rank-5), meaning it is not at all advised for human consumption. One sample that was deemed unsafe for consumption and with poor water quality (rank-IV) was identified. Roughly 8% of the samples were categorized as fair grade water (rank-III), meaning that they are just somewhat fit for human consumption. However, before fair-quality water is utilized for residential purposes, pretreatment is advised. 56% of the samples had excellent water quality, while about 32% of the samples were classified as good quality. Drinking water with a high F^- content may have a detrimental effect on human health and cause serious sickness. Hazard quotient (HQ) values were used to weigh the possible health impacts of F^-. No negative health consequences are anticipated if the calculated HQ is less than 1, and consumers are at serious risk if the HQ is more than 1. Hazard quotient fluoride (HQF) values varied between 0.24 and 6.71 for children, 0.160 and 4.47 for adults. The average value of HQF for children is 1.12 and for adults is 0.74. HQF > 1 was reported for 35.59% and 15.25%, of the samples for children and adults. Fluoride concentration (Cw) is particularly sensitive, according to the FOE, which is followed by exposure frequency (EF), intake rate (IR), and body weight (BW). According to the SOE scores, the most crucial input criteria for determining the danger to children's oral health are IR and Bw. The interactions Cw–IR for adults had the greatest Sobol score, followed by those for children. Additionally, the findings indicate that the oral risk is higher in the children's groups than in the adult groups.

The nature of groundwater is slightly alkaline in nature and the concentration of fluoride exceeded the maximum permissible limit of 1.5 mg/l in 42.37% of the total groundwater samples. The majority of the groundwater in the examined area had fair to excellent water quality, according to the analysis of EWQI values, making it fit for human consumption. The HQ value for F^- indicates that 35.59% and 15.25%, of the samples, for children and adults exceed the acceptable limit respectively. Additionally, the study investigates if the SSA approach can be used to another pollutant and whether it is feasible to examine the impacts of various input parameters for the health risk model. Improving the quality of groundwater is essential for protecting public health, particularly for vulnerable groups like children. These results highlight the need for careful monitoring and management techniques to protect groundwater quality from various contamination sources.

Keywords: *Groundwater quality, EWQI,* Sobol sensitivity *analysis, human health risk, Gangetic Palin*

A COMPARATIVE STUDY OF BIOFILTER, VERMIFILTER, AND MACROPHYTE-ASSISTED VERMIFILTER FOR TREATMENT OF CATTLE FEEDLOT WASTEWATER

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Macrophyte-assisted vermifiltration (MaVF) is an emerging technology for the treatment of cattle feedlot wastewater, proving to be efficient and sustainable compared to conventional methods. Contaminants released from untreated cattle feedlot wastewater are released into surface water, percolating into groundwater, leading to groundwater pollution. The contaminants present in cattle feedlot wastewater comprises of organic matter, nutrients and antibiotics. Antibiotics are one of the constituents frequently found in cattle feedlot wastewater, which poses a serious health concern. Moreover, the persistence of these contaminants in water and soil systems can have long-term ecological impacts, including toxicity to aquatic life and alterations in nutrient cycling. Antibiotics present in cattle feedlot wastewater pose significant environmental risks, including the development of antibiotic resistance in microorganisms. The wastewater containing the antibiotics and antibiotic resistance genes (ARGs) is further released into wastewater treatment plants (WWTPs). MaVF is a sustainable recent technology introduced for the treatment of wastewater, but a comparative analysis between different MaVFs and other biological treatment systems remains unexplored. Thus, in the present study, we performed a comparative analysis between three different technologies- biofilter (BF), vermifilter (VF), and macrophyte-assisted vermifilter for the treatment of cattle feedlot wastewater. The removal efficiency of Chemical Oxygen Demand (COD), Total Nitrogen (TN), ammonia, Total Phosphorous (TP), and antibiotics in the influent (i.e., cattle wastewater) through different bioreactors was evaluated. Three horizontal subsurface flow MaVFs were set up, namely T1, T2 and T3. T1 was MaVF planted with *Canna indica,* T2 was vermifilter bioreactor, and T3 was biofilter. The species of earthworms introduced in VF and MaVF were *Eisenia fetida,* commonly found in tropical areas. Synthetically prepared cattle wastewater containing antibiotics were applied to these systems through gravity feeding at a hydraulic loading rate (HLR) of 0.6 m^3/m^2/day. The bioreactors were examined for 120 days, and the effluent was analysed for different water quality parameters.

The results indicated substantial removal rates in different water quality parameters, including antibiotics. The average COD removal efficiency for T1, T2, and T3 were 60.2±1.9%, 52.9±1.1% and 42.4±1.2%, respectively. The average DO in T1, T2 and T3 effluent was 7.4 mg/L, 4.6 mg/L, and 3.06 mg/L respectively. The pH for influent wastewater was in the range of 9.16±0.4, whereas the effluent pH ranged between 8.46-8.97 for all the reactors. Both macrophyte-assisted and conventional filters contributed to the buffering capacity of the system, though no significant difference in pH regulation was observed between the reactors. The removal efficiency of TN for T1, T2, and T3 were 28.3±1.4%, 19.6±1.2% and 17±1.4% respectively while for ammonia, T1 demonstrated higher removal efficiency (53.4±1.4%) in comparison to T2 (38.6±1.8%) and T3 (27.8±1.2%). The superior nitrogen removal in T1 is likely due to the nitrification-denitrification processes enhanced by *Canna indica* and further phytoaccumulation of nutrients in macrophytes. The plant's root structure supports a diverse microbial community that converts ammonia and organic nitrogen into nitrate, followed by denitrification to nitrogen gas. The limited microbial colonization in T2 and T3 restricted nitrogen removal efficiency in those systems. Removal efficiency for TP for T1, T2, and T3 was 34±1.2%, 25±1.2%, and 21±1.4%, respectively. Observational analysis revealed the efficiency of MAVF in comparison to VF and BF in terms of clogging. The superior performance of T1(MaVF) in comparison to T2 and T3 can be attributed to the presence of an extensive and dense root structure by *Canna indica*, providing a larger surface area for attachment of microbes, increasing the microbial activity. In the preliminary analysis, it was observed that MAVF reactors were more efficient in antibiotic removal than VF and BF. However, further quantitative analysis is needed to fully understand the mechanisms and extent of antibiotic removal. The environmental and economic benefits of MaVF systems make them a viable alternative to conventional wastewater treatment methods. Using locally available macrophyte species further enhances the sustainability of this approach by reducing costs and ensuring adaptability to regional conditions. Modularization of MaVF systems could facilitate broader applications and provide higher removal efficiencies for organics and antibiotics while extending their lifespan.

Future research should focus on expanding the scope of this study by evaluating additional macrophyte species and optimizing operational parameters such as hydraulic loading rates and retention times. Long-term monitoring of MaVF systems is also essential to assess their durability and performance under varying environmental conditions. Furthermore, advanced analytical techniques should be employed to quantify antibiotic removal and understand the underlying mechanisms in greater detail. By addressing these research gaps, Macrophyte assisted vermifiltration technology can be developed into a robust and sustainable solution for managing cattle feedlot wastewater and mitigating its environmental impacts. Thus, it can be concluded that if modularized, the application of MAVF systems for higher removal efficiency of organics and antibiotics and expanded life span.

Keywords: *Canna indica, Macrophyte, Vermifiltration, Cattle-feedlot wastewater, Antibiotics, Organics*

HYDRO-GEOCHEMICAL INVESTIGATIONS AND SUITABILITY OF GROUNDWATER FOR DRINKING PURPOSES IN INDORE DISTRICT, MADHYA PRADESH, INDIA

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Water covers approximately 71% of the Earth's surface, largely in seas and oceans, with minor proportions as groundwater (1.7%), glaciers, and atmospheric vapours. Groundwater is a vital source of drinking water for nearly one-third of the global population. Despite its abundance, challenges related to freshwater scarcity and contamination persist worldwide. Key water quality parameters, including Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), Chlorides, and microbial contamination, impact human health and ecosystem sustainability. Globally, over one billion people lack access to safe drinking water, with rural populations being disproportionately affected. In India, groundwater meets 85% of the public water demand, but contamination from pathogens, agricultural runoff, and industrial pollutants poses significant challenges. In this paper we investigate the hydro-geochemical characteristics of groundwater and surface water in Manglia Village, located in the Indore District of Madhya Pradesh, to evaluate its suitability for drinking purposes. Indore spans 530 km² and is geographically positioned between latitudes 22°48′00″N to 22°50′00″N and longitudes 75°54′00″E to 75°56′30″E, bordered by the Chambal River to the west and the Kshipra River to the east. The Deccan Traps, which are the predominant rocks in the district, have wide variation in the water bearing properties of the different units constituting them. The massive basalts, their weathered zones and secondary porosities and the vesicular basalts with their minutely connected and partially filled vesicles play an important role in determining the occurrence, movement and storage of groundwater. These invariably form potential aquifers. In the alluvial areas, the occurrence of groundwater is governed by sand/clay ratio. The sand beds generally form good aquifers, but due to the limited thickness and erratic occurrence in the form of lenses, the ground water structures in them are poor to moderately productive. During the post-monsoon season, 19 water samples, including groundwater, surface water and 11 (5 sites) soil samples, were collected within a 5-kilometer radius of Manglia Village from bore wells and surface water sources. The samples were analyzed for pollution indicator ions and trace metals. Ion chromatography (IC) determined the concentrations of anions (Cl^-, SO_4^{2-}, NO_3^-), while Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) was used for trace metal analysis. The soil texture was analyzed using of the sieve test and the laser diffraction method. Soil samples were digested using the Multiwave PRO microwave for chemical analysis. All analyses were conducted in triplicate to ensure accuracy and reliability. The pH, EC and DO of water samples ranged from 6.82 to 7.6, 808 to 2640 µS/cm, and 0.94 to 3.10 mg/L, with average values of 7.14, 1516 µS/cm, and 1.77 mg/L, respectively. Anion concentrations in groundwater were as follows: chloride (Cl^-) ranged from 45 to 460 mg/L, sulfate (SO_4^{2-}) from 1 to 130 mg/L, and nitrate (NO_3^-) from 0.2 to 4.9 mg/L, with average values of 215 mg/L, 48 mg/L, and 1.51 mg/L, respectively. Surface water samples follow similar trends as groundwater, with chloride ranging from 45 to 306 mg/L, sulfate from 24 to 36 mg/L, and nitrate from 0.7 to 3.2 mg/L, with average values of 155 mg/L, 31 mg/L, and 1.6 mg/L, respectively. All anion

concentrations were within permissible limits established by the Bureau of Indian Standards (BIS, 2012). Trace metal concentrations in groundwater showed arsenic (As) levels ranging from 3.3 to 9 ppb, iron (Fe) from ND to 2910 ppb, manganese (Mn) from 1 to 5696 ppb, nickel (Ni) from 1.41 to 9.41 ppb, lead (Pb) from 4.2 to 7.98 ppb, zinc (Zn) from 44 to 304 ppb, and copper (Cu) from 0.6 to 15 ppb. Average concentrations of above metals (in same sequence) were 6.5, 442, 604, 5.41, 6.09, 130, and 5.2 ppb, respectively. Surface water samples revealed similar patterns, As, Fe, Mn, Ni, Pb, Zn, and Cu ranged from 3.3 to 7.9 ppb, 200 to 950 ppb, 14 to 364 ppb, ND to 10.7 ppb, 4.3 to 6.7 ppb, 42 to 406 ppb, 4.2 to 46 ppb, with respective averages of 5.5, 610, 207, 10.7, 5.4, 202, and 22 ppb. All measured trace metals except Fe and Mn were within permissible limits as prescribed by the BIS, 2012. High concentrations of iron generally cause inky flavour, bitter and astringent taste. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable Odours. Trace metal concentrations in soil samples showed variability, with arsenic, cadmium, lead, chromium, nickel, zinc, copper iron, aluminium, and manganese ranged from 114 to 169 mg/kg, 30 to 43 mg/kg, 107 to 310 mg/kg, 430 to 699 mg/kg, 512 to 736 mg/kg, 489 to 1017 mg/kg, and 512 to 736 mg/kg, 205 to 270 mg/kg, 179 to 286 mg/kg, and 6 to 23 mg/kg respectively. In the soils samples clay contents ranged from 4.3 to 24.0%, silt and sand contents had wider ranges of volume percent; silt contents ranged from 32.6 to 75.4%; while sand contents ranged from 8.1 to 38.8% and gravel percentage varied from 0.2 % to 37.6% in the study area. However coarse size fractions increase with depth in these soils with reduction in fine size fractions. Based on textural classification of soil samples, the soil of the study area is mainly silty loam type. It is concluded that all the measured ions and trace metals are within the permissible limit except iron and manganese. However, the water quality monitoring, including physicochemical and trace metal parameters, can identify potential risks early and it should be monitored regularly.

Keywords: *Water quality, groundwater, drinking water, Indore*

POTASSIUM RETENTION AND TRANSPORT IN AGRICULTURAL SOILS UNDER TREATED WASTEWATER IRRIGATION: MECHANISMS AND ENVIRONMENTAL IMPLICATIONS

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Potassium (K) is an essential macronutrient for plant growth, animal health, and human nutrition. It plays a significant role in various physiological functions, including enzyme activation, photosynthesis, and water regulation in plants. In agricultural soils, the availability of potassium is primarily governed by the soil’s buffering capacity and retention properties, which determine its mobility and subsequent uptake by plants. The retention of potassium in soil is a complex process influenced by multiple physical, chemical, and biological factors. Traditionally, potassium is supplied to crops through chemical fertilizers; however, with growing concerns regarding sustainable agricultural practices and resource conservation, alternative sources of nutrients are being explored. One such alternative is the use of treated wastewater (TWW), which contains essential nutrients, including potassium, and can serve as a supplementary nutrient source for crop production. To evaluate the feasibility of using TWW as a potassium source, it is crucial to understand the interactions between potassium and soil, particularly its retention mechanisms and transport behaviour in the vadose zone. This study aims to investigate these aspects by analysing soil samples collected from agricultural fields. The physicochemical properties of the soil were assessed to determine key factors influencing potassium retention. A series of controlled batch experiments were conducted to examine potassium retention under varying conditions, including pH (ranging from 2 to 10), contact time (from 0 to 24 hours), and isotherm behaviour at room temperature. The adsorption kinetics were studied to determine the rate at which potassium binds to soil particles. Additionally, a column experiment was performed to analyse potassium transport under dynamic conditions. The experiment utilized a 0.01 M NaCl background solution containing 25 ppm potassium, applied under a constant hydraulic head of 50 mm. The experimental setup consisted of cylindrical polyvinyl chloride (PVC) columns with an inner diameter of 5 cm, a column length of 25 cm, and a soil fill depth of 20 cm. The soil was packed in column to achieve a bulk density of 1.37 g/cm³. All potassium concentrations were measured using flame photometry and ion chromatography. The study revealed that potassium retention in soil is influenced by pH conditions. Under acidic conditions, potassium retention was lower due to electrostatic repulsion. Since potassium carries a positive charge, and acidic environments are also characterized by an abundance of hydrogen ions (H^+), strong repulsion forces hinder potassium adsorption. This leads to higher potassium mobility and potential leaching risks in acidic soils. The kinetic analysis demonstrated that potassium retention follows a second-order kinetic model, suggesting that the adsorption process is primarily governed by chemical interactions rather than simple diffusion. Furthermore, isotherm studies indicated that the Freundlich isotherm model provided the best fit for potassium adsorption data, highlighting the heterogeneous nature of potassium binding sites within the soil matrix. For transport analysis, the experimental data were simulated using the STANMOD software to model potassium movement through soil. The results indicated that the presence of competing cations, such as sodium, calcium, and magnesium, in TWW effluent reduces potassium retention capacity in the soil matrix. This

effect enhances potassium mobility, increasing the likelihood of leaching into deeper soil layers and potentially contaminating groundwater. The use of TWW for irrigation has both beneficial and adverse implications for potassium dynamics in agricultural soils. On the positive side, TWW enhances potassium availability, reducing the reliance on synthetic fertilizers and contributing to improved soil fertility. However, excessive potassium accumulation can disrupt nutrient balance, negatively affecting the uptake of other essential cations such as calcium and magnesium. This imbalance can have implications for plant health and crop yields. Potassium dynamics also play a role in shaping microbial communities in the soil, potentially altering nutrient cycling and organic matter decomposition. The long-term application of TWW for irrigation requires careful management to prevent soil degradation and ensure sustainable nutrient availability while mitigating risks to water quality and ecosystem health. This research highlights the complex interactions between potassium, soil properties, and TWW application in agricultural systems. The study underscores the importance of understanding soil-specific retention mechanisms and transport dynamics to optimize nutrient management strategies. While TWW serves as a valuable resource for potassium supplementation, its use must be carefully managed to balance agronomic benefits with environmental risks. The insights gained from this study provide a foundation for developing best practices in wastewater reuse, contributing to sustainable agriculture and resource conservation. Policymakers, and agricultural practitioners, can utilize these findings to improve wastewater management strategies, ensuring that nutrient benefits are maximized while minimizing ecological risks. By integrating sustainable irrigation practices, we can enhance soil fertility, promote efficient nutrient use, and mitigate potential threats to groundwater quality and ecosystem stability.

Keywords: *Nutrients, retention, transport, treated wastewater, potassium*

HYDROGEOCHEMISTRY AND LEAD CONTAMINATION OF GROUNDWATER IN GUWAHATI CITY, ASSAM, INDIA

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Water is a basic human right. Assessing and predicting quality of groundwater is crucial in managing groundwater availability effectively. Groundwater is an essential resource. However, landuse and landcover changes facilitated by population growth, over exploitation, urbanization, industrialization and agricultural practices have overwhelming impacted this vital resource. Population density, landuse changes and complex geology pose greater problems in urban areas compared to rural. Both point and non-point sources contribute to greater water quality degradation in urban areas. Leakage from sewer mains, industrial effluents, urban runoff and household discharges contribute to the hydrogeological challenges faced by urban groundwater systems. Pollution of groundwater by dissolved trace elements has been recognized as a major threat to safe drinking water. The pollution of groundwater by dissolved trace elements has raised serious global concerns due to their persistence, carcinogenicity, and environmental impacts. While the presences of certain trace elements are deemed essential for human health, their presence above guideline values is a major threat to human health and the ecosystem. Groundwater contamination due to arsenic and fluoride has been widely reported over the past decade, emergent contaminants like Pb in groundwater has only been recognized more recently. More than 80% of urban and rural population in India relies on groundwater for meeting their water needs. However, groundwater in most cities across India are contaminated with trace elements like arsenic, fluoride, lead, zinc cadmium, mercury etc. Communities consuming such contaminated water face severe health consequences.

The presence of arsenic (As) and fluoride (F) in groundwater of Guwahati city, the gateway to the northeastern part of Assam, India has been widely reported. A limited number of studies have also reported the presence of trace elements like lead (Pb), cadmium (Cd) and iron (Fe) in groundwater. This study is thus an attempt to access the groundwater hydrogeochemistry in Guwahati city to evaluate the origin and geochemical mechanism driving groundwater quality and lead (Pb) contamination in groundwater of Guwahati City, Assam, India. 61 groundwater samples were collected from shallow tubewells and dugwells (depth <50 m) from across the study area**.** The water samples were collected in cleaned 500 ml PE (polythene) bottles, which were washed in the laboratory with 10% nitric acid (HNO_3), and then rinsed with ultrapure water few times. Samples designated for trace elements analysis were preserved with 7M HNO_3. The analysis of cations and trace elements was conducted using inductively coupled plasma mass spectrometry (ICP-MS, NexION 350, PerkinElmer Instrument, USA), while anions were analyzed using ion chromatography (IC, Thermo Scientific Dionex Integrion RFIC system, USA). All the laboratory analyses were conducted at the Global Centre for Environmental Remediation (GCER), The University of

Newcastle, Australia.The concentrations of major cations followed the order calcium (Ca^{2+}) > sodium (Na^{+}) > magnesium (Mg^{2+}) > potassium (K^{+}) while chloride (Cl−) is the most dominant anion in the groundwater. Piper plot demonstrated that the groundwater is predominantly of Ca–HCO_3 typealong with mixed Ca–Mg–Cl, Na–K–HCO_3, and Ca–Cl types, indicating the dominance of alkaline earth over weak acids. Groundwater hydrogeochemistry is mainly controlled by rock water interactionsand evolves through the processes of silicate weathering, carbonate weathering, and cation exchange. Alarmingly, 54% of samples exceeded the permissible limits of 10µg/L set by both World Health Organization (WHO) and Bureau of Indian Standards (BIS), indicating serious concerns for the local inhabitants. Lead concentrations ranged from 3.05 µg/L to 74 µg/L, with a mean of 13 µg/L. Lead is a naturally occurring toxic metal, typically sourced from both geogenic and/or anthropogenic sources. It is used for various purposes such as automobile fuels, paint, and batteries, and can be found in wastewater. High Pb concentrations in drinking water can have serious health implications, such as the disruption of the biosynthesis of hemoglobin, increased blood pressure, renal damage, disruption of the nervous systems, neurological damage, and diminished learning abilities in children. Spatial distribution maps of Heavy Metal pollution (HPI) indicates wide-spread groundwater contamination in the study area, except for isolated pockets with good to excellent groundwater in the central portion of the study area.Regular monitoring and intervention of groundwater sources in the hotspot areas are essential for long-term use. The findings of this study will assist policymakers in devising strategies for sustainable management of groundwater in the study area and regions facing similar challenges.

Keywords: *Groundwater, Hydrogeochemistry, Lead Contamination, Piper Plot, Management*

ASSESSING GROUNDWATER CONTAMINATION IN MADHYA PRADESH: SOURCES, IMPACTS, AND REGULATORY RESPONSES IN A RAPIDLY INDUSTRIALIZING LANDSCAPE

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Groundwater contamination in Madhya Pradesh, a rapidly industrializing state in India, has become a pressing environmental concern. This review paper comprehensively examines the prevalent sources, pathways, and impacts of groundwater contamination arising from industrial activities within the state. Specific focus is placed on industries such as chemical manufacturing, textiles, pharmaceuticals, and metal processing, which are known contributors to contamination. The paper delves into the various contaminants released by these industries, including heavy metals, organic compounds, and inorganic substances. Additionally, it explores the geological and hydrological factors that influence the movement and distribution of contaminants in the unconfined aquifers. An overview of the potential environmental and health risks associated with groundwater contamination is discussed, highlighting the potential implications for agriculture, drinking water supplies, and human well-being. Finally, the paper provides a review of existing regulations, monitoring practices, and remediation technologies employed in Madhya Pradesh to address groundwater contamination. By synthesizing the current knowledge and research, this review aims to contribute to a better understanding of the issue. It allows decision makers to make informed policy decisions for sustainable industrial development and groundwater protection in the region. Groundwater contamination is challenging to detect due to its subsurface nature, making monitoring efforts expensive and time-consuming. Addressing these challenges requires improved pollution control strategies, stringent wastewater management policies, and enhanced groundwater monitoring systems.

Madhya Pradesh, a state with a low industrial development rate, has several large and medium-scale manufacturing centres in Indore, Gwalior, Bhopal, and Jabalpur. Government-sponsored industries include paper milling, cement production, and heavy electrical items. Private sector facilities produce sugar, textiles, lumber, flour, and seed and vegetable oils. Other products include fertilizer, synthetic fibres, and chemicals. The hand-loom industry has flourished, with saris made in Chanderi, gold and silver thread embroidery in Bhopal, and carpets woven in Gwalior. Gwalior artisans also produce handmade pottery. Jabalpur and Sagar are known for manufacturing bidis, hand-rolled cigarettes. These industries produce different wastes such as organic wastes, heavy metals (Pb, Hg, Cd, Cr, As, Ni, and Zn), and harmful chemicals. Due to the industrial area and their waste releases the groundwater is contaminated, and the land is polluted. Dewas is such area located in Ujjain Revenue Division, is situated on the Malwa plateau in West-central Madhya Pradesh, India situated between 20°17´ and 23°20´ North latitude and 75°54´ and 77°08´ East longitude. Large-scale concentrated sources of pollutants, such as industrial discharge and subsurface chemical injection, are evident in the groundwater (Kori, et al., 2020). The Mandideep industrial area in Madhya Pradesh, located near Bhopal, was the focus of a study conducted from 2017 to 2018. The study analyzed physico-chemical parameters of ground water, following standard guidelines and Central Pollution Control Board guidelines. The results showed high

contamination in ground waters, with nitrate concentrations ranging from 3.74 mg/l to 27.88 mg/l, and fluoride concentrations ranging from 0.23 mg/l to 1.11 mg/l. Another study analysed the physico-chemical characterization of groundwater in a village near the Malanpur and banmore industrial area in Bhind and Morena, Madhya Pradesh, from April 2018 to March 2020. The samples were analyzed for parameters such as pH, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, chloride, sulphate, and fluoride. The study also found that the dominant presence of fluoride, salt, sodium, and calcium had severe effects on teeth, skeletal, kidney, and rural people. The high levels of ions in the groundwater were attributed to the seepage of industrial effluent discharged without treatment on the land. The study suggests a proper management plan to improve groundwater quality for human health and sustainable development.

Considering these we calculated the Water Quality Index (WQI) based on acceptable and permissible limits for each parameter, and we have taken the applicable averages of these values to calculate the normalized index. A groundwater quality investigation conducted across four industrial regions in Madhya Pradesh Dewas, Mandideep, Malanpur, and Banmore reveals significant deviations in physico-chemical parameters from the acceptable drinking water limits. Based on the WQI, we have classified groundwater risk into three zones: low-risk (WQI < 0.35), moderate-risk (WQI 0.35–0.70), and high-risk (WQI > 0.70). Analysis of acceptable WQI values indicates that all four regions fall within the high-risk zone, with values ranging from 0.72 (Mandideep) to 0.89 (Banmore), indicating severe groundwater contamination. However, based on permissible WQI standards, all regions are categorized under moderate risk, with values between 0.53 (Mandideep) and 0.65 (Malanpur). This deterioration in groundwater quality is likely attributed to industrial activities, including the discharge of untreated or partially treated effluents, which directly or indirectly impact aquifer systems. The findings underscore the urgent need for comprehensive groundwater management strategies, stricter industrial wastewater regulations, and enhanced monitoring frameworks to mitigate contamination risks and safeguard groundwater resources for sustainable use.

Keywords: *Groundwater contamination, industrial pollution, heavy metal contamination, Madhya Pradesh*

ASSESMENT OF GROUNDWATER QUALITY WITH SPECIAL REFERENCES TO FLOURIDE CONCENTRATION AROUND BHIWAPUR, NAGPUR DISTRICT, MAHARASHTRA, INDIA

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Groundwater is an important source of freshwater for world's population. It is used for domestic, agricultural manufacturing and industrial purposes. The groundwater regime of any area is controlled by parameters like lithology, structure, geomorphology, slope land use/land pattern etc. Quality of water plays an important role in promoting agricultural production and standard of human health for assessment and management of groundwater resources, it is essential to understand the hydrogeological and hydrogeochemical properties of aquifer. The geochemical composition of groundwater is mainly influenced by natural factors such as wet and dry deposition of atmospheric salt, precipitation, evapotranspiration, soil matrix, rock water interaction, residence time etc. Assessment and classification of groundwater based on its quality can be obtained by analyzing its chemical characteristics. Variations in ion chemistry of groundwater are used to identify geochemical processes that control groundwater quality. Presence of low or high concentration of certain ions is a major issue as they make groundwater unsuitable for various purposes. Fluoride is such one ion that causes problem to people's health. The studies' main objectives are to define major hydrogeological processes, assess groundwater quality and pinpoint village where groundwater is suitable or unsuitable for drinking water purposes in the study area.

The study area is a part of Bhiwapur taluka adjoining villages WGM-2 Watershed which is situated at about 60 km SE to Nagpur district headquarters. The Maroo is main river which flowing NE direction. In this area mainly comprises rock types of Granatic gneiss, Migmatite Gneiss, Amphibolite, Quartzites which is of Amgaon gneissic group of Archean age. Depth of dug well is 8 to 17 mbgl. Diameter of well is between 3 to 5 m and yield of well is 50 to 100 m^3/day. While depth of borewell ranges from 60 to 70 mbgl. Hydrological data collected in study area was carried out during post monsoon season of year 2023. Total 21 villages samples are taken for analysis. Out of 21 samples 7 samples from borewell and 14 samples from dugwell are analyzed. Major chemical parameters were analysed in laboratory.

The result was evaluated in accordance with World Health Organization and standard specification of BIS Standards. Total 21 samples analysis concentration of F-result village wise is Bhagabori 0.53mg/l, Borgaon-1.30mg/l, Chikhali-0.5mg/l, Dongargaon -1.48mg/l, Jaoli- 1.20 mg/l, Kinhala-0.53mg/l, Mangali-0.55 mg/l,Manora-1.90 mg/l, Mendala-0.44mg/l, Murhapur-1.30 mg/l, Nakshi-0.54 mg/l,Pandharabodi-1.30mg/l,Botezari-1.70mg/l, Ranmangali-1.30 mg/l, Sarandi-0.81 mg/l, Seloti-0.95 mg/l,Somnala-1.90mg/l, Tas-1.50 mg/l,Chichada-2.0mg/l, Wadadha-0.27 mg/l, Taka-1.70mg/l. Out of 21 samples 16 villages having F^- concentration range between 0.27 mg/lit to 1.50 mg/l is in permissible limit. While 5 samples show F^- concentration range is 1.60 to 2.0 mg/l. these villages are F^-concentration above permissible limits, so groundwater of these sources is not suitable for drinking purposes.

The main rock formation in water sampling study area are Archeans and it comprises of granitic gneisses, amphibolite, quartzite, migmatite gneiss. It seems more appropriate that rock rich in fluoride minerals have contributed to the enriched fluoride content of groundwater during the course of weathering of rock. Dissolution activity of fluoride minerals is more important for fluoride concentration in groundwater rather than fluoride - bearing minerals present in rock. Thus, concentration of fluoride in ground water is depends on concentration of fluoride -bearing minerals in rock types. Their decompositional, dissociational and dissolutional activities along with residence time of the chemical reaction are important. In acidic medium (acidic pH), fluoride is absorbed in clay; however, in alkaline medium it is desorbed and, thus alkaline pH is more favorable for fluoride dissolution activity. In present case all water samples were found alkaline in nature and their pH value varied from 7.4 to 8.4. The aqueous ionic concentration of groundwater also influenced the fluoride solubility behaviors; for example, in presence of excessive sodiumbicarbonates in groundwater, the dissociation activity of fluoride will be high, and this can be expressed as $CaF_2+2NaHCO_3=CaCo_3+2Na+2F+H_2O+CO_2$. Mineral composition of these rocks is plagioclase feldspar, anthrophyllite, garnet, mica, epidote, hornblend, orthopyroxenes, biotite and illimanite and all these minerals are fluoride bearing minerals. Weathering of these rock and prolonged residence time leads to occur high fluoride concentration in groundwater. It is observed that in study area fluoride concentration occurs in groundwater is due to natural cause where principal source of F-in water are fluoride bearing minerals present in rocks. Most of villages in study area groundwater are suitable for drinking & domestic purposes.

Keywords: *Geoenvironmental, fluoride concentration, Bhiwapu, ion exchange, Water quality*

ASSESSMENT OF HYDROCHEMISTRY AND SOURCE IDENTIFICATION OF GROUNDWATER CONTAMINATION ALONG THE COASTLINE OF ODISHA, INDIA USING GEOSPATIAL AND STATISTICAL TOOLS

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Groundwater is an essential resource for drinking, irrigation, and industrial activities, particularly in coastal regions where surface water availability is often limited. However, the quality of groundwater in such areas is significantly influenced by both natural and anthropogenic factors. The present study aims to analyze the groundwater geochemistry in parts of Jagatsinghpur district, Odisha, with a focus on identifying the geochemical processes influencing groundwater composition and potential contamination sources. Jagatsinghpur district is situated on the east coast of India, forming part of the fertile plains of the Mahanadi delta. The region experiences tropical monsoonal climatic conditions, with a significant influence from seasonal variations in precipitation and tidal interactions due to its proximity to the Bay of Bengal. The district's fertile soils and abundant groundwater resources provide favorable conditions for agricultural activities, making it essential to evaluate groundwater quality and potential contamination threats. To conduct the assessment, a total of 62 groundwater samples were collected from various locations across the study area during both the pre- and post-monsoon seasons of the year 2023. These samples were analyzed for various physicochemical parameters, including pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and concentrations of major cations and anions sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), chloride (Cl^-), bicarbonate (HCO_3^-), sulfate (SO_4^{2-}), and nitrate (NO_3^-). The analytical procedures followed standard protocols as recommended by the American Public Health Association (APHA, 2017). Water samples were filtered, preserved, and analyzed using titrimetric, spectrophotometric, and flame photometric techniques. Statistical analyses, including correlation matrices, cluster analysis, and dendrogram construction, were employed to identify trends and potential contamination sources. The Water Quality Index (WQI) method was also utilized to assess the overall suitability of groundwater for human consumption. The electrical conductivity (EC) of groundwater in the study area exhibited a wide range, varying from 287 µS/cm to 37,586 µS/cm during the pre-monsoon season and from 336 µS/cm to 39,339 µS/cm in the post-monsoon season. This substantial variation indicates diverse hydrochemical processes affecting groundwater quality. The higher EC values suggest significant dissolved ion content, which may arise from seawater intrusion, agricultural runoff, or rock-water interactions. The dominance order of major cations in the groundwater samples was found to be $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while the anion composition followed the order $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$. The elevated sodium and chloride concentrations indicate a considerable influence of saline water intrusion, which is a common issue in coastal aquifers subjected to over-extraction and altered hydraulic gradients. A strong positive correlation ($r > 0.9$) was observed between chloride concentration and other parameters such as EC, sodium, calcium, and magnesium in both seasons. This strong correlation suggests that seawater intrusion plays a predominant role in controlling the groundwater chemistry in the study area. The intrusion is likely exacerbated by excessive groundwater extraction for irrigation and drinking water supply, which leads to reversed hydraulic gradients, allowing seawater to

encroach into the freshwater aquifer. The correlation between chloride (Cl^-) & sulfate (SO_4^{2-}) ranged from r = 0.1 to r = 0.88 from the pre- to post-monsoon season. This variation suggests that additional factors, such as agricultural activities and soil leaching, influence groundwater chemistry, particularly during the post-monsoon period. The increased use of chemical fertilizers post-harvest may contribute to higher sulfate concentrations in the groundwater. Agricultural practices significantly impact groundwater quality in the region. The use of chemical fertilizers, pesticides, and herbicides can introduce various contaminants, including nitrates and phosphates, into the groundwater system. The relatively high concentrations of NO_3^- observed in some samples indicate potential leaching from agricultural fields. Post-monsoon variations in groundwater chemistry further suggest that irrigation return flow and soil leaching contribute to elevated solute concentrations. Increased rainfall during the monsoon season enhances the mobilization of agricultural chemicals, leading to their percolation into the groundwater system. To evaluate the suitability of groundwater for human consumption, the Water Quality Index (WQI) was calculated based on weighted averages of key water quality parameters. The WQI values were categorized into different classes ranging from excellent to unfit for consumption. The results indicated that a significant proportion of groundwater samples fell into the poor to very poor categories, particularly in regions experiencing higher EC and chloride concentrations. This assessment highlights the need for stringent water quality monitoring and management strategies. Cluster analysis and dendrogram techniques were employed to identify key factors influencing groundwater quality. The analysis revealed distinct clusters, indicating multiple sources of contamination. The findings of this study indicate that groundwater quality in Jagatsinghpur district is influenced by multiple geochemical processes, with seawater intrusion being a significant factor. The impact of agricultural activities further exacerbates water quality deterioration, particularly during the post-monsoon season. Given the critical dependence of local communities on groundwater resources, it is imperative to implement sustainable groundwater management strategies. This extended analysis provides a more comprehensive understanding of groundwater quality dynamics in Jagatsinghpur district, emphasizing the need for effective management interventions to mitigate contamination risks.

Keywords: *Groundwater chemistry, ion exchange, saltwater intrusion, cluster analysis, coastal aquifers*

FATE OF ORGANO-ARSENIC COMPOUNDS WITH NATURAL MINERALS AND SOILS: INSIGHTS FROM ROXARSONE STUDIES

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Arsenic poisoning in drinking water is a significant global environmental crisis, impacting millions annually, with sources of inorganic arsenic stemming from both geogenic and anthropogenic origins. While substantial research has been conducted on the fate, transport, and speciation of inorganic arsenic in various geochemical conditions, studies on organo-arsenic compounds remain limited. Evidence suggests that inorganic arsenic (As(III) and As(V)) can be effectively removed by iron minerals such as hematite and magnetite. Organo-arsenic compounds, including those adsorbed onto iron minerals like hematite and goethite, exhibit adsorption behaviors influenced by molecular size, methyl group content, and soil characteristics, including Fe and aluminum content. Adsorption is inversely related to total organic carbon (TOC) in the soil. Desorption of these compounds varies with anions such as sulfate, phosphate, and chloride, and microbial or photodegradation can convert organo-arsenic to inorganic arsenic, with potential biotransformation occurring in reverse by bacteria. Roxarsone (4-Hydroxy-3-nitrophenyl arsonic acid) (ROX) is an organo-arsenic compound used as feed additives to improve the quality and pigmentation of meat in poultry and swine farms. In this study the sorption of roxarsone on naturally occurring non-iron minerals: K-feldspar, serpentine, calcite, gypsum; iron minerals: hematite, magnetite and maghemite and clay colloids: bentonite and kaolinite, were done for the groundwater matrices. The non-iron minerals used in this study were natural and bought from Hindustan Minerals, Kolkata. Then these samples were crushed for the experiments. Iron minerals were synthesized in the AquaNano Lab by wet chemical synthesis methods. The soil samples: alluvial soil, red soil and black soil are field samples collected from different parts of India. The soil samples were collected from the field removing the top soil in the field and then air dried and sieved in the lab for further experiments. Batch experiments were conducted for 24 hours. The experiments were conducted for 10 mg/L ROX solution in groundwater matrices. The pH of the solutions after interaction were near neutral. The final concentrations of ROX after 24 hours were determined using UV-Vis spectrophotometer in AquaNano Lab. Results suggested that ROX had minimal to zero sorption for the non-iron minerals. Magnetite showed the highest sorption in case of ROX with the sorption capacity of 55.99%. The sorption capacity of ROX in decreasing order as follows: Magnetite > maghemite > hematite. The clay colloids had zero to minimal interactions with the ROX. Bentonite and kaolinite had zero sorption of ROX. The results revealed that ROX was not interacting with major rock forming non-iron minerals and soils suggesting adverse leaching to the subsurface level and posing a greater threat to the subsurface groundwater contamination and transport which warrant further investigation.

Keywords: *Organo-arsenic, roxarsone, sorption, geochemical interactions, groundwater contamination, iron minerals, soil characteristics, environmental fate and transport*

WATER QUALITY ANALYSIS OF NAINITAL LAKE BY INTEGRATING SATELLITE DATA AND LABORATORY EXPERIMENTS

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Nainital Lake is one of the pristine freshwater sources in the Kumaon region of Uttarakhand, India, and the sole source of drinking water for the local population. It has been a significant tourist spot for decades. According to the census report of 1981, the population of Nainital district is 27,002, while the 2011 census reported 3 time increase in the population of Nainital district, which is 954,605. Also, according to the tourist bureau statistics record, there is almost twice the increase in the number of tourists from 4.17 lakh in 1988 to 7.84 lakh in 2023; these lead to anthropogenic load in the lake, which degrades its water quality. The average rainfall in the Nainital region is around 2500 mm and the additional water source of the lake is from two springs, Chunadhara and Pardadhara. Although these natural inflows support the lake, unregulated urban runoffs, sewage discharge, and heightened sedimentation have disrupted its biological equilibrium. We have employed an integrated method that combines satellite remote sensing and laboratory studies to continuously monitor water quality indicators, including temporal changes in water clarity, suspended sediments, and critical physicochemical parameters.

For this study, we are integrating two approaches to easily monitor and analyze the water quality of the Nainital Lake. The first approach is to utilize the satellite data; we have leveraged the high-resolution Sentinel-2 multispectral satellite data for our study. Initially, we planned a preliminary analysis with an index-based approach in which we calculated the Modified Normalized Difference Water Index (MNDWI) and Normalized Difference Suspended Sediment Index (NDSSI). MNDWI is derived from green (Band 3) and shortwave infrared (SWIR, Band 11), which measures water clarity by suppressing non-water features whose higher values denote lower turbidity. The NDSSI is derived from red (Band 4) and near-infrared (NIR, Band 8) bands measuring the suspended sediment concentration, where higher values indicate increased loads due to runoff or human activities. We did a time series analysis of the Nainital Lake water quality based on these indexes to obtain the temporal variations in water quality from 2017 to 2024. This duration significantly alters the human-induced pollution load in the lake due to the COVID-19 pandemic. So, we did a double-period water quality analysis using these indices that have been undertaken, looking at a three-year pre-COVID period of March 2017-2019 against the period 2022-2024 to examine the impacts incurred during the lockdown of COVID-19. In the second approach, we have planned to do a laboratory-based water quality analysis. For that, we collected 12 water samples from the 12 different locations of the Nainital Lake. We analyzed physicochemical properties: Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), and Oxidation-Reduction Potential (ORP). This investigation showed significant changes in the water quality and degrading nature of the Lake’s self-sustaining capability.

After both these approaches, we aim to build a correlation equation developed by machine-learning algorithm using satellite and ground truth data to obtain the water quality by analyzing the satellite data. Initial trends indicate distinct patterns that have emerged between the pre-and post-COVID periods. Pre-COVID (2017-2020): Higher NDSSI values during

monsoon captures showed increased sedimentation, while fluctuating MNDWI values suggested alterations in water clarity due to tourism and urban runoff. COVID Period (2020–2021): Lower values of NDSSI and higher values of MNDWI would indicate enhanced water quality due to decreased human interference around the lake. Post-COVID (2022–2024): There is a partial recovery to pre-COVID conditions that may be due to increased anthropogenic stressors. From the laboratory analysis, we found that the pH values ranged from 5.16 to 8.4, reflecting localized variations caused by organic matter breakdown and human waste outflow. Dissolved oxygen (DO) concentrations varied from 0.4 to 8.2 mg/L, with specific areas exhibiting hypoxic conditions, presumably attributable to nutrient enrichment and microbial activity. Apart from this, we are focusing on the analysis of TOC, especially for the chlorophyll study, turbidity, and nutrient levels, which seem to be the major causes affecting Nainital Lake's self-cleaning cycle. Furthermore, we will include these lab results to validate satellite observations.

Keywords: *Lakes, Water quality, remote sensing, Nainital*

INVENTORY OF RADON ABUNDANCE IN GROUNDWATER ALONG THE YAMUNA RIVER, INDIA

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Climate change has led to higher dependence of anthropogenic activities on groundwater. This demands the regular monitoring of groundwater source and quality. Recently, the abundance of radon (Rn) in groundwater has received global attention due to its geogenic source as well as adverse effects on human health. The higher exposure to radon via directly injected water or inhaled gas has proved to be carcinogenic in nature. The international organizations like US Environmental Protection Agency, European Atomic Energy Community have set the maximum concentration for safety level of radon in water to 11 Bq/L. This highlights the need to understand the source and abundance of radon in regional groundwater to avoid higher annual dose effect. The large tropical river basins host dense population due to rich groundwater resources. However, the groundwater in these large tropical river basins interacts with diverse lithology leading to higher possibility of radon exposure. In India, the large river basins of the Himalayas (Ganga, Yamuna, Brahmaputra and Indus) are well known for their dense population and agricultural intensive land use. However, there are only few reports on the radon abundance though it has significant human health impact. The available literature on radon concentration in groundwater of India or the Himalayan terrain shows observations mainly focusing on certain villages or in patches of major cities. With this in view, the present study investigated the radon concentration in groundwater of the Yamuna River basin which hosts rich groundwater resources, diverse climate and topography suitable for larger livelihood. This study provides for the first time an inventory on the status of radon concentration in the entire stretch of Yamuna River. The objectives of this study were to identify the spatial distribution variability of radon, understand the lithological controls on radon abundance, fingerprint the groundwater - river water interactions, and record the groundwater contamination status for radon along the Yamuna River.

River Yamuna originates from the Yamunotri Glacier located at an altitude of about 6300 m above msl in Uttarkashi district of Uttarakhand, India near Bandarpooch peak of the Himalayas. It flows through several states like Punjab, Haryana and Delhi before joining the Ganga River at Prayagraj, Uttar Pradesh. In addition, the major southern tributaries like Chambal, Ken and Betwa flow through the states of Rajasthan and Madhya Pradesh before joining the main channel of Yamuna River. The other tributaries of Yamuna River include the rivers like Tons, Giri, Asan, Bata, Hindon, Sindh, etc. The overall length of Yamuna River system from its origin to the joining of Ganga at Prayagraj is about 1,376 km while the river basin covers an area of about 3,66,223 km^2. The region experiences different climatic conditions with its upper reaches exhibiting cold winter and mild summer whereas in the downstream region and southwestern tributaries exhibit seasonal climate similar to major parts of Peninsular India with hot summer, relatively mild winter. The lithology is mainly dominated by silicate rocks like granites, gneiss, schists, etc. while the carbonate rocks are also present in patches throughout the basin. For this study, the groundwater samples were collected from about seventy locations adjacent to the main channel and major tributaries of the Yamuna River during June-July, 2024. About 250 ml of groundwater sample was

collected at each station in a tightly sealed glass bottle. The shallow depth groundwater (<30 m) was sampled mainly using handpumps from Janaki Chatti (upper reaches) to Prayagraj (lower reaches) along the Yamuna River. Before the sample collection, the water was pumped for a longer period to avoid the previously stored water in surface. The glass bottle was also rinsed onsite thoroughly before filling with the groundwater sample for analysis. The collected groundwater samples were analyzed for radon abundance within few hours of collection which was usually within three to four hours. The radon concentration in groundwater samples were measured using RAD7 detector (Durridge Ltd.). The RAD7 instrument is a highly efficient portable alpha detector and uses passive implanted planer silicon semiconductor detector to measure alpha activity in gaseous samples. The radon concentration is then obtained from the measured alpha activity. The instrumental set-up was well purged before analysis. The measured radon concentrations in groundwater along the Yamuna River were in the range of 1.29 - 84 Bq/L during the sampling period. The lower radon abundances were found in the downstream stations which could be due to the clayey lithology. The lower radon concentration in groundwater along the river channel could also be due to the mixing of river water which are generally less enriched with radon. The higher abundances of radon were observed in the groundwater located at upper reaches of Yamuna River which may be attributed to the decay of naturally distributed uranium in source rocks. However, the average radon concentration in measured groundwater samples is found to be slightly higher than the global safety level. The generated database on radon abundance in groundwater along the Yamuna River is one of the useful tools to explore the present status of water contamination and to develop a mass awareness for sustainable water utilization in the Himalayan River basins. The government departments may utilize the radon database as an environmental tracer to demarcate the groundwater sensitive zones in the Himalayan River basins as it is a major health hazard.

Keywords: *Radon concentration, groundwater assessment, water rock interactions, river basin*

GEOSPATIAL ANALYTICS FOR ANALYSING FLUORIDE CONCENTRATIONS AND GROUNDWATER QUALITY STATUS IN PARTS OF NALGONDA, TELANGANA, INDIA

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The most reliable freshwater source in the world is groundwater. Because around 2.5 billion people worldwide depend on groundwater, its sustainability and quality are vital. Access to safe drinking water is a fundamental human right across the globe and in India, 85% of drinking water supplies are dependent on groundwater. The groundwater resources are not equally distributed or of sufficient quality, which causes shortages and issues with suitability for intended uses. Further, variations in groundwater supply and quality are influenced by both natural and anthropogenic factors. The vulnerability of water borne diseases are significantly influenced by the quality of groundwater. Fluoride is one of the major contaminants among the many water quality indicators that has drawn attention and causes considerable health dangers. A prime example of this is Nalgonda, in Telangana, which was previously the epicentre of fluorosis in India and is known for having high rates of the disease due to contaminated groundwater. High fluoride concentrations in groundwater, that occur naturally, pose a health risk to approximately 180 million people potentially affected worldwide, primarily in the global south. Within a certain range, fluoride (F^-) in groundwater can be good for human health but, when the concentrations are too high or too low, it can have negative effects. A number of factors affect groundwater quality in terms of suitableness that can be evaluated using water quality indices (WQI) and other water quality indices. In this direction, this study envisages evaluating the impact of factors affecting the status of the water quality using spatial analysis tools.

The study area chosen for the research is severely fluoride affected parts of Nalgonda district with four sub-districts (mandals). The Study area falls under semi-arid regions of the country. The four mandals (sub-districts) of the district were chosen to conduct the research, namely., Marigudda, Munugode, Chandur and Chityal. There are 17 villages within these mandals, which are susceptible to serious fluorosis as a result of drinking groundwater. The South-West Monsoon season is from June – September, Winter is January – February, Pre-Monsoon is from March – May, and Post-Monsoon (North-East Monsoon) is from October – December. The Principal Aquifer in Dindi watershed is Banded Gneissic complex. The Specific Yield in the aquifer varies from 1% - 4%. The recharge from rainfall is reported to be in the range of 5% – 12%.

The water quality parameters of 19 groundwater samples during pre and post monsoon seasons of the years 2018 to 2022 were used for the analysis. The groundwater quality parameters were analysed for pH, Electrical conductivity, Total dissolved solids, Sodium, Potassium, Calcium, Magnesium, Chloride, Bicarbonates and carbonates, Sulphates, Nitrates, Fluoride and Total Hardness. These parameters were further analysed by generating WQI. To determine whether the groundwater samples are suitable for irrigation, indicators such as the sodium adsorption ratio (SAR), electrical conductivity (EC), percentage of sodium (Na%),

residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), permeability index (PI) and magnesium ratio (MR) were estimated. These indicators were then attributed to spatial distribution analytics for determining groundwater vulnerability. The study utilized spatial interpolation method that effectively interpolates the groundwater water quality index, resulting in the creation of spatial distribution maps.

The results indicate that the groundwater is contaminated by high fluoride, total dissolved solids, nitrates and salinity ions. The findings show that in this area, fluoride determines about 80% of the WQI, rendering it unfit for human consumption. The WQI indicates that the groundwater is in poor to very poor condition, however, the fluoride concentration is within the acceptable bounds. When the fluoride concentrations are reduced to the lowest possible levels, the WQI is excellent to good quality. Since all villages in the study area rely on groundwater and 19 wells fall within unfit category water quality ratings, population of nearly 60,000 individuals are vulnerable to waterborne diseases consuming this groundwater.

Using the groundwater in this region with high magnesium concentration for prolonged irrigation may result in progressive degradation of soil structure, decreased soil permeability, and marked decrease in crop productivity. In this study, Residual sodium carbonate (RSC) and bicarbonate concentration (RSBC) measurements provide more accurate assessments than salinity relative to salt (SAR), particularly at lower salinities levels. Calcium and magnesium carbonates tend to precipitate out in waters with a high bicarbonate concentration. Utilizing excess of this groundwater can affect natural soil structures, leading to oxidative and alkaline stress, ion toxicity and crop yield deficits as well as nutritional deficiencies in both soil and crop yields. Furthermore, salinization interferes with nitrogen absorption by plants, slowing their growth and lower productivity.

Nalgonda District is well known for its fluoride contamination. By creating suitable artificial structures and desilting local natural tanks, rainwater harvesting and implementation of Tank filling schemes can increase the groundwater availability while simultaneously decreasing fluorosis incidences among its local population. In order to take additional action to improve the condition of groundwater quality, the spatial approach employed in this study seems suitable for evaluating the crucial parameters associated with groundwater quality in other hard rock regions affected by fluoride.

Keywords: *Groundwater quality mapping, geospatial analytics for WQI, fluoride concentrations, irrigation suitability indices, Nalgonda fluorosis*

ASSESSMENT OF GROUNDWATER VULNERABILITY IN JHARKHAND REGION OF INDIA USING DRASTIC MODEL

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In areas like Jharkhand, India, where groundwater is the main supply for a variety of social demands, assessing groundwater vulnerability is essential for efficient management of water resources. The danger of contamination that groundwater resources confront as a result of a mix of natural and human activity processes is known as groundwater vulnerability. Evaluating this susceptibility is essential to managing water resources effectively and preventing pollution. The state of Jharkhand, in eastern India, is distinguished by its varied terrain, which includes dense forests, mineral-rich plateaus, and a complex web of rivers. Groundwater is essential to Jharkhand's agriculture, industry, and home needs because it is an agrarian state. But a combination of natural and human-caused factors is putting this vital resource in jeopardy more often. To make sure that groundwater is shielded from pollution and misuse, it is imperative to assess its vulnerability. Groundwater vulnerability in Jharkhand is impacted by a complex web of interrelated causes, including human activity, land use patterns, and geological features. Evaluating groundwater vulnerability is crucial to maintaining sustainable management and safeguarding this priceless resource. A significant supply of drinking water, agriculture, and a number of industrial operations are all supported by groundwater. Besides a variety of human activities, including inappropriate waste disposal, industrial discharges, and agricultural runoff, as well as natural processes like soil erosion and geochemical leaching can contaminate it. By identifying regions that are most vulnerable to contamination, groundwater vulnerability assessment facilitates targeted interventions and preventive actions. Groundwater vulnerability evaluations are a vital component of land use planning, helping to direct choices about industrial siting, zoning, and agricultural methods. Policymakers and other stakeholders can put policies in place that reduce threats to groundwater quality by identifying the locations that are most vulnerable to pollution. The creation of environmental norms and regulatory frameworks to protect water resources is also supported by this evaluation. Furthermore, because contaminated groundwater can have far-reaching effects on ecosystems and communities, it is essential for maintaining environmental sustainability and public health. In the long term, thorough evaluations of groundwater risk facilitate well-informed decision-making and proactive resource management. In addition to promoting environmentally responsible development, it helps guarantee that groundwater will always be a dependable source of clean water for present and future generations.

This study intends to identify the unique vulnerabilities of Jharkhand's groundwater systems through a thorough analysis of the parameters of the Drastic model. The Drastic model, which takes into account a wide range of variables such as depth to water table, recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity is one of the most well-known techniques for assessing groundwater susceptibility. The Drastic model analyses a number of important factors, such as hydraulic conductivity, recharge, topography, impact of the vadose zone, depth to the water table, and aquifer and soil media. When taken as a whole, these components provide a thorough grasp of the hazards that Jharkhand's groundwater resources confront. It was developed as a qualitative

tool to identify areas at risk of groundwater pollution based on various hydrogeological parameters. The acronym DRASTIC stands for Depth to Water table, Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity. Shallow water tables are generally more susceptible to contamination as pollutants have a shorter distance to travel before reaching the groundwater. The depth to the water table is a critical factor in assessing vulnerability. Recharge refers to the rate at which water replenishes the aquifer. Areas with low recharge rates may be more vulnerable to contamination as there is less dilution of pollutants. The characteristics of the aquifer material, such as its permeability and porosity, influence how easily contaminants can move through it. Highly permeable aquifers are more vulnerable to rapid contaminant transport. The type of soil through which water percolates before reaching the aquifer affects vulnerability. Different soils have varying capacities to filter and attenuate contaminants. Topography plays a role in directing the flow of groundwater. Contaminants may travel more rapidly downhill, affecting vulnerability in certain topographic settings. The vadose zone is the unsaturated zone above the water table. It filters and transforms contaminants before they reach the groundwater. Understanding the impact of this zone is crucial for assessing vulnerability.

DRASTIC model and the overlay sum weighted approach are used to identify the Jharkhand groundwater vulnerable areas. The region is categorized into five groups by the final vulnerability map according to the DRASTIC index values: low (75 - 107.83), moderate low (107.84 - 117.11), moderate (117.12 - 127.1), moderate high (127.11 - 138.16) and high (138.17 - 166). The visualization indicates that the majority of Jharkhand's low-vulnerability zones are found in the state's northern and central regions including portions of the districts of Hazaribagh, Giridih and Dumka. Deeper water tables, slower recharge rates and less porous aquifer media and soil help these places by lowering the danger of contamination. On the other hand, large areas of the state's southern regions such as East Singhbhum, West Singhbhum and Southern Jharkhand are concentrated in high vulnerability zones which are more prone to groundwater contamination due to their extremely shallow water tables, high rate of recharge, highly permeable soil and aquifer materials. While moderate and moderate low exposure zones include a number of localities including Palamu, Garhwa and Ranchi, moderate high vulnerability areas are also noteworthy, encompassing portions of Lohardaga, Simdega and Bokaro. Policymakers and environmental managers may use this evaluation as a vital tool to help them prioritize and put groundwater conservation measures into action. The results emphasize the necessity of taking prompt action in high-vulnerability areas to stop pollution and guarantee long-term groundwater management across Jharkhand.

***Keywords*:** *Groundwater, vulnerability, DRASTIC model, overlay sum weighted approach, DRASTIC index, Jharkhand*