Groundwater Contamination: Challenges and Role of Sustainable Management Practices

Anurag Tewari[1,*], Sadhna Awasthi[2], and Vikrant Pachouri[3]

ARTICLEINFO

Article history:
Received: 18 May 2023
Revised: 23 August 2023
Accepted: 31 August, 2023

Keywords:
Groundwater
Geo-chemistry
Contaminants
Heavy metals
Sustainable practice
Aquifers

ABSTRACT

Groundwater serves humans in multiple ways; in addition to offering a wide range of other services, it is crucial as a biotic component for sustainable existence. Compared to natural water, it frequently has lower toxicity and pollution risks. Nevertheless, various soil degradation & freshwater anthropogenic activities put this precious natural resource in peril. Groundwater quality changes due to natural infiltration processes, rates, and materials disruptions. Due to unscientific development and a lack of understanding of the dynamics of groundwater flow and geo-hydro chemical processes, excessive groundwater use for industrial and irrigation purposes is creating pollution of the aquifer, affecting the quality of groundwater and accelerating mineralization. The causes and actions that led to the contamination of water resources, the situation regarding groundwater pollution, and the various ways to treat the polluted water have all been emphasized in this study. The predicted effects of climate change on the occurrence, accessibility, and quality of groundwater resources have been tried to cover along with the environmentally eco-friendly, cost-effective treatment technologies and sustainable management practices that are now required for sustainable living and can be utilized to reduce groundwater contamination.

1. INTRODUCTION

International organizations believe that access to clean water is essential for human growth, health, and well-being [1], [2]. It is one of the 10th goals in the Millennium Development Goals (MDGs). Although water supply and sanitation were included in India's national agenda during the first five-year planning period (1951–1956), there is still a long way to go before the goals can be realized [3]. The problems in most developing countries are worsening due to rapid population increase, changing industrial culture, rising consumerism, careless use of resources, poor waste and water management practices, inappropriate use of technology, and unsustainable lifestyles [4]. For millions of people in rural and urban parts of India, underground water is a critical decentralized water resource and a range of other services. It meets 50% of the country's urban water needs and more than 80% of its household water needs in rural areas. As well as being less prone to contamination, groundwater is said to be devoid of viruses and suspended particles [5], [6]. However, over-exploitation and pollution brought on by numerous human activities have greatly diminished its quality over many decades. At a worldwide level, the most major groundwater contaminants are caused by heavy metals, microbiological, fluoride and arsenic, and their impacts are more severe in some local environments [7], [8]. Groundwater contamination, unlike other types, is significant because once an aquifer is polluted, it is sometimes exceedingly tricky, expensive, and time-consuming to clean it up and may remain useless for decades [9], [10]. With this framework, the present study gives an overview of the problem of groundwater pollution in the context of India, where a variety of anthropogenic unsustainable activities, climate change, the type of toxins, and corrective efforts to limit the origins and effects of pollution have all been explored in the present study [11].

2. INDIA- WATER RESOURCES AND AVAILABILITY OF GROUNDWATER

Inputs of water to India's water resources are estimated to be roughly 4000 km^3 of precipitation on Indian soil, and 500 km^3 of trans-border flows in rivers and aquifers from the upper riparian nations. Only 433 km^3 of this total may be used for beneficial purposes as groundwater, which is less than 10% of the total inflow every year. Due to the extensive variance in the sub-geology, continent's climate, and geography, the availability is once again quite unequal [12], [13].The entire nation has been largely split into five separate groundwater zones, including (i) mountainous terrain and hilly areas, (ii) Indo-Gangetic-Brahmaputra alluvial plains, (iii) peninsular shield area, (iv) coastal area,

[1]*Department of Basic Science and Humanities, Pranveer Singh Instittue of Technology, Bhauti,Kanpur-209305 (UP), India.*
[2]*Department of Chemistry, School of Applied and Life Sciences, Uttaranchal University, Dehradun-248007(UK), India.*
[3]*Department of Civil Engineering, Uttaranchal University, Dehradun-248007(UK), India.*
[*]*Corresponding author:* Anurag Tewari; Phone: +91-9415735630; Email: anuragtewari70@gmail.com.

and (v) central alluvial areas, based on unique physiographic features as well as the occurrence and distribution of groundwater. Out of 5723 assessment units (Blocks/Mandals/Talukas) in the nation, 839 are "overexploited," 226 are "critical," and 550 are "semi-critical units" based on the stage of groundwater development and long-term water level dropping tendency [14], [15].

3. OCCURRENCE OF GROUNDWATER CONTAMINATION

The various pollutants that have been found in groundwater include microorganisms, micronutrients, heavy metals, chlorinated hydrocarbons, phenols, cyanide, pesticides, other dangerous substances, nitrates, and other compounds, including salt (coastal and inland), fluoride, sulphide, iron, manganese, arsenic, nitrate, chloride, zinc, chromium, other heavy metals, pesticides, and pathogens [16] Inland salinity develops in dry and semi-arid areas as a result of the high rate of evaporation there, especially in inundated canal sections and other places with shallow water table [17]. At 25°C, the electrical conductivity value is >4000 μS/cm and can occasionally exceed 10000 μS/cm (several places in Rajasthan and southern Haryana).On the other hand, coastal salinity develops due to connate water or seawater that has been trapped ,as well as seawater infiltration, leachates from salt pans and navigation canals built along the shore [18]. In coastal locations, three circumstances, including (i) a saline water layer atop a freshwater aquifer, (ii) a freshwater layer overlying a saline water layer, and (iii) an alternation of fresh water and salty water aquifers, tend to occur. In Rajasthan and Haryana states, where >3.5mg/L fluoride is detected, problems associated with excessive fluoride levels (permissible limit, 1.5 ppm) have been noticed (Together with boron and nitrate toxicity) [19]. Arsenicism illnesses induced by arsenic (permissible limit, 0.01 ppm) in West Bengal, UP, Punjab, and many other parts of the Ganges deltaic regions (including areas in Bangladesh and Nepal). Arsenic is not present in deeper aquifers than intermediate aquifers (20–100 m). In more than 1.1 lakh habitations across the nation, high concentrations of iron (>1.0 ppm) in groundwater have been discovered [20]. The majority of India's hydrogeological formations have high nitrate concentrations (> 45 ppm) in their groundwater (3080 ppm, Bikaner in Rajasthan) [21]. The uncontrolled discharge of industrial effluents is the primary cause of heavy metals like chromium, lead, nickel, etc., in groundwater that have been recorded from various geographical parts of the country [22].

4. SOURCES OF GROUNDWATER CONTAMINATION

When there is a change in the physical properties of groundwater's chemistry due to pollutants from anthropogenic or natural sources, it becomes detrimental to human health and/or other uses [23]. The numerous causes and forms of groundwater contamination are linked to different resource or waste management options. On the other hand, sources like agricultural fields, septic tanks, run-off from metropolitan areas, etc., are nonpoint source pollution. Since these nonpoint sources occur across a wide region, they can collectively have a more significant impact. Natural materials found in the aquifer sediments, such as arsenic, fluoride, radon gas, etc., can cause some groundwater contamination [24].

4.1 Land contamination

Various inorganic and organic contaminants, including contaminants, polycyclic aromatic hydrocarbons, and volatile compounds, have polluted the ground due to industrial activity. These chemicals can cause substantial groundwater contamination. Compared to other nations, polluted soil plays a significant role in groundwater contamination. Serious groundwater pollution incidents have resulted from the legacy of contamination left behind by anthropogenic activities in the past and today and will continue to do so [25], [26].

4.2 Heavy Metals

Water frequently contains trace quantities of heavy metals. The most frequent sources of pollution include mining, sewage sludge, fertilizers, agricultural waste, urban and industrial effluents, and fossil fuels. Due to their propensity for bio-magnification, contaminants are hazardous. When a chemical's concentration in a biological organism rises over time relative to its concentration in the environment, it is called bio-magnification. Metals may harm people and animals, even in minimal concentrations. Examples of heavy metals that are more harmful are chromium (Cr), mercury (Hg), lead (Pb), cadmium (Cd), zinc (Zn), arsenic (As), copper (Cu), and nickel (Ni) [27], [28].

4.3 Landfills

According to studies, landfills provide one of the biggest dangers to groundwater supplies. Groundwater contamination might be quite severe from landfill leachate. Several studies have been conducted recently on the impact of sludge on the surface and groundwater systems [29].

4.4 Microbiological Contaminants

Human or animal sewage is the primary source of the microbiological contamination of groundwater. Sewage may include many pathogens, including harmful bacteria, viruses, and protozoa. If found in a water supply, these pollutants may pose a significant hazard to human health [30]. Microbiological pollutants may infiltrate the subterranean environment through leaky septic tanks, cesspits, sewers, soakaway systems, abandoned mines as disposal pathways, garbage dumps or trumpet discharge used as fertilizer on the land. These buildings immediately discharge sewage or waste into the underground environment, which can contaminate groundwater. How wastewater is contained and treated, and the area's hydrogeology influence the prevalence of sewage pollution [31]. Large amounts of inadvertent sewage are accidentally discharged into the groundwater underneath cities and less developed regions, where the sewage is originally produced via sewers through leaks. Bacteria, viruses, and nitrates are the most typical pollutants discovered in groundwater beneath these systems. Numerous individual contamination episodes have been documented, and it has been commonly considered that polluted groundwater may be able to transmit infectious diseases [32].

4.5 Fertilizers and Pesticides

Insecticides, fungicides, and herbicides are all pesticides often employed in business, government, and agriculture. Given their ability to bioaccumulate throughout the food chain, they can harm human health. They may be dangerous and persistent in the environment, harming human health. It is a significant issue that point sources and routine, extensive land application of nitrogen-based fertilizers and pesticides contribute to groundwater contamination [33].

5. PHYSICO-CHEMICAL PROPERTIES, ANALYSIS AND WATER QUALITY INDEX

According to various researches, the Water Quality Index (WQI.) is a helpful and distinctive assessment for summarizing the water quality status and deciding the most effective treatment method to address the challenges. First, WQI is the most often utilized indicators of groundwater resources; it has been widely used and authorized in countries in Europe, Africa, and Asia and measures things like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, and chloride. In the U.P., India[34], [35], scientists are investigating aquifers' Physical and chemical Characteristics. pH, DO, EC, TDS, alkalinity, turbidity, Ca and Mg hardness, total hardness, NO_3, F, and Fe^{+3} (fluoride), and iron and chlorine have all been evaluated. When compared with the water quality standards, it has been revealed that the parameters are out of bounds. The following parameters are studied for the Evolution of the Water Quality Index: pH, EC, TDS, Total Hardness, DO, COD, BOD, Cl^-, NO_3 and Mg to understand the water quality of a region. According to the analysis, some treatment is required before drinking the local groundwater [36],[37]. The characteristics of aquifers and the water quality index in Bidar, Karnataka, have been the subject of research. The factors include pH, total hardness, calcium (Ca), magnesium (Mg), chloride (Cl^-), nitrate (NO_3), sulphate (SO_4), total solids (TS), iron (Fe^{+3}), fluoride (F), sodium (Na), potassium (K), alkalinity, manganese (Mn), dolomite (DO), and zinc (Zn) [38], [39].

6. TREATMENT STRATEGY FOR GROUNDWATER CONTAMINATION

Treatment options include specific filters, evaporative towers, reverse osmosis, surfactants, oxidizing solutions, sorptive filtration, activated alumina, steam, or hot water at the point of application. Reverse osmosis (RO), a pump-and-clean technique, has the potential to remove heavy metals, fluoride, and residues from pesticides and fertilizers [40], [41]. However, unit costs are somewhat more significant. Similarly, arsenic may be removed at the household level using a ferric chloride coagulation device. Another method for removing arsenic is sorptive screening based on a metal soil layer; however, it is only partially efficient [42]. As a domestic defluoridation treatment option, activated alumina or the Nalgonda method might be used. Another method of remediating the aquifer involves chemically or biologically immobilizing or detoxifying the toxins (using bacteria). The alternative strategy is to physically, chemically, or hydraulically confine the pollutants to stop them from moving away from their source [43].

7. MANAGEMENT AND REGULATION OF GROUNDWATERRESOURCES

1) Registering the buildings used to collect groundwater and regulating them through water audits and assessments analysis of the potential changes in the spatiotemporal variability of groundwater availability and demand throughout all of the significant hydrogeological regions of the nation under climate change [44].
2) Giving priority to watersheds that are susceptible to flow variations and creating decision support systems to enable prompt and effective responses; using RS/GIS to control groundwater; water harvesting, artificial recharge, and strengthening connections with wetland conservation programs will improve the recharging of deeper groundwater aquifers' sources and recharge zones [45].
3) Implementing water usage efficiency initiatives, including water recycling, piped water systems, virtual water acceptable, and rationalization energy supply. Under altered climate and land use conditions, the environment and food security are prioritized during groundwater allocation [46].
4) Using decentralized treatment as the second choice, centralized treatment as the third option, and recycling and reuse solutions for wastewater and solid wastes as the first and final options. Accurate planning, construction, creation, and upkeep of the sewage and landfill systems (sanitary and storm water). An absolute ban on dumping sewage or

contaminated water into an aquifer that supplies groundwater [47].

5) Land use patterns in catchments are surveyed, mapped, and evaluated, with a focus on drainage, plant cover, silting, encroachment, preservation of mangrove regions and other wetlands, human settlements, and human activities, as well as their effects on catchments and water bodies; increasing public awareness; increasing the storage capabilities of multifunctional hydro projects, fusing drainage and irrigation infrastructures, and restoring ageing water tanks [48].
6) The excessively unwanted elements in the water must be removed using a specialized treatment method before it is used for human consumption if there is no other reliable supply of clean water. Proper cementing should be carried out to prevent contact between the contaminated aquifers and the unpolluted aquifers [49].
7) In flood-prone locations, such as coastal areas, it may be possible to build sanctuary wells that may be used as monitoring wells and as a reserve during natural disasters [50].
8) It has been suggested that an effective decision-making tool for groundwater management is an integrated participative strategy based on Bayesian belief networks (BBN) and evolutionary multi-objective optimization [51]. The combination of BBN and evolutionary multi-objective optimization enables the investigation of trade-offs between several goals and the incorporation and recognition of a wider range of choice goals [52], [53].

8. CONCLUSION

Negligence, accidents, and unsustainable resource and waste management methods primarily cause groundwater contamination. Still, it is more of a worry when these behaviors are intentional, such as releasing contaminants directly into groundwater and surface water. Pollution of this priceless resource will significantly impact the nation's ability to grow sustainably in nations like India, where most of the population lives in remote areas with no infrastructure, inadequate sanitation, and poor hygiene. Eco-friendly, cost-effective technologies for treating groundwater contamination and sustainable management practices, which are now essential for a sustainable future, can be used to reduce groundwater contamination. The management of groundwater is crucial to the livability and production of locations worldwide, according to numerous studies, which emphasize that it is a local resource. Water policymakers, consumers, researchers, and individuals must closely monitor this irreplaceable natural resource before it is contaminated or exhausted, resulting in significant economic, environmental, and social disturbances.

ACKNOWLEDGEMENT

The authors thank the Director and state government officials for supporting this work.

REFERENCES

[1] Singh, S., Tewari, A., & Dubey, A. (2014). Wastewater reuse: An integrated approach towards water resource management. *Pollut Res*, 33 (04), 797–800. [Online] Available:http://www.envirobiotechjournals.com/article_abstract.php?aid=5582&iid=181&jid=4.

[2] Tewari, A., and Paroha, P. P. (2021). Emerging Contaminants: Challenge for Ground and Surface Water Management. *Indian Journal of Environmental Protection*, 41, (12), 1391–1398. [Online] Available: https://www.e-ijep.co.in/41-12-1391-1398/.

[3] Hering, J. G., Chen, P.Y., Wilkie, J. A., & Elimelech, M. (1997). Arsenic Removal from Drinking Water during Coagulation. *Journal of Environmental Engineering*, 123(8), 800–807. https://doi.org/10.1061/(ASCE)0733-9372(1997) 123: 8(800).

[4] Mulligan, C. N., Yong, R. N., & Gibbs, B. F. (2001). Remediation technologies for metal-contaminated soils and groundwater: An evaluation. *Eng Geol*, 60(1–4), 193–207. https://doi.org/ 10.1016/S0013-7952(00)00101-0.

[5] Dubey, A., Tewari, A., & Sharma, D. (2020). Electrocoagulation Reactor and Process for Defluoridation of Drinking Water. *Indian Journal of Environmental Protection*, 40 (2), 168-173.

[6] Tewari, A., & Dubey, A. (2015). Variation of fluoride concentration in aquifers of different depths: possible geologic reasons. *Ecology, Environment and Conservation*, 21(2), 1035–1038. [Online] Available: http://www.envirobiotechjournals.com/article_abstract.php?aid=6063&iid=192&jid=3.

[7] Garg, V. K. (2008). Drinking water quality in villages of southwestern Haryana, India: assessing human health risks associated with hydrochemistry. *Environmental Geology*, 58 (6), 1329–1340. [Online] Available: https://www.academia.edu/4747130/Drinking_water_quality_in_villages_of_southwestern_Haryana_India_assessing_human_health_risks_associated_with_hydrochemistry.

[8] Artabe, A. E., Cunha Silva, H, & Barranco, A. (2020). Enzymatic assays for assessing toxic effects of halogenated organic contaminants in water and food. *Food and Chemical Toxicology*, 145. 111677. https://doi.org/ 10.1016/J.FCT.2020.111677.

[9] Ahluwalia, S. S., & Goyal, D. (2007). Microbial and plant derived biomass for removal of heavy metals from wastewater. *Bioresour Technol*, 98(12), 2243–2257. https://doi.org /10.1016/J.BIORTECH.2005.12.006.

[10] Ali, I. & Gupta, V. K. (2007). Advances in water treatment by adsorption technology. *Nature Protocols*, 1 (6), 2661–2667. https://doi.org/ 10.1038/nprot.2006.370.

[11] Mohammadi, S., Binesh, A., & Pourhabib, Z. (2012). A study on heavy radioactive pollution: Radon and Radium in streams and drinking water of Ramsar region by measured Prassi system. *Iranian Journal of Physics Research*, 11(4), 397–403. https://doi.org/79dc7eb100544e99b7ac9102f81905da.

[12] Liu, G. D., Wu, W. L., & Zhang, J. (2005). Regional differentiation of nonpoint source pollution of agriculture-derived nitrate-nitrogen in groundwater in northern China.

Agric Ecosyst Environ, 107(2–3), 211–220. https://doi.org/ 10.1016/J.AGEE.2004.11.010.

[13] Kumar, A. R., & Riyazuddin, P. (2010). Chromium speciation in groundwater of a tannery polluted area of Chennai City, India. *Environ Monit Assess*, 160(1–4), 579–591. https://doi.org/10.1007/S10661-008-0720-9.

[14] Sukthanapirat, R., Suttibak, S., & Jaikaew, P. (2017). Assessment of Nhong Han Lake, Sakon Nakhon, Thailand by using water quality index. *GMSARN International Journal*, 11, 123-128.

[15] Moussa, D., El, Naas, M. (2017). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. *Elsevier*, 186(pt-1), 24-41. https://www.sciencedirect.com/science/article/pii/S0301479716308106.

[16] Rakesh, K., Singh R. D., & Sharma K. D. (2005). Water resources of India. *Curr Sci*, 89 (5), 794–811. Available: https://www.jstor.org/stable/24111024.

[17] Singleton, M. J., & Moran, J. E. (2010). Dissolved noble gas and isotopic tracers reveal the vulnerability of groundwater in a small, high-elevation catchment to predicted climate changes. *Water Resour Res*, 46(12), https://doi.org/ 10.1029/2009WR008718.

[18] Kong, R. Y. C., Mak, M. M. H., & Wu, R. S. S. (2009). DNA technologies for monitoring waterborne pathogens: A revolution in water pollution monitoring. *Ocean Coast Manag*, 52(7), 355–358. https://doi.org/ 10.1016/J.OCECO AMAN.2009.04.011.

[19] Green, T. R. (2011). Beneath the surface of global change: Impacts of climate change on groundwater. *J Hydrol (Amst)*, 405(405), 532–560. https://doi.org/ 10.1016/J.JHYDROL. 2011.05.002.

[20] Gupta, S.K., Gupta, R.C., Seth, A.K., Gupta, A.B., Bassin, J.K., and Gupta, A. (2000). Methaemoglobinaemia in areas with high nitrate concentration in drinking water. *Natl Med J India*, 13(2),58-61. [Online]. Available: http://archive. nmji.in/archives/Volume-13/issue-2/original-articles-1.pdf.

[21] Gaya, U. I., & Abdullah, A. H. (2008). Heterogeneous photocatalytic degradation of organic contaminants over titanium dioxide: A review of fundamentals, progress and problems. *Journal of Photochemistry and Photobiology C-photochemistry Reviews*, 9(1), 1–12. https://doi.org/ 10.1016/J.JPHOTOCHEMREV.2007.12.003.

[22] Chaudhary, V., Kumar, M., Sharma, M., & Yadav, B. S. (2010). Fluoride, boron and nitrate toxicity in groundwater of north-west Rajasthan, India. *Environ Monit Assess*, 161(1–4), 343–348. https://doi.org/ 10.1007/S10661-009-0750-Y.

[23] Mohan, N., & Balasubramanian, N. (2006). In situ electrocatalytic oxidation of acid violet 12 dye effluent. *J Hazard Mater*, 136(2), 239–243. https://doi.org/ 10.1016/J.JHAZMAT.2005.11.074.

[24] Moore, M. T. (2001). Transport and fate of atrazine and lambda-cyhalothrin in an agricultural drainage ditch in the Mississippi Delta, USA. *Agric Ecosyst Environ*, 3(87), 309–314. [Online]. Available: https://www.infona.pl//resource/ bwmeta1.element.elsevier-8a70f7aa-f546-33ea-b09d-ef33418736bd.

[25] Harper, T. R., & Kingham, N. W. (1992). Removal of arsenic from wastewater using chemical precipitation methods. *Water Environment Research*, 64(3), 200–203. https://doi.org/ 10.2175/WER.64.3.2.

[26] Gabrielli, C., Jaouhari, R., Maurin, G., & Keddam, M. (2001). Magnetic water treatment for scale prevention. *Water Res*, 35(13), 3249–3259. https://doi.org/ 10.1016/ S0043-1354(01)00010-0.

[27] Ghosh, U., Weber, A. S., Jensen, J. N., & Smith, J. R. (1999). Granular Activated Carbon and Biological Activated Carbon Treatment of Dissolved and Sorbed Polychlorinated Biphenyls. *Water Environment Research*, 71(2), 232–240, https://doi.org/ 10.2175/106143098X121761.

[28] Madhavan, N., & Subramanian, V. (2006). Factors affecting arsenic concentration in groundwater in West Bengal. *Environ Chem Lett*, 4(2), 79–82. https://doi.org/ 10.1007/S10311-006-0037-2/METRICS.

[29] Meenakshi, & Maheshwari, R. C. (2006). Fluoride in drinking water and its removal. *J Hazard Mater*, 137(1), 456–463. https://doi.org/ 10.1016/J.JHAZMAT.2006.02.024.

[30] Manyatshe, A., Fosso-Kankeu, E., Van der Berg, D., Lemmer, N., Waanders, F., Tutu, H. (2017). Dispersion of inorganic contaminants in surface water in the vicinity of Potchefstroom. *Elsevier*, 100, 86-93. https://doi.org/ 10.1016/j.pce.2017.04.008.

[31] Eggins, B. R., Palmer, F. L., & Byrne, J. A. (1977). Photocatalytic treatment of humic substances in drinking water. *Water Res*, 31(5), 1223–1226. https://doi.org/ 10.1016/S0043-1354(96)00341-7.

[32] Gorchev, H. Galal. (1996). Chlorine in water disinfection. *Pure and Applied Chemistry*, 68(9), 1731–1735. https://doi.org/ 10.1351/PAC199668091731/HTML.

[33] Goodwin, J. A. S., & Forster, C. F. (1985). A further examination into the composition of activated sludge surfaces in relation to their settlement characteristics. *Water Res*, 19(4), 527–533. https://doi.org/ 10.1016/0043-1354(85) 90045-4.

[34] Matlock, M. M., Howerton, B. S., & Atwood, D. A. (2002). Chemical precipitation of heavy metals from acid mine drainage. *Water Res*, 36(19), 4757–4764. https://doi.org/ 10.1016/S0043-1354(02)00149-5.

[35] Matlock, M., Howerton, B., & Atwood, D. A. (2022). Chemical precipitation of heavy metals from acid mine drainage. *Elsevier*, 36(19), 3757-3464. https://doi.org/ 10.1016/S0043-1354(02)00149-5.

[36] Mikami, I., Sakamoto, Y., Yoshinaga, Y., & Okuhara, T. (2003). Kinetic and adsorption studies on the hydrogenation of nitrate and nitrite in water using Pd-Cu on active carbon support. *Appl Catal B*, 44(1), 79–86. https://doi.org/ 10.1016/S0926-3373(03)00021-3.

[37] Mikami, I., Kitayama, R., & Okuhara, T. (2006). Hydrogenations of nitrate and nitrite in water over Pt–promoted Ni catalysts. *Appl Catal A Gen*, 297(1), 24–30. https://doi.org/ 10.1016/J.APCATA.2005.08.038.

[38] Unc, A., & Goss, M. J. (2003). Movement of faecal bacteria through the vadose zone. *Water, Air, and Soil Pollution*, 149, 327-337. https://doi.org/10.1023/A:1025693109248.

[39] Martínez-Huitle C. A., & Ferro, S. (2006). Electrochemical oxidation of organic pollutants for the wastewater treatment: direct and indirect processes. *Chem Soc Rev*, 35(12), 1324–1340.https://doi.org/10.1039/B517632H.

[40] Mulligan, C. N., Yong, R. N. & Gibbs, B. F. (2009) Remediation technologies for metal-contaminated soils and groundwater: an evaluation. *Eng Geol*, 60(1–4), 193–207. https://doi.org/10.1016/S0013-7952(00)00101-0.

[41] Quarrie, Mac., P. R., Viriyasakultorn, V., & Wolf, A. T. (2008). Promoting cooperation in the Mekong region through water conflict management, regional collaboration, and capacity building. *GMSARN International Journal*, 2(4), 175-186.

[42] Hundal, H. S., Singh, K., & Singh, D. (2009). Arsenic

content in-ground and canal waters of Punjab, North-West India. *Environ Monit Assess*,154(1–4), 393–400. https://doi.org/ 10.1007/S10661-008-0406-3.

[43] Agrawal, G. D., Lunkad, S. K. & Malkhed, T. (1999). Diffuse agricultural nitrate pollution of groundwaters in India. *Water Science and Technology*, 39(3), 67–75. https://doi.org/ 10.1016/S0273-1223(99)00033-5.

[44] Tewari, A., Dubey, A., & Chaturvedi, M. K. (2012). Assessment of exposure, intake and toxicity of fluoride from groundwater sources. *Rasayan Journal of Chemistry*, 5(2), 199-202. [Online] Available: https://www.rasayanjournal.co.in/vol-5/issue-2/13.pdf.

[45] Tewari, A., & Sharma, D. (2017). Geological contamination of arsenic in groundwater: A review. *Rasayan Journal of Chemistry,* 10 (4), 1412-1416. [Online] Available: http://www.rasayanjournal.co.in/admin/php/upload/293_pdf.pdf.

[46] Ghrefatet, H. (2014). Geochemical assessment of groundwater contamination with special emphasis on fluoride, a case study from Midyan Basin, northwestern Saudi Arabia. *Environ Earth Sci.*, 71(4), 1495–1505. https://doi.org/ 10.1007/S12665-013-2554-1.

[47] Jain, S. K., Agarwal, P. K., & Singh, V. P. (2007). Problems Related to Water Resources Management in India. *Hydrology and Water Resources of India,* 57, 871–936. https://doi.org/ 10.1007/1-4020-5180-8_18.

[48] Radif, A. Al., (1999). Integrated water resources management (IWRM): an approach to face the challenges of the next century and to avert future crises. *Desalination*, 124(1–3), 145–153. https://doi.org/ 10.1016/S0011-9164(99)00099-5.

[49] Chuenchooklin, S. (2023). Influence of Large Irrigation Dam Operation on Water Quality of Surface Water Bodies in Thai Wetlands near Saline Soil Spots. GMSARN International Journal, 17, 46-56.

[50] Foote, Lee. A., Pandey, S., & Krogman, N. T. (1996). Processes of wetland loss in India. *Environ Conserv*, 23(1), 45–54. https://doi.org/ 10.1017/S0376892900038248.

[51] Farmani, R., Henriksen, H. J., Savic, D., & Butler, D. (2012). An evolutionary Bayesian belief network methodology for participatory decision making under uncertainty: an application to groundwater management. *Integr Environ Assess Manag*, 8(3), 456–461. https://doi.org/ 10.1002/IEAM.192.

[52] Dixit, A. (2003). Floods and vulnerability: Need to rethink flood management. *Natural Hazards*, 28(1), 155–179. https://doi.org/ 10.1023/A:1021134218121/METRICS.

[53] Laumanns, M., Thiele, L., Deb, K., & Zitzler, E. (2002). Combining convergence and diversity in evolutionary multi-objective optimization. *Evol Comput*, 10 (3), 263–282. https://doi.org/ 10.1162/10636560276023410.