A Comprehensive Look at India's Water Pollution Landscape

Examining the Status and Sources of Groundwater Pollution

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An estimated 100-300 million people across India have been exposed to health concerns such as arsenicosis, fluorosis, carcinogenicity, and death due to ingestion of non-point-source geogenic contaminants. The prevalence, extent, variability, and environmental impact of these groundwater-borne contaminants have been extensively examined and discussed by water and health researchers over the past four decades. However, as of the date, a full understanding the provenance/sources, natural fate and transport of these contaminants in various geological media and consequent aquifers are not very well discerned. This article highlights types of groundwater pollutants and their status in Indian context and also highlights the role of isotope tracers in deducing source and mechanism of groundwater pollution.

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In both pre- and post-independence India, the use of untreated waters has led to frequent outbreaks of water-borne illnesses. In order to meet the drinking and household water needs, various urban and rural communities of the country have been increasingly depending on groundwater sources since the 1970s. Currently, groundwater provides more than 70% of the nation's residential water supply. However, the presence of natural pollutants in many regions has raised concerns regarding the supply of safe water (Mukherjee et al., 2015; Mukherjee, 2018a).

According to recent estimates, around one-fourth of the 300 billion m^3 of groundwater in the Indus Ganga and Brahmaputra (IGB) aquifer is brackish and unfit for human use. Additionally, naturally occurring, elevated concentrations of non-point sourced pollutants contaminate about 40% of groundwater, putting the public health of over 100 million people at risk (Fig. 1, Mukherjee et al., 2015). As a result, approximately 60% of the groundwater in the IGB aquifers is classified as unsafe and unusable (MacDonald et al., 2016). It has not yet been determined the amount and impact of other newly discovered and unidentified groundwater contaminants (such as pesticides, radiogens, antibiotics, etc.). According to Saha and Alam (2014), intensive agriculture is linked to a significant amount of chemical and synthetic pesticide input that seeps into groundwater systems. A more pervasive and acute, but less documented groundwater contamination can be linked to sanitation-sourced pollution, causing larger public health concerns.

Natural groundwater pollutants

In certain parts of India, elevated levels of naturally occurring, geogenic contaminants, like arsenic (As) and fluoride (F), are frequently found in groundwater. The geological formations of the aquifers, where As and F are present as trace elements in rocks, are the source of these toxins. There have been reports of As contamination of groundwater in 86 districts across 10 Indian states (Mukherjee et al., 2015; Bhattacharya et al., 2014), and it has exposed over 50 million people in the Bengal Basin alone, causing “the largest mass poisoning in human history” (Smith

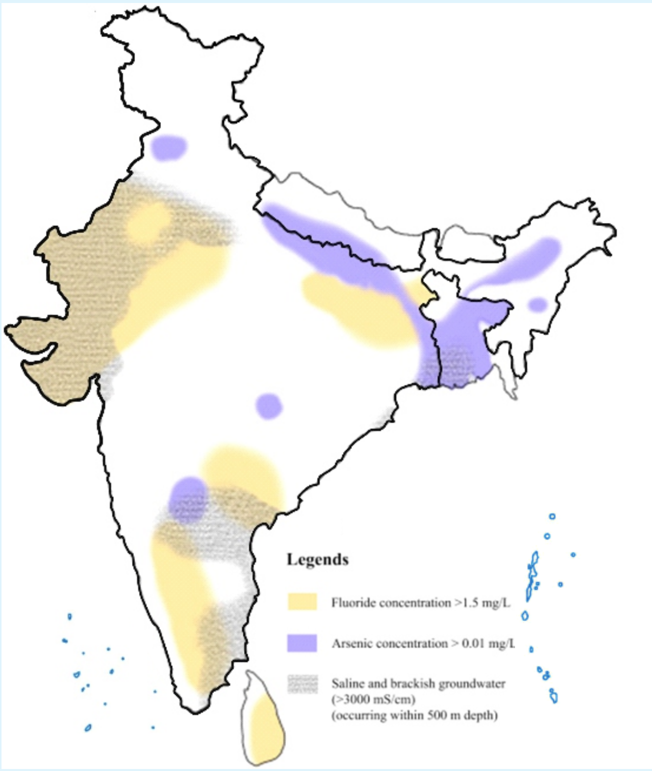

Fig.1: A pictorial representation of extent of major geogenic groundwater contaminants across India (Mukherjee et al., 2015)

et al., 2000). The Ganges-Brahmaputra river basin aquifers in the Indian states of West Bengal, Assam, Bihar, and Uttar Pradesh are reported to have arsenic in groundwater. The contaminant has been proposed to be associated with the Siwalik deposits from the eastern Himalayas. Although it hasn't been verified, widespread pollution from Punjab's Indus basin has also been proposed recently. According to Bhattacharya et al. (2011), the anoxic groundwater of these IGB aquifers supports redox-dominated metal cycling mechanisms. According to Mukherjee et al. (2011), widespread groundwater abstraction may have contributed to the pollution's worsening. The first occurrences of health problems linked to contaminated water were noted in West Bengal and Bangladesh in the early 1980s, and they were documented in the medical literature by Garai et al (1984).

Long-term exposure to water containing high amounts of As can cause severe health problems, such as melanosis, hyperkeratosis, skin lesions, and cancer in several organs, some of which can be lethal. Although the health implications of drinking As-contaminated water are widely known, it is still unclear how it may affect the food chain, particularly crops that are irrigated with polluted water. Numerous factors, such as the soil's redox potential, pH, organic matter content, soil microorganisms, and the amounts of iron (Fe), manganese (Mn), phosphorus (P), and calcium carbonate ($CaCO_3$), affect the bioavailability of As for crops. Furthermore, the majority of As absorbed by plants tends to build up in the roots, with progressively less accumulation in the stems, leaves, and grains.

There have also been reports of high levels of F in groundwater, primarily in crystalline aquifers in portions of 19 states (Maheshwari, 2006). In India, it is estimated that over 66 million people are exposed to excessive levels of F in their groundwater (Mumtaz et al. 2017). The states of Rajasthan, Gujarat, and Andhra Pradesh are the most severely impacted. Higher amounts (1.5-2 mg/L) can cause dental fluorosis, however a dosage of 0.8-1.0 mg/L is necessary for the calcification of tooth enamel. Even greater concentrations (3-6 mg F/L) cause skeletal fluorosis, which damages ligaments and bones.

Many aquifers across the nation have also been found to contain high levels of groundwater nitrate (NO_3-) and iron (Fe) (CGWB, 2014b). While highly saline groundwater is also common in the inland aquifers of various states, sea water intrusion that causes aquifer salinization has also been reported in several of the aquifers that border the coastal regions of the Arabian Sea and Bay of Bengal (CGWB, 2014a, MacDonald et al., 2016). Such inland salinization may be associated with agricultural pollution and/or mineral dissolution.

Human sourced groundwater pollution

Agricultural and Industrial pollution

The "Green Revolution" in the 1960s and 1970s saw the introduction of agricultural practices that heavily relied on agrochemicals to boost crop yields. These practises led to overuse of croplands and application of excess pesticides and fertilisers, which seep through subsurface and contaminate groundwater sources (Saha and Alam, 2004). Due to the increased prevalence of nitrogen and phosphate fertilisers in groundwater, the redox condition and the chemistry of aquifers were altered, producing a powerful feedback effect. Due to their slow rate of degradation, many agricultural pesticides remain in groundwater for extended periods of time. The pesticide residues tend to both bioaccumulate and become biomagnified in creatures that consume contaminated groundwater.

Further, India has experienced rapid industrial and agricultural growth in recent decades, exposing people to a wide variety of chemical contaminants that are progressively contaminating groundwater and surface water (ITT, 2018). Since the adoption of best practices for cleaner industrial processes is not keeping pace with the growth of overall industrial production in a wide variety of industrial facilities, industrial pollution is generally on the rise. Large amounts of industrial effluent pollutants are produced during the processing of industrial chemicals for food production as well. Agricultural runoff is diffuse non-point source pollution that originates from wide areas, whereas industrial effluent is usually concentrated through "point source" contamination from discrete facilities (Mukherjee et al., 2011, 2018b). The chemical and biological contaminants found in these effluents, such as antibiotics, polycyclic aromatic hydrocarbons (PAH), persistent organic pollutants (PoPs), are highly poisonous, flammable, corrosive, and reactive, and they can have detrimental impacts on human health. Moreover, endocrine disruptors and heavy metals are two particularly alarming categories of pollutants released into groundwater through industrial effluents (Mondal et al., 2012). Lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) are among the heavy elements that is frequently found in these effluents. These contaminants bioaccumulate in the body over time and are not biodegradable. Numerous human systems are impacted by Pb exposure. Young children are especially susceptible to the harmful effects of Pb, which can disrupt the body's normal hormone balance and result in irreversible harm to the brain and nervous system (Sorensen et al., 2016).

Sanitation sourced pollution

India's social and economic development is very complex with wide variations across the regions and communities. Limited access to safe drinking water sources or/and inadequate sanitation pushed a vast majority of the Indian population particularly vulnerable to widespread outbreaks of water-borne illnesses. According to ITT (2018), there were six cholera pandemics in the IGB region and discovered that cholera during some of the past episodes was caused by the usage of contaminated water and poor hygiene. Global estimates show that till about 2016, over 500 million Indians (about 40%) likely still defecate in the open, accounting for more than half of the approximately 1 billion people worldwide who lack access to adequate sanitation and engage in this behaviour (Sorensen et al., 2016). However, as India's economy expands, a concerted effort has been made in the past ten years, particularly in the last few years, to end open defecation. The ambitious plans aim to provide all residents with access to adequate household sanitation, which will lower water-borne pathogens and improve public health. However, quantitative analyses show that since the 1990s, there has been a significant decline in the prevalence of water-borne illnesses including diarrhoea. The proportion of children under five who are under-developed has also decreased. Between 1990 and 2010, India's total number of cases of diarrhoea in children under five years old dropped from 320 million to 280 million (UNICEF, 2017). According to recent research, Indian administrative policies have been encouraging the construction of basic sanitation infrastructure over the past few years, which has helped to advance the country's attempts to meet UN Sustainable Development Goal 6 (clean water and sanitation). Water quality has improved because of a considerable drop in groundwater microbiological pollution (faecal coliform), according to studies conducted throughout the IGB basin. Even though areas with poorer water quality and improper human practices were found to outweigh economic development patterns in these areas indicated a clear inverse relationship with faecal coliform concentrations in groundwater in the majority of areas (Mukherjee et al., 2019).

Isotope tracers for pollutant source identification

Isotope techniques are instrumental in tracking how pollutants move and change within water systems (Keesari, 2024). By examining the ratios of isotopes of boron ($^{11}B/^{10}B$), nitrogen ($^{15}N/^{14}N$), sulphur ($^{34}S/^{32}S$), etc., researchers can distinguish among different pollutant sources. For contaminant sources with overlapping signatures of one isotope and dual isotopic signatures can be used to identify different contaminant sources that are chemically similar. Examples of dual isotopes are; for NO_3^- ($\delta^{15}N$-$\delta^{18}O$), for SO_4^{2-} ($\delta^{34}S$-$\delta^{18}O$). Isotope of trace metals such as $^{53}Cr/^{52}Cr$, $^{66}Zn/^{64}Zn$, $^{56}Fe/^{54}Fe$, $^{60}Ni/^{58}Ni$, $^{65}Cu/^{63}Cu$, $^{80}Se/^{78}Se$, $^{114}Cd/^{110}Cd$, $^{199}Hg/^{198}Hg$ and $^{206}Pb/^{204}Pb$ are used for a variety of water quality related issues. Isotopic methods contribute to the detection of specific sources and pathways of pollution, assessment of remediation effectiveness by monitoring the isotopic changes over time. These insights are essential to plan development of targeted interventions, evaluate the success of pollution mitigation strategies, ultimately leading to access to clean drinking water for all.

Summary and Way Forward

Public health impacts due to emerging, human-sourced contaminants are still palpable and on rise. It is reasonably well documented that the individuals who are most affected by health impacts of contaminated water are primarily from lower-income groups. Further, contaminant distribution and fate can be influenced by human activities such as vigorous pumping and land use-land cover alterations. As a result, some of these contaminants, mostly the non-point sourced ones, may affect millions of people by contaminating their food crops and drinking water. Mitigation strategies are developed in response to contamination through detection, monitoring, prediction, and interventions using in-situ and ex-situ remediation techniques as well as the exploration of natural solutions, such as drilling to safer aquifers and changing water sources, for the supply of uncontaminated water. Isotope techniques offer a powerful suite of tools for addressing water pollution challenges. By providing detailed insights into the sources, movement, and transformation of contaminants, these methods enable more effective monitoring, detection, and informed decision-making for water resource protection and pollution mitigation.

References for this article have been consolidated and are available upon request.

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