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GROUNDWATER POLLUTION AND ITS IMPACT ON HEALTH GEOGRAPHY IN RAJASTHAN: A REVIEW

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Abstract- Increasing groundwater contamination is emerging as major public health and environmental challenge in Rajasthan given that more than 90% of the state population, particularly in rural areas is using groundwater for drinking and domestic purposes. The special geology of the region and excessive use of aquifers have led to high concentrations of geogenic, and in some instances anthropogenic contaminants being found in deep and shallow wells, particularly fluoride, arsenic, nitrate and uranium. Long-term consumption of these pollutants has resulted in an increase in major health problems such as dental and skeletal fluorosis, methemoglobinemia, and kidney diseases. This study examines the spatial variability of the distribution of pollutants in the groundwater in two of the most affected districts in Rajasthan, and its likely sources as well as the socio-economic vulnerability posed to the affected communities in terms of the public health geography framework. The study points out that the marginalized populations are heavily affected due to poor availability of safe water options, lack of knowledge, and poor health care systems. By adopting an interdisciplinary framework including spatial mapping, literature review and policy analysis, the study suggests comprehensive adaptation strategies, including alternative sources for potable water, sustainable agricultural practice, inexpensive water filtration, and public education. The objective of the results is to assist evidence-based planning and local interventions for water security and health protection in Rajasthan.

Keywords- Groundwater Contamination, Rajasthan, Fluoride, Arsenic, Nitrate, Uranium, Public Health, Fluorosis, Methemoglobinemia, Vulnerability, Water Pollution, Environmental Health, Rural Areas

I. INTRODUCTION

Rajasthan, India's largest state by area, has a rich cultural heritage and ample shortage but has to also grapple with a water crisis that is endangering the overall well-being of its population and sustainable development. groundwater, which in this largely arid and semiarid part of the world you can hardly rely on—either for its availability or its quality—is the source of more than 90% of the drinking water on the part of rural, and substantial urban, populations. Increasing reliance on groundwater has resulted in its overpumping, and more significantly, a progressive but assailing impairment in its quality. But while surface water contamination is immediate and visible, groundwater pollution is silent and sometimes goes undetected until we start seeing health impacts. The problem is not only one of scarcity; it is exacerbated by the presence of naturally occurring toxicants such as fluoride, arsenic, nitrate and uranium along with contaminants from human activities such as agriculture and industry.

Groundwater quality and public health are crucially related in the cold desert region of Rajasthan considering poverty-driven profile of its inhabitants, which includes significant fractions of economically backward rural communities with poor health infrastructure, alternative sources of water besides environmental knowledge/sanitation. The problem of contaminated groundwater is, therefore, a silent but ubiquitous risk factor for public health. Chronic exposure to pollutants such as high fluoride levels have resulted in an increase in the prevalence of dental and skeletal fluorosis in specific districts, and high nitrate levels are associated with methemoglobinemia, particularly in infants. Uranium contamination has been an issue in some parts, which could cause kidney diseases and pose cancer threats. Despite such urgent problems, mitigation measures are either insufficient, scattered, or not properly implemented, which are causing public health geography becomes increasingly vulnerable to water-based hazards. The objective of this study is to assess the prevalence of groundwater contamination in Rajasthan, map its sources, and analyze the socio-economic vulnerability of the affected communities, offering a geographical dimension of an emerging public health catastrophe.

II. BACKGROUND

Groundwater contamination problems of Rajasthan are well rooted in its geological, climatic and socio-economic con¬text. State wise average annual rainfall is about 500 mm, which is not only lower than national average but also unevenly distributed. The annual rainfall in Western part of the state is less than 250 in Barmer, Jaisalmer and Bikaner, while, it exceeds 1000 in Udaipur and Kota in south east and other areas receive amount between these extremes. But even these relatively “wet” regions suffer through longer and longer droughts and dropping water tables. Due to this, residents have always depended on borewells and deeper aquifiers for their water. The geology of Rajasthan comprises hard rock, and it contains waters with fluoride and uranium that seep into the groundwater. Under conditions of high evaporation and sparse recharge, these minerals concentrate, resulting in contamination that far exceeds safe standards.

For example, fluoride contamination is found in over 20 districts including Jaisalmer, Jhunjhunu, Nagaur, Ajmer and Bhilwara. Fluoride levels of over 10 mg/L have been recorded in some places instead of the World Health Organization's recommended 1.5 mg/L; chronic consumption of the water over time results in irreversible health complications, including skeletal fluorosis, incapacitating entire communities. Nitrate pollution is of equal concern, particularly in agricultural regions where overuse of chemical fertilizers and poor waste management has contaminated shallow aquifers. “Districts such as Kota, Bharatpur and Dausa have repeatedly reported nitrate levels higher than the permissible limit of 50 mg/L by WHO, and infants consuming such water are prone to being afflicted with methemoglobinemia, an life-threatening blood disorder that prevents blood from transporting oxygen.

Uranium has become another toxic pollutant in areas of Rajasthan in recent years. Naturally occurring but enhanced by falling water tables, which causes more heavy metals to be released from rock stratas to aquifers. Studies carried out in districts such as Jhunjhunu and Hanumangarh reveal that the levels of uranium in some places are higher than 30 µg/L, which is the safe level set by the AERB (Atomic Energy Regulatory Board) of India. The health effects of chronic exposure to uranium include nephrotoxicity and potential carcinogenicity, particularly among subjects with poor nutritional conditions and low immunity in rural areas.

The social and economic aspects of groundwater pollution further complicate the situation. It is common among impoverished households in rural communities to lack resources to obtain safe water from bottled or filtered sources. Women and children are the most affected, since women are the water carriers and the first people to demonstrate effects as a result of the continuous exposure. Poor knowledge, low educational status, and social embarrassment towards the visible fluorosis signs who stop the contact with medical help. Moreover, public health institutions catering to rural Rajasthan are poorly funded and woefully ill-equipped to promptly diagnose, treat, and provide continued care for water-related illnesses. Government schemes for water safety have witnessed pockets of success, for instance, with the Jal Jeevan Mission and the National Rural Drinking Water Programme, but deficiencies in implementation, operation and maintenance, plus political hurdles have hindered complete success of these programmes.

The complexities of groundwater contamination in Rajasthan are not purely scientific or environmental, but deeply human: they affect livelihoods, schools, the survival of rural communities. Amidst this context, there is an urgent call for an integrated strategy that marries scientific evaluation, geographic mapping, community training, and policy transformation in addressing the escalating public health emergency.

III. FLUORIDE CONTAMINATION IN RAJASTHAN: A DISTRICT-WISE ANALYSIS

Groundwater fluoride contamination in Rajasthan has been widely investigated and acknowledged as a major public health problem.

- Lowest water table and maximum fluoride concentration occur in the dry pre-monsoon season in Jaisalmer District, in India. The arid atmosphere and high evaporation rates worsen fluoride in aquifers also. People here often suffer from crippling stages of skeletal fluorosis, which makes walking and earning a living nearly impossible.
- Nearly 11% of the groundwater samples collected from Jhunjhunu district are showing above 1.5 mg/L of fluoride, the safe limit prescribed by WHO and long term consumption of such water has resulted in increase in dental fluorosis among children and skeletal fluorosis among adults especially those who belong to underprivileged section of the rural community who are entirely dependent on borewell water.

- The Ajmer Division, in various districts, has recorded 0.1-34.0 ppm of fluoride that is high and well above normal limits. This extensive pollution has impacted on both the human and livestock populations, and many individuals are presenting cases of joint deformities, chronic pain and visible dental fluorosis. Worse, in rural blocks, where there is no treated or piped water, most of the residents are having to rely on high-fluoride wells.
- Morbidity and mortality rates for [1] [2] [3] [4]Several studies,[5-6] reports and looks from Graphy Publications, Taylor & Francis, PubMed indicates the prevalence of fluoride contaminations in Rajasthan and as one of the major causes of long term disability. Lack of efficient defluoridation units and less awareness in the public add to the health hazard.

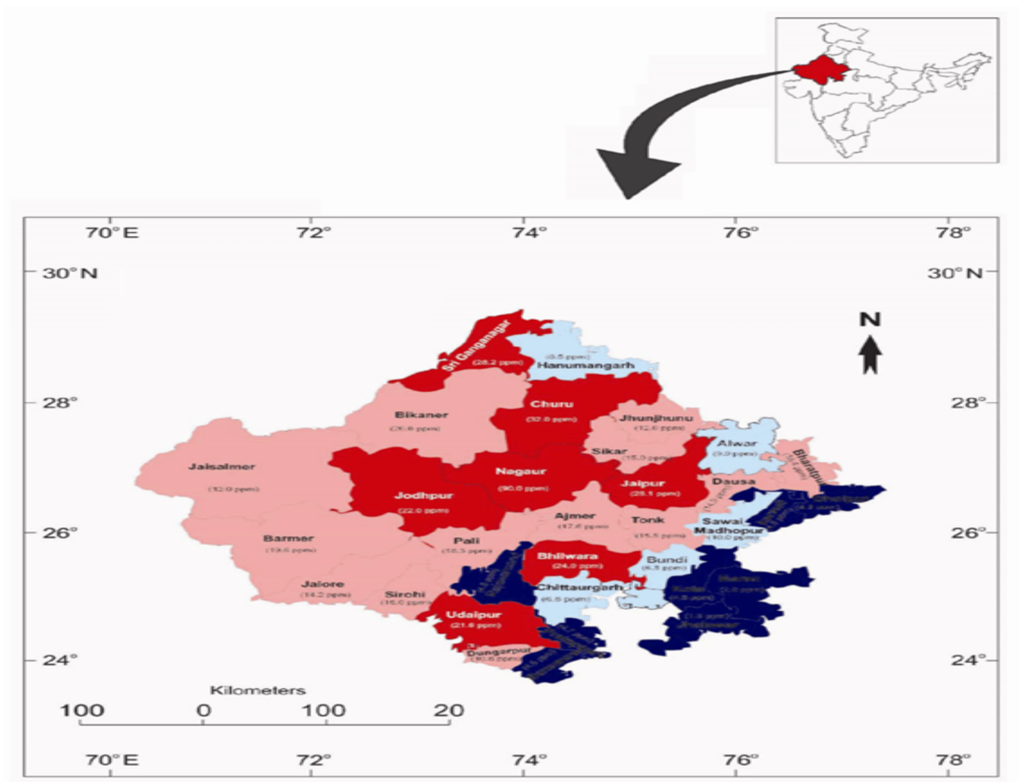

Fig.1. Morbidity and mortality rates studies

IV. LITERATURE REVIEW

Table.1.summary of recent research groundwater contamination and health highlighting the relationship between outcomes in various districts of Rajasthan

Study Title	Location	Key Findings
Proc.Physico-chemical parameters of Ground Water and Saturday 08, March Water Born Diseases spreading in Jhunjhunu District of RajasthanCollege of Pharmacy, I..Agric.Univ.	Jhunjhunu District	High levels of pH, EC, TDS, alkalinity, total hardness, chloride, sulfate, and coliform bacteria were found, correlating with diseases like cholera, dysentery, hepatitis, fluorosis, and blue baby syndrome.
Groundwater quality and its relation to human health in Dungarpur District of Rajasthan, India	Dungarpur District	Excessive fluoride and iron concentrations were linked to water-borne diseases; water quality index indicated 'very poor' to 'unsuitable' water quality in certain areas.
Evaluation of Drinking Ground Water Quality and Health Risk from Fluoride and Nitrate in Groundwater of Churu District, Rajasthan (India)	Churu District	Fluoride and nitrate levels exceeded permissible limits in many samples; hazard index values suggested significant health risks, especially for children.
Health Risk and Potability of Groundwater of Jhunjhunu District of Rajasthan, India for Fluoride and Nitrate pubs.iscience.in	Jhunjhunu District	Elevated fluoride and nitrate levels posed significant health hazards; water quality index indicated that a substantial proportion of samples were unsuitable for drinking.
185 Fluoride Concentration in Ground Water Quality of Some Villages of Rajasthan, India	Various Villages	Natural fluoride contamination was prevalent; excessive fluoride concentration in drinking water led to fluorosis affecting all age groups.
Seasonal variation of groundwater quality in rural region of Jaipur district, Rajasthan	Jaipur District	Significant seasonal variations in physicochemical parameters; water quality was unsuitable for drinking and industrial purposes.
Evaluation of Groundwater Quality	Bikaner	High salinity, fluoride, and nitrate

in Some Areas of Bikaner Region, Rajasthan	District	concentrations made groundwater unsuitable for consumption; suggested desalination and artificial recharge as remedial measures.
Human Health Risk of Nitrate in Groundwater of Tonk District of Rajasthan State, North Western India	Tonk District	Anthropogenic activities increased nitrate levels; health risk assessment indicated significant non-carcinogenic risks, especially for children.
Hydrochemical Profile and Human Health Risk Assessment for Nitrate, Fluoride and Uranium Contamination in Kota District, Rajasthan, India	Kota District	Elevated levels of uranium, fluoride, and nitrate; health risk assessment showed children were more at risk than adults.
Evaluation of Hydrogeochemistry of Pratap Nagar Groundwater in Sanganer Tehsil, District Jaipur, Rajasthan	Pratap Nagar, Jaipur	Average fluoride concentration was at the permissible limit; certain areas exceeded safe levels, posing health risks.

Groundwater contamination in Rajasthan, India is a serious public health problem predominantly due to high fluoride and nitrate and uranium concentrations. These pollutants are associated with variety of health problems like dental and skeletal fluorosis, methemoglobinemia (blue baby syndrome) and possible nephrotoxicity. This study identifies sources of these pollutants, their distribution in space, and social vulberality that result in increased health risks to estimates of the co-relatin of ground water risks in the region.

1. **Fluoride Pollution and Its Health Effects**

Fluoride is a naturally occurring component and its concentration varies in ground water. In Rajasthan, some areas have fluoride levels higher than WHO permissible limit of 1.5 mg/L for tooth protection and intake values of fluoride, for example in north-eastern region of Rajasthan, in the range of 0.04-8.2mg/L with 85 percent samples found to exceed permissible limit reported. Excessive intake of fluoride due to exposure to high concentration of fluoride may lead to dental and skeletal fluorosis, which are recognized by the presence of mottled teeth and bone/joint disease, respectively. The report said 55% of samples appeared to show a risk of people's teeth being affected by too much fluoride, while 42% indicated a risk of bone deformities of the knees and hips.

2. Nitrate pollution and health hazards

Agriculture runoff, unsound waste management methods, and septic systems are major contributors of nitrate pollution in groundwater. In the Kota district of Rajasthan, during different seasons, nitrate levels have been reported to be in the range of 9.8-954.0 mg/L, which is far above the maximum acceptable limit of 50 mg/L as per WHO guidelines; increased nitrates have been demonstrated to be harmful to infants, causing methemoglobinemia (or ″blue baby syndrome"), that is, the inability of blood to carry oxygen. The exposure to these risks was assessed by the health risk assessment, and the result showed children were more vulnerable than adults.

3. Uranium Presence and Health Considerations

Uranium, a lesser-heard-about contamination, has been found in the groundwater in Rajasthan. Uranium levels were detected near to the permissible limit (30 µg/L) in cases same study from district Kota but at few places exceeded. Regularly consuming uranium in drinking water can cause kidney damage and cancer. The risk risk assessment of the study indicated that the excess cancer risk value and hazard quotients were lower than the standard levels and however, some villages showed higher levels that mandates attention.

4. Mapping Contamination Sources

Geospatial applications played a significant role in detecting and mapping the pollution intake. Phagi Tehsil of Jaipur–India (non-endemic) Spatial distribution maps in Phagi Tehsil of Jaipur, indicate that high TDS and fluoride concentration affected areas. Water quality index (WQI) showed that majority of the villages had undrinkable water without treatment. It's important to prioritize the intervention area and launch specific remediation. These maps were the key to do that.

5. Vulnerabilities of Social Nature and Economy

Their effects on waterborne disease burden are also promoted by social-economic circumstances. In places such as Jhunjhunu and Churu districts, large number of people have to depend on contaminated underground water for drinking. 71% of ground water samples were found to be health hazardous to males, 78% for females and 75% for children as reported by various studies conducted in Jhunjhunu. In Churu District also, the hazard index values resulted in a strong health risk of all age group. Inadequate exposure to alternative water sources, low knowledge and poor health facilities further increase the susceptibility of these communities.

V. MANAGEMENT MEASURES GROUNDWATER POLLUTION IN RAJASTHAN

Solving groundwater contamination in Rajasthan will require an integrated, multi-pronged strategy that animates infrastructure with good policy with active citizenry.

1. Other Water Sources need to be implemented to minimize reliance on contaminated groundwater. This includes surface water schemes, rainwater harvesting, and distribution services to treated piped water in rural areas. In areas affected by fluoride and nitrate contamination introducing canal water supply schemes or drawing water from less contaminated aquifers can be a short term solution.
2. Water Treatment Solutions need to be made available and affordable - especially in low income and remote regions. Fluoride has also been effective removed using activated alumina filters, reverse osmosis (RO) units and bone char filters. Locally managed units can be a sustainable option for small local blocks of villages. Treatment vans can also temporarily serve isolated areas while longer-term infrastructure is developed.
3. Agriculture Practice Remodeling is the key to eliminate nitrate pollution. Farmers should also be educated and encouraged to employ organic fertilizers, compost, and bio-fertilizers, which are less prone to leach pollutants into the ground. Drip irrigation and precision farming technology can also help mitigate water usage and fertilizer runoff. Sustainable input use can be supported through soil testing and advisory services.
4. Public Health Education Campaigns have a serious role in risk reduction. Education on the signs of fluorosis and risks associated with nitrate exposure, as well as for safe water use, in local language(s) can be used to enhance the local communities capacity in making decisions. Interventions in schools, health camps, and locally speaking visual aids can facilitate engagement and

initiate behaviour change. It also creates demand for clean water, forcing local governance to respond.

5. There must be significant reinforcement in Policy and Regulation. Effective implementation of the rules pertaining to discharge of industrial waste, agriculture run off and illegal borewell digging is crucial. Monitoring of water quality should be made compulsory at the panchayat level, and accessible to the public. Policies and politics at the state level need to earmark dedicated funds for rural water safety planning; provide periodic review of highrisk zones and public-private partnership for water infra investment.

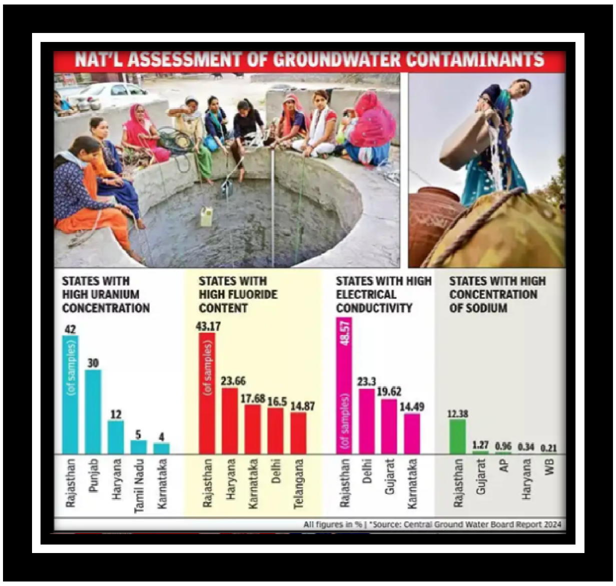

Fig.2. Assessment of groundwater contamination

VI. Conclusion

Groundwater contamination in Rajasthan is a major and complex problem that negatively impacts public health, environmental integrity, and socioeconomic progress. The ubiquitous presence of contaminants such as fluoride, arsenic, nitrate, uranium, etc. in the drinking water sources in the state is attributed to both natural and anthropogenic factors like over-extraction, unscientific agricultural practices and industrial pollution. Indeed, findings of this study have demonstrated that health effects due to inASIC, including dental and skeletal fluorosis, methemoglobinemia, and kidney damage, are being experienced by rural and impoverished communities without the availability of alternative water supplies, effective treatment, or sufficient health care. Mapping hotspots of contamination and assessing vulnerability have not only indicated the geographic extent of the crisis but also the social inequalities that are worsening its impact. Dealing with this problem necessitates to pursue an integrated strategy involving scientific evaluation, public health planning, technological research, and communitybased mobilization. Policies should focus on ground water monitoring, strictly implement water quality control, and promote the use of sustainable water supplies. In addition public information and local capacity development have to accompany an enabling environment by which communities can protect their health. To sum up, access to safe drinking water in Rajasthan is not only a technical necessity but also an imperative towards environmental justice and better quality of life of its people.

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