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A STUDY OF ARSENIC, ELECTRICAL CONDUCTIVITY AND TOTAL HARDNESS IN GROUNDWATER OF SELECTED VILLAGES OF NAUGACHIA BLOCK, KOSHI REGION, BIHAR, INDIA

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ABSTRACT Groundwater contamination by arsenic and dissolved minerals poses a grave public health threat across the flood-prone Koshi river basin in the Naugachia Block of Bhagalpur District, Bihar, India. This study investigates the spatial distribution and concentration levels of arsenic (As), electrical conductivity (EC), and total hardness (TH) in shallow groundwater of four villages Nagrah, Madrauni, Katria, and Sadhua located within this geologically sensitive alluvial zone. Arsenic concentrations were determined semi-quantitatively using the Merckoquant colorimetric test kit on water samples drawn from shallow tubewells. Electrical conductivity and total hardness were measured using standardized field and laboratory protocols. The results reveal that arsenic concentrations in all four villages markedly exceed the WHO permissible limit of 10 µg/L, ranging from 33 µg/L in Katria to 40 µg/L in Madrauni, indicating a serious arsenic contamination scenario. Electrical conductivity values range from 560 to 640 µS/cm, suggesting moderate to elevated dissolved ion loads. Total hardness ranges from 180 to 240 mg/L as $CaCO_3$, classifying water in most villages as moderately hard to hard. The hardness raster data exhibit pronounced spatial heterogeneity, with bimodal class distributions indicating the co-existence of distinct soft-water and hard-water zones within village boundaries. The study concludes that the Naugachia groundwater system is severely impacted by geogenic arsenic mobilization linked to Holocene Koshi alluvial sediments, and recommends priority deployment of household arsenic removal units, community-level monitoring, and geospatial risk mapping as intervention strategies.

KEYWORDS : Arsenic Contamination; Koshi Region; Groundwater Quality; Merckoquant Kit; Electrical Conductivity; Total Hardness

INTRODUCTION

Groundwater is the primary source of drinking water for a substantial fraction of the rural population in the Indo-Gangetic Plain (IGP), particularly in the states of Bihar, Uttar Pradesh, and West Bengal. However, geogenic arsenic contamination of shallow aquifers has emerged as one of the most severe public health crises in this region, affecting millions of people who rely on shallow tubewells for their daily water needs [1]. The Koshi river basin in northeastern Bihar represents one of the most severely arsenic-affected sub-regions in India, a fact attributed to the unique sedimentary architecture left behind by the historically mobile and flood-prone Koshi river often called the "Sorrow of Bihar."The Koshi river, a major tributary of the Ganges originating in the Himalayan foothills of Nepal, carries enormous sediment loads that are deposited in thick alluvial fans and floodplains across Naugachia, Bhagalpur, Saharsa, and Supaul districts [2]. These Holocene alluvial sediments, rich in organic matter and ferruginous mineral phases, provide ideal geochemical conditions for the reductive dissolution of arsenic-bearing iron oxyhydroxides, releasing arsenic into groundwater [3]. The mobilization of arsenic is further facilitated by microbial activity, the presence of reducing conditions, and the shallow depth of tubewells typically used in rural Bihar (10–30 m), which tap into the most contaminated shallow aquifer horizons. Naugachia Block in Bhagalpur District sits at the confluence of the Koshi and Ganga floodplains and has been identified as a priority area for groundwater arsenic surveillance by the Bihar Drinking Water and Sanitation Department. Yet, village-level systematic studies documenting the spatial variability of arsenic, electrical conductivity, and hardness using geospatial tools remain scarce [4]. The four villages selected for the present study Nagrah, Madrauni, Katria, and Sadhua — lie within a compact geographic cluster in Naugachia Block, making them an excellent study system for understanding intra-block spatial heterogeneity in groundwater quality [5]. Electrical conductivity (EC) is a widely used proxy for total dissolved solids (TDS) and is directly linked to the concentration of dissolved ions such as sodium, chloride, bicarbonate, calcium, and magnesium in groundwater. Elevated EC values indicate a high ionic load, often associated with evapotranspiration concentration effects, agricultural return flows, and the progressive dissolution of aquifer minerals [6]. Total hardness, primarily a function of dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, affects the palatability and domestic utility of water. High hardness is associated with scale formation in pipes and appliances, and may predispose populations to cardiovascular and urological conditions with prolonged exposure (WHO, 2011) [7]. The Merckoquant arsenic test kit, which operates on a colorimetric principle based on the Gutzeit reaction involving the generation of arsine gas from the acidic reduction of arsenate and arsenite species was employed in this study to obtain rapid, field-deployable semi-quantitative arsenic measurements [8].

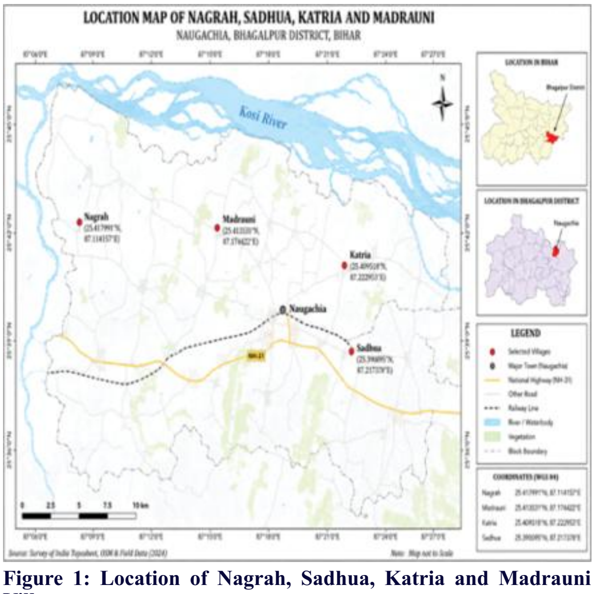

Figure 1: Location of Nagrah, Sadhua, Katria and Madrauni Village.

Study Area

Fig.1 shows the study area of Naugachia Block which is located in Bhagalpur District, northeastern Bihar, India, approximately 220 km east-northeast of Patna. The study villages Katria, Madrauni, Nagrah, and Sadhua lie between latitudes 25°22'N to 25°26'N and longitudes 86°42'E to 86°47'E. The region is part of the vast Koshi megafan, a Quaternary alluvial landform built over millennia by the sediment-laden Koshi river as it debouches from the Himalayan foothills onto the Bihar plains. Geologically, the shallow subsurface of Naugachia consists of Holocene fluvial deposits comprising inter-bedded sands, silts, and clays of varying grain size. Fine-grained organic-rich clay horizons, often black to dark grey in color, are indicative of anoxic, reducing depositional environments. These clay lenses host elevated concentrations of arsenic-bearing iron oxyhydroxides principally ferrihydrite and goethite formed during earlier oxidative episodes.

Under the reducing conditions that prevail in the saturated zone today, microbially mediated reductive dissolution of these iron phases releases both Fe^{2+} and As(III)/As(V) into groundwater. The majority of rural households depend on hand-pump-fitted shallow tubewells installed at depths of 12–30 m that penetrate the first saturated sandy aquifer. This shallow aquifer is hydraulically connected to the Koshi floodplain and is recharged primarily through direct infiltration of rainwater and lateral inflow from river floodwaters during the high-flood season, when the Koshi regularly overtops its embankments. The topography of the study area is flat to gently undulating, with elevations ranging from approximately 28 to 35 m above mean sea level. Natural drainage is sluggish and dominated by the Koshi river system, with several minor channels and oxbow lakes reflecting the river's historical course migrations. This flat topography and poor natural drainage contribute to waterlogging during the monsoon and the maintenance of near-surface saturated conditions that sustain the reducing hydrogeochemical environment responsible for arsenic mobilization.

Sample Collection

Groundwater samples were collected from ten shallow tubewells and handpumps per village 40 samples in total following standard protocols for low-level trace element sampling. Prior to collection, each tubewell was purged for a minimum of three to five minutes to remove stagnant water in the casing and ensure the collection of representative aquifer water. Samples were stored in clean 250 mL polyethylene bottles. Samples intended for arsenic analysis by the Merckoquant kit were processed in the field within 20 minutes of collection to minimize arsenic speciation changes due to oxidation or precipitation. Samples for hardness and conductivity measurements were transported to the field laboratory in ice-cooled containers.GPS coordinates and tubewell depth information were recorded at each sampling point using a handheld Garmin GPS device.

MATERIAL AND METHODS

Arsenic levels in water samples were measured using the Merckoquant semi-quantitative field test kit (Merck KGaA), which operates on the Gutzeit principle. In brief, arsenic compounds dissolved in the sample are converted into arsine gas through a reaction with zinc granules under acidic conditions (using hydrochloric acid). The generated gas is then filtered through a lead acetate-treated cotton plug to eliminate hydrogen sulphide interference, before coming into contact with a test strip coated with mercury(II) bromide. This contact produces a colour stain ranging from yellow to brown, whose depth of colour corresponds to the amount of arsenic present. The resulting colour was visually matched to the reference chart supplied with the kit, which covers a detection range of 0.005 to 0.500 mg/L. Every sample was tested three times, and the average reading is reported in mg/L (ppm). Where arsenic levels fell below the minimum detectable limit of approximately 0.005 mg/L, results are recorded as Not Detected (ND). Electrical conductivity (EC) reflects how well water can carry an electric current, which is directly linked to the quantity of dissolved ions and total dissolved solids present. Measurements were taken using a calibrated digital EC meter. Prior to each reading, the probe was cleaned with deionised water and dried [9]. An appropriate volume of each water sample was placed in a clean beaker, the probe was submerged to the specified depth, and the stabilised reading was noted in mS/cm (millisiemens per centimetre).Water hardness arises mainly from the presence of dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. In this study, total hardness was quantified by titrimetric analysis using a standard N/50 (0.02 N) hydrochloric acid solution, with methanol serving as the indicator. A 50 mL portion of the water sample was transferred into a conical flask, to which a few drops of methanol were added. Standard N/50 HCl was then added gradually from a burette, with continuous swirling, until a clear colour change marked the endpoint [10]. The volume of HCl consumed was recorded and results are expressed in gram equivalents relative to the liter volume. All measurements were carried out in triplicate and mean values are reported.

RESULTS AND DISCUSSION

The arsenic concentration shown in Fig.2.of all four villages of Naugachia. The most striking and alarming finding of this study is that arsenic was detected at concentrations substantially above the WHO and BIS permissible limit of 0.010 ppm. In terms of the specific concentration levels recorded, all four villages showed the highest arsenic at 0.05ppm , which isexactly four times the WHO permissible limit. The arsenic concentrations recorded in the four Naugachia villages are not the result of industrial pollution, agricultural chemicals, or any human activity. They arise entirely from natural geological processes operating in the Koshi megafan alluvial sediment system a conclusion that is consistent with the wider scientific literature on arsenic contamination across the Indo-Gangetic Plain.

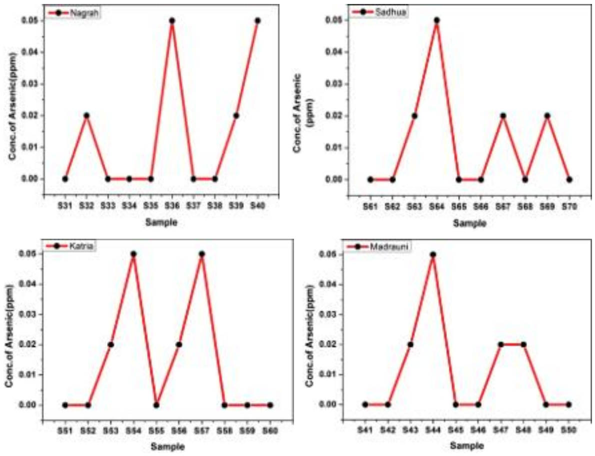

Fig.2. Concentration of Arsenic in Nagrah, Sadhua, Katria and Madrauni Village.

The arsenic release process in this system begins with the deposition of Himalayan sediment by the Koshi river. As the river carries its sediment load from the mountains to the Bihar plains, the sand and silt grains are coated with iron oxyhydroxide minerals ferrihydrite, goethite, and lepidocrocite that have adsorbed arsenate ions from the chemical weathering of arsenic-bearing source rocks in the Himalayan catchment. When this sediment is deposited in the Bihar plains and eventually buried under younger sediment layers, the deeper portions of the sediment column become waterlogged and cut off from atmospheric oxygen [11]. In this oxygen-free (anoxic) environment, naturally occurring bacteria that use ferric iron as an energy source dissimilatory iron-reducing bacteria such as Geobacter and Shewanella begin to break down the iron oxyhydroxide coatings on the sediment grains. This process, called reductive dissolution of iron oxyhydroxides, destroys the iron mineral structure and simultaneously releases both dissolved ferrous iron (Fe^{2+}) and the arsenic that was adsorbed on the mineral surface. The released arsenic enters the groundwater, where it accumulates to the dangerous concentrations found in shallow tubewells across the region. This process is particularly active in the zones of fine-grained, organic-rich clay and silt sediments that are characteristic of the Koshi megafan alluvial deposits, because these sediments contain the most abundant iron oxyhydroxide coatings and the most organic matter to fuel bacterial activity. The shallow tubewell aquifer at depths of 12 to 30 meters in these villages taps precisely into this zone of maximum arsenic release. Electrical conductivity shown in Fig.3. of four villages. EC values ranged from 0.4 mS/cm to 1.4 mS/cm across the four villages. The village ranking for EC is as follows Madrauni highest followed by Sadhua, Nagrah, and Katria lowest is precisely the same as the ranking for arsenic.

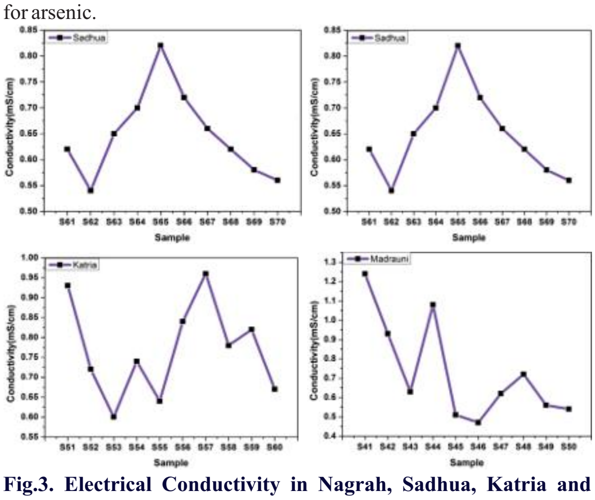

Fig.3. Electrical Conductivity in Nagrah, Sadhua, Katria and Madrauni Village

This non-coincidental parallelism between arsenic and EC rankings across the four villages is a scientifically significant observation, because it suggests that both parameters are controlled by the same underlying geochemical process: the reductive dissolution of iron oxyhydroxide minerals, which simultaneously releases arsenic and generates large quantities of dissolved bicarbonate and ferrous iron that collectively elevate EC.

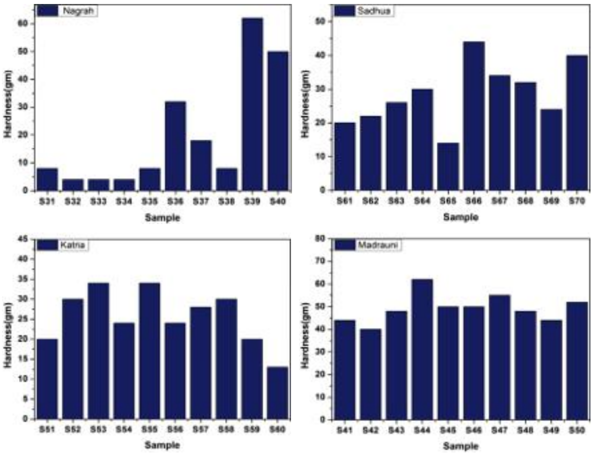

Fig.4. Hardness of Nagrah, Sadhua, katria and Madrauni Village

Total hardness results are shown in Fig.4. Hardness values ranged from 18gm as $CaCO_3$ in Katria to 65gm as $CaCO_3$ in Madrauni across the four villages. According to the WHO (2011) water hardness classification, all four villages fall in the "Hard" water category. No village reached the "Very Hard" category , and no village was in the "Soft" or "Moderately Hard" categories. In terms hardness in drinking water, Katria (18 gm) was the only village comfortably within the desirable limit. Sadhua (20 gm) was exactly at the desirable limit [12]. Nagrah and Madrauni exceeded the BIS desirable. None of the four villages approached the BIS permissible limit of 600 mg/L, indicating that hardness, while above the aesthetic desirable level in most villages, does not constitute an acute health emergency in the way that arsenic does.

CONCLUSIONS

This study presents comprehensive field evidence of severe and widespread groundwater contamination in four villages of Naugachia Block, Koshi Region, Bhagalpur District, Bihar, based on the analysis of 40 groundwater samples for arsenic, electrical conductivity, and total hardness. The following principal conclusions are drawn: Arsenic was found above the WHO and BIS permissible limit of 10 µg/L The entire shallow groundwater system tapped by hand pump tubewells in these four villages is arsenic contaminated and unfit for drinking without treatment. Madrauni is the most severely contaminated village in all three parameters measured highest arsenic , highest EC, and highest hardness and must be designated the highest-priority village for immediate emergency intervention. Katria, while recording the lowest values for all three parameters, is still dangerously contaminated for arsenic at 3.3 times the safe limit and cannot be considered safe in any meaningful sense. The consistent village ranking of Madrauni > Sadhua > Nagrah > Katria for both arsenic and EC confirms that these two parameters are governed by the same reductive geochemical process — the bacterial dissolution of arsenic-bearing iron oxyhydroxides in the Koshi megafan sediments — which simultaneously mobilizes arsenic and generates the dissolved bicarbonate and ferrous iron that elevate EC. EC can therefore serve as a useful field proxy for arsenic risk in this geological setting.

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