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Groundwater in Bihar at a Crossroad - A Review of Groundwater Quality

Govind Kumar[1], Rameswar Behera[2], Deepti Prava Sahoo[3], Milusan Nayak[4]

[1] Central University of Punjab, Bathinda
Corresponding Author Email: *govindkumar730cu[at]gmail.com*

[2]Central University of Punjab, Bathinda
Email: *kunuxperia[at]gmail.com*

[3]Central University of Punjab, Bathinda
Email: *sahoo.mama2000[at]gmail.com*

[4]Central University of Punjab, Bathinda
Email: *milusannayak1998[at]gmail.com*

Abstract: ***Groundwater is the most utilized source for drinking water, and its quality in recent times is at alarming stage. This study aims to provide a comprehensive review on the groundwater quality of the state Bihar by compiling data of more than 8, 000 locations from published studies/reports. A total of 13 parameters were concluded finally. Out of the total studied parameters, Bhojpur and Siwan districts were found exceeding the permissible limits of more than 10 parameters, while Sitamarhi was found exceeding the permissible limit in only 3 parameters. Most prevailing parameters exceeding Permissible Limit in majority of the districts were Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Total Dissolved Solids (TDS), Chloride (Cl^{-}), Nitrate (NO_3^{-}), and Fluoride (F^{-}). This widespread prevalence of non-compliance with BIS standards highlights significant concerns regarding water quality and underscores the need for measures to mitigate the adverse impacts on public health. The results also highlight the need for targeted water quality management and mitigation strategies in the concerned districts, while maintaining relatively better conditions in rest ones. The findings of this research paper are expected to provide valuable insights for policymakers, water resource managers, and researchers involved in groundwater management and quality improvement in Bihar and India.***

Keywords: Groundwater quality, Heavy metals Contamination, physicochemical properties, SDG, Bihar

1. Introduction

Groundwater is the most vital resource and a critical component of the hydrological cycle favoring the survival of living organisms. It is an irreplaceable entity sustaining various sectors such as agriculture, industry, transportation, etc. Chemically it is an aqueous solution in the sub-surface geological formation which is primarily used for fulfilling people's irrigation and drinking needs across the globe. Nearly 50% of the world's urban population depends on groundwater resources, with the human demand currently being about 3.5 times the actual volume of aquifers (United Nations., 2022; leeson et al., 2012). In India, approximately 89% of irrigation and 80% of drinking water demands are met by groundwater (CGWB, 2019; Mukherjee et al., 2020). About 80% of all the diseases in human beings are caused by water (Kavitha et al., 2010). These figures and findings concludes that groundwater quality is an alarming concern in recent decades due to the mounting anthropogenic pressure of industrialization, urbanization and modernization (Mukherjee et al., 2020, Castaño-Sánchez et al., 2020; Mammola et al., 2019; Vaccarelli et al., 2023, Kumar et al., 2024, Kumar et al., 2025, Ijumulana et al., 2020; Kumar et al., 2020a; Verma et al., 2023).

Bihar, located in north-eastern part of India, is predominantly dependent on groundwater for meeting its water demands. With its rapidly growing population and increasing urbanization, the state faces significant challenges in maintaining the quality of its groundwater resources. According to the State Public health and engineering department's groundwater quality report a total of 13 districts with prevalance of Arsenic, 11 with Fluoride and 9 with Iron was reported affecting a total of 250 blocks and impacting more than 25000 inhabitants. Sustainability and quality of groundwater in Bihar has really become an alarming concern due to various anthropogenic activities and natural processes. Understanding the dynamics of groundwater quality time to time is a needful for ensuring the availability of safe drinking water, public health safety and sustainable development in the region.

Through an in-depth analysis of pH, Cl^{-}, SO_4^{2-}, NO^{3-}, TH, Ca^{2+}, Mg^{2+}, F^{-}, TDS, As, Cu, Fe & Pb parameters and the available data, this study aims to put a comprehensivereview of the physico-chemical parameters of the ground water of the state of Bihar and the changes that has taken place in recent decade. The findings of this review are expected to provide valuable insights for policymakers, water resource managers, and researchers involved in groundwater management and help to identify the target areas for impactful implementation of Sustainable Development's 6th goal i. e, Clean water and sanitation in the State of Bihar.

2. Study Area

Bihar is a landlocked state stretching between 24°20′10" and 27°31′15" N latitudes and 82°19′50" and 88°17′40" E longitudes (Bose et al., 2015; Roy et al., 2016). It is the 12th largest state in terms of land area, with an area of 98, 940 sq.

Km, and the 3rd most populous state in India (Ranjan., 2016). As a part of the Gangetic Plain, Bihar's population density is nearly 3 times the national average (382 per square kilometre) (Chandramouli and General., 2011). It is in the Temperate zone's subtropical area. Regarding climate, economy, and culture, Bihar is in a transitional position because of its location. Majority of the area of the state contains undifferentiated sediments of quaternary era. The southern extent containing chotanagpur gneissic complex dates back to the proterozoic era and the Bihar mica belt group to the paleoprotero-mesoproterozoic era respectively. (Fig.1B, 1C). The state land is major of fluvial origin in nature dominating in the northern, central and some part of southwest followed by denudational origin stretched in the southern part of the state. Some patches of structural with anthropogenic origin is also seen. The network of water bodies is stretched all across the state (Fig.1A). The state experiences a modest amount of rain, significantly impacting the agricultural and fishery sectors. The region is also characterised by its alluvial soil, deposited by the mighty rivers flowing down from the Himalayas. The flat terrain and favourable climate have made it an agricultural hotspot. The agrarian sector of Bihar accounts for 21.3 % of the state's Gross Domestic Product (GDP). It will remain vital to the state's economic development and primary source of income for around 90 % of the people living here (GOB, 2015). The Ganga River, flowing through the heart of the state from west to east, splits the Bihar plain into two unequal portions (North Bihar and South Bihar).

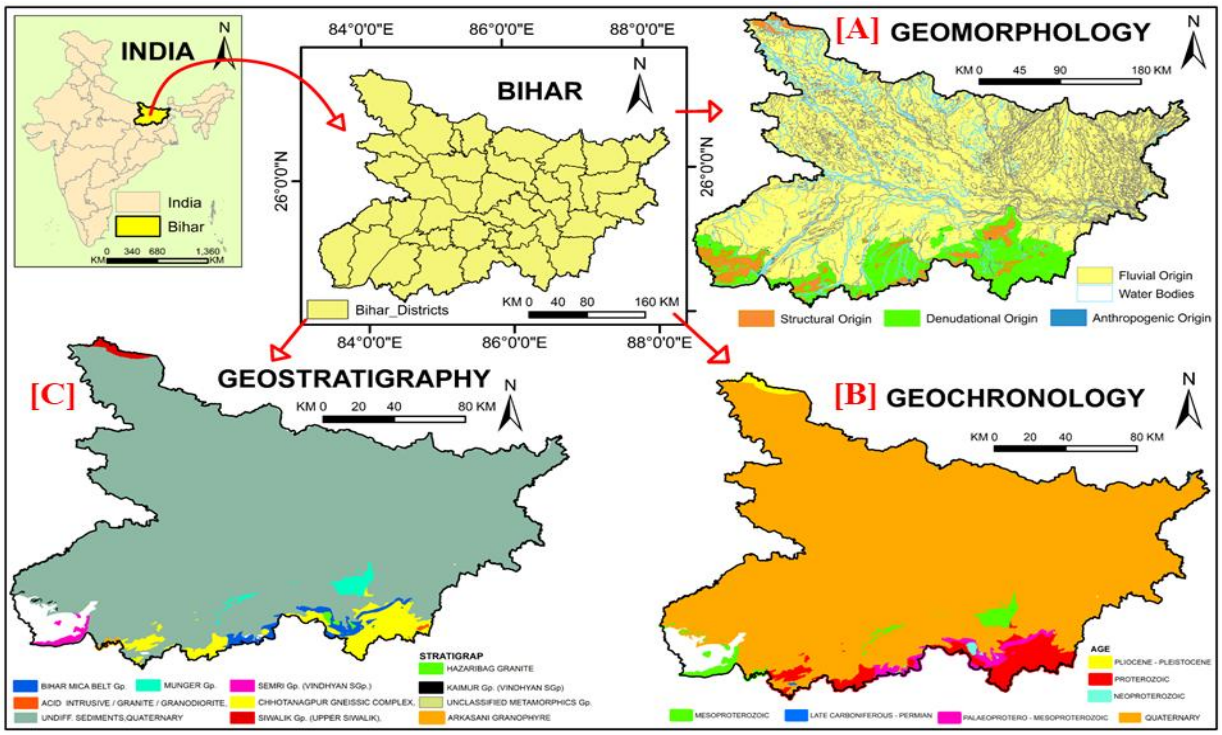

Figure 1: Study area description map of Bihar showing Geomorphology (A), Geochronology (B) and Geostratigraphy (C) of the state.

3. Methodology

The methodology involved a systematic search and collecting data from relevant publicationsand CGWB reports on groundwater quality assessment in Bihar. Further the collected data was critically analysed and evaluated to extract the key findings and trends in the data. Data from more than 8, 000 locations were covered ranging from year 2010 -2024. This extensive temporal and spatial coverage gives a detailed assessment of groundwater quality dynamics, helping to establish long-term trends and correlations with potential influencing factors such as industrial expansion, agricultural activities, and climatic variations. The systematic approach ensured that the findings were based on a robust and well-documented dataset, enhancing the reliability and relevance of the study.

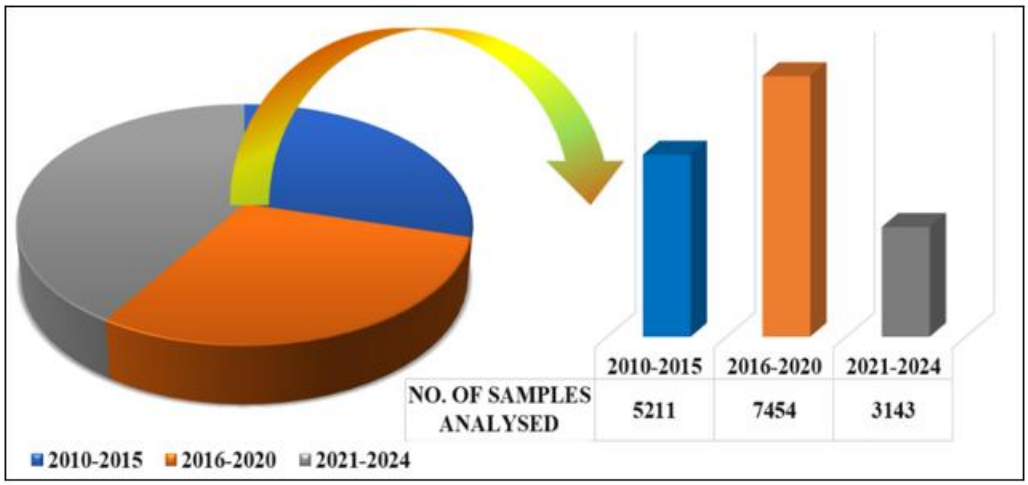

Figure 2: Description of years and samples data taken in review for data conclusion.

4. Result

Physicochemical Parameters

The analysis of groundwater physicochemical parameters across Bihar reveals significant variations between districts. The pH ranges from 4.6 to 9.3, with acidic conditions observed in Bhagalpur, Banka, and Saharsa, which fall below the BIS permissible lower limit of 6.5, increasing risks of metal leaching and water pipe corrosion. Conversely, alkaline conditions exceeding the upper limit of 8.5 are noted in Siwan and Sheikhpura, potentially affecting water taste and treatment processes. Districts such as Gaya, Rohtas, and Munger exhibit normal pH values, indicating relatively safe water. Electrical conductivity (EC) is highest in Khagaria and Begusarai, surpassing the safe range (750 µS/cm), which indicates high salinity and reduced water usability for drinking and irrigation. Districts like Araria and Supaul have low EC values, reflecting safer water quality. Total dissolved solids (TDS) are alarmingly high in Bhagalpur, Begusarai, and Khagaria, exceeding the permissible limit of 500 mg/L, potentially leading to kidney stones and hypertension. However, districts such as Sheohar, Darbhanga, and Madhubani maintain low TDS levels, making their water safer for consumption. Elevated bicarbonate concentrations in Jamui and Bhagalpur contribute to high alkalinity and scaling issues, while Madhubani and Supaul show low bicarbonate levels, indicating better water quality. Nitrate contamination exceeds permissible limits (BIS: 45 mg/L, WHO: 50 mg/L) in Patna, Araria, and Begusarai, primarily from agricultural runoff, posing risks of methemoglobinemia, while districts like Munger and Banka report low nitrate levels, marking them as safer zones.

Heavy Metals

Heavy metal contamination poses significant risks in several districts. Bhagalpur, Patna, and Samastipur report arsenic levels as high as 84.6 mg/L, far exceeding the BIS and WHO permissible limit of 0.01 mg/L, with severe health implications such as cancer and skin lesions. Sheikhpura and Kishanganj have low arsenic levels, indicating safer water. Iron concentrations are critically high in Gaya, Patna, and Bhagalpur, surpassing the BIS limit of 0.3 mg/L, leading to metallic-tasting water and staining issues, while Sheohar and Vaishaliexhibit low iron levels, marking them as safer zones. Lead contamination exceeding the 0.01 mg/L limit is recorded in Bhojpur and Patna, linked to neurological and cardiovascular risks, whereas Madhubani and Munger have negligible lead levels. Zinc concentrations remain within permissible limits across all districts, posing no significant health concerns. However, Patna, Bhagalpur, and Khagaria are among the districts where multiple parameters, both physicochemical and heavy metals, exceed safety limits, while Darbhanga, Madhubani, and Supaul emerge as relatively safer districts, with most parameters within permissible ranges. The analysis of cation and anion concentrations in Bihar's groundwater highlights significant spatial variability, reflecting the influence of geological and anthropogenic factors. Among cations, calcium (Ca^{2+}) levels range from 4 to 306 mg/L, with Arwal, Aurangabad, Bhagalpur, and Patna reporting higher concentrations, exceeding the BIS permissible limit of 75 mg/L. These districts face risks of water hardness, which can lead to scaling in plumbing systems and cardiovascular concerns in long-term exposure. Magnesium (Mg^{2+}), ranging between 1 and 269 mg/L, surpasses the permissible limit (30 mg/L) in Bhojpur, Gaya, and Samastipur, potentially leading to laxative effects and mineral imbalance. Sodium (Na^{+}) and potassium (K^{+}) levels exhibit considerable variation, with Bhagalpur and Banka showing elevated sodium (up to 573 mg/L), which poses risks for hypertensive individuals, while potassium remains within safe limits across districts. For anions, chloride (Cl^{-}) levels peak at 1, 306 mg/L, far above the BIS threshold of 250 mg/L in Patna, Gaya, and Bhagalpur, raising concerns about salinity and corrosion. Sulfate (SO_4^{2-}) concentrations range from below detectable levels to 435 mg/L, with districts such as Gaya, Nalanda, and Aurangabad recording higher values that may contribute to gastrointestinal distress. Nitrate (NO_3^{-}) levels are critically high in Patna, Buxar, and Muzaffarpur, exceeding the WHO limit of 50 mg/L, posing risks of methemoglobinemia (blue baby syndrome) and other health issues. While bicarbonate (HCO_3^{-}) is significantly elevated in Jamui and Bhagalpur, carbonate (CO_3^{2-}) remains below detectable levels in most areas. The observed disparities call for district-specific management strategies to mitigate health risks and ensure safe drinking water.

Table 1: Table showing water quality parameters, comparison with permissible limits and prevailing districts of concern in Bihar

S. No	Parameters	Unit	Min	Max	P. L BIS	P. L WHO	Districts exceeding maximum permissible limit
1	pH	-	4.6	9.3	6.5-8.5	6.5-8.5	Bhagalpur, Banka, Bhojpur, Begusarai, Jamuni. Jehnabad, Siwan, khagaria, Madhepura, Patna, Saharsa, Sheikhpura
2	Cl-	mg/L	0.26	1306	250	250	Bhagalpur, Arwal, **Gaya**, Aurangabad, Jamui, Banka, Begusarai, **Samastipur**, Bhojpur Siwan, Buxar, E Champaran, Gopalganj, Jehnabad, Kaimur, Khagaria, Lakshisarai, Madhubani, Muzaffarpur, Nalanda, Nawada, Patna, Purnea, Saharsa, Saran, Sheikhpura, W. Champaran
3	SO_4^{2-}	mg/L	BDL	435	200	250	**Gaya**, Siwan, Aurangabad, Bhojpur, Jamui, Jehnabad, Kaimur, Katihar, Nalanda, Purnea, Rohtas, Saran
4	NO_3^-	mg/L	BDL	233	45	50	**Bhojpur**, Araria, **Gaya**, Arwal, Aurangabad, Begusarai, **Siwan,** Buxar, E Champaran, Jehnabad, Kaimur, Katihar, kishanganj, Lakshisarai, Madhubani, Muzaffarpur, Nalanda, NAWADA, Patna, Purnea, rohtas, samASTIPUR, saran, SHEOHAR, supaul, vaishali, w. Champaran
5	TH	mg/L	35	1510	200	500	**Bhagalpur**, Araria, **Bhojpur**, Arwal, **Buxar,** Aurangabad, Banka, **Gaya**, Begusarai, **Khagaria**, **Mujaffarpur, Nawada**, **Patna**, Darbhanga, **Samastipur**, E Champaran, **Saran**, **Siwan**, Gopalganj, Jamui, Jehnabad, Kaimur, Katihar, Kishanganj, Lakshisarai, Madhepura, Madhubani, Munger, Nalanda, Purnea, Rohtas, Saharsa, sheohar, Sitamarhi, Supaul, Vaishali, W. Champaran
6	Ca^{2+}	mg/L	4	306	75	-	Arwal, Aurangabad, Banka, Begusarai, **Bhagalpur**, **Bhojpur**, Buxar, Darbhanga, E Champaran, **Gaya**, Gopalganj, Jamui, Jehnabad, Kaimur, Katihar, Khagaria, kishanganj, Lakshisarai, Madhepura, Madhubani, Munger, Muzaffarpur, Nalanda, **Nawada**, **Patna**, Purnea, Rohtas, Saharsa, **Samastipur**, Saran, SHEOHAR, sitamarhi, Siwan, Supaul, Vaishali, W. Champaran
7	Mg^{2+}	mg/L	1	269	30	-	Araria, **Bhagalpur**, Arwal, **Bhojpur**, Aurangabad, **Gaya**, Banka, **Jamui**, Begusarai, **Nawada**, **Patna**, Buxar, Darbhanga, **Samastipur**, E Champaran, Gopalganj, Jehnabad, Kaimur, Katihar, Khagaria, kishanganj, Lakshisarai, Madhepura, Madhubani, Munger, Muzaffarpur, Nalanda, Purnea, Rohtas, Saharsa, Saran, sheikhpura, Sheohar, sitamarhi, Siwan, Supaul, Vaishali, W. Champaran
8	F^-	mg/L	BDL	4.7	1	1.5	Aurangabad, Banka, Gaya, Bhagalpur, **Jamui**, Bhojpur, **Nawada**, Buxar, Darbhanga, E Champaran, **Seikhpura**, **Siwan,** Gopalganj, Kaimur, kishanganj, Lakshisarai, Madhepura, Madhubani, Munger, Muzaffarpur, Nalanda, Patna, Rohtas, Saharsa, Samastipur, Supaul, W. Champaran
9	TDS	mg/L	58	3004	500	500	Araria, Arwal, Aurangabad, Banka, Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, E Champaran, Gaya, Gopalganj, Jamui, Jehnabad, Kaimur, Katihar, Khagaria, Lakshisarai, Madhepura, Madhubani, Munger, Muzaffarpur, Nalanda NAWADA, Patna, Purnea, Rohtas, Saharsa, SAMASTIPUR, Saran, SHEOHAR, Siwan, Supaul, Vaishali, W. Champaran
10	As	mg/L	0.002	84.6	10 µg/L	10 µg/L	Ararea, Bhagalpur, Bhojpur, Patna, Samastipur, Saran, Siwan, Vaishali
11	Cu	mg/L	BDL	0.01	0.05 µg/L	2000 µg/L	Bhojpur
12	Fe	mg/L	BDL	20	0.3	0.3	Bhojpur, Bhagalpur, Gaya, Patna, Samastipur, Siwan
13	Pb	mg/L	BDL	0.040	10 µg/L	10 µg/L	Bhojpur

Parameter Prevalence

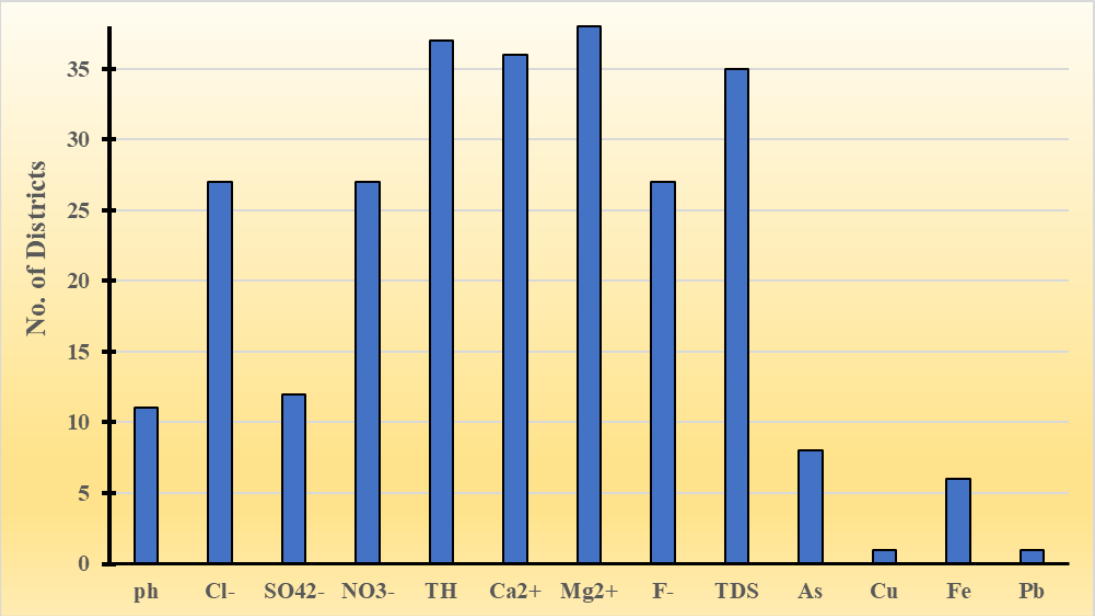

Figure 3: Parameter Vs No. of districts it was found to be exceeding the permissible limit.

From the study, it was observed that among the studied water quality parameters, including Total Hardness, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Total Dissolved Solids (TDS), Chloride (Cl^{-}), Nitrate (NO_3^{-}), and Fluoride (F^{-}), several were found to exceed the permissible limits prescribed by the Bureau of Indian Standards (BIS). Notably, these parameters were found to be above the acceptable thresholds in more than 25 districts of the state. This widespread prevalence of non-compliance with BIS standards highlights significant concerns regarding water quality and underscores the urgent need for remedial measures to mitigate the adverse impacts on public health and the environment.

District Prevalence

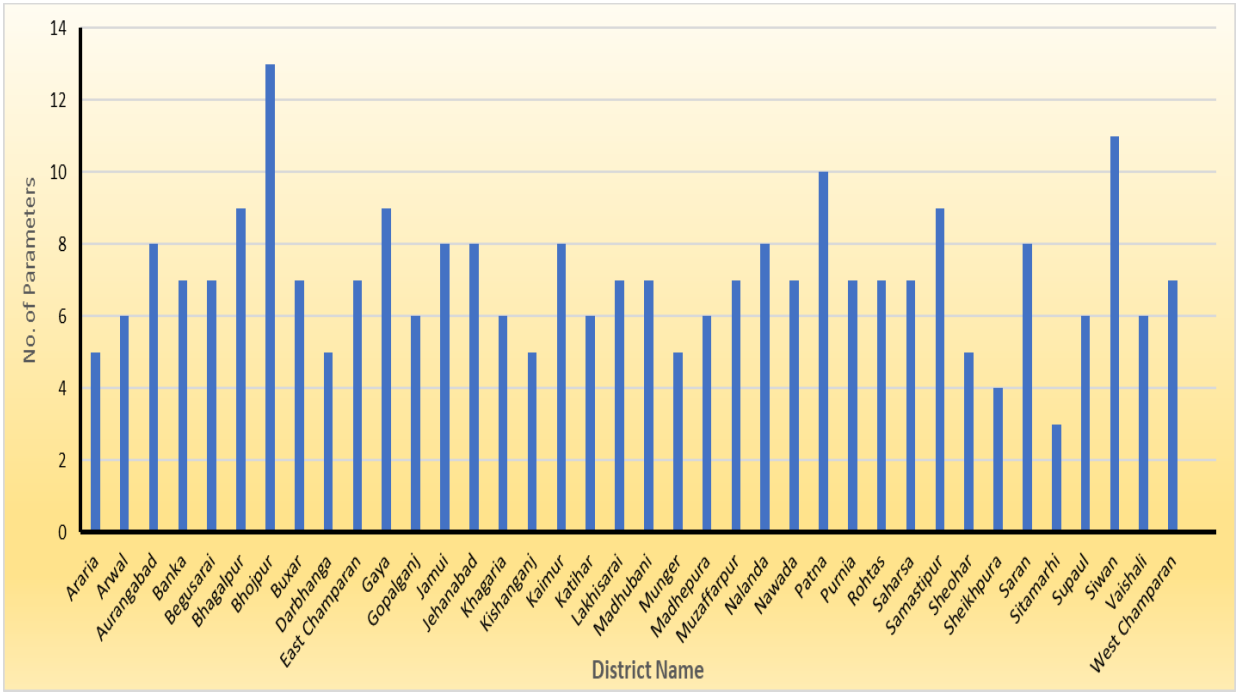

Figure 4: District Vs No. of parameter water exceeded BIS permissible limit

From this study, it was observed that the Bhojpur and Siwan districts exhibited water quality exceeding the permissible limits in most of the tested parameters, indicating significant contamination and potential health risks for the local population. In contrast, Sitamarhi district demonstrated better water quality, with the least number of parameters exceeding the permissible limits, suggesting relatively lower contamination levels. These findings highlight the urgent need for targeted water quality management and mitigation strategies in the concerned districts, while maintaining the relatively better conditions in rest ones.

5. Conclusion

The analysis of groundwater quality in Bihar reveals significant spatial and parametric variability, with several districts exhibiting concentrations of physicochemical parameters and heavy metals exceeding permissible limits set

by BIS and WHO standards. Among physicochemical parameters, districts such as Bhagalpur, Banka, and Patna show critically high values for pH, TDS, and EC, which may pose health risks and affect agricultural productivity. Elevated nitrate levels in Patna, Buxar, and Muzaffarpur raise serious public health concerns, particularly the risk of methemoglobinemia. The high concentrations of chloride, bicarbonates, and sulfates in certain districts underscore the growing salinity issues and the need for water treatment interventions. The distribution of heavy metals like arsenic, iron, and lead highlights acute contamination in Bhojpur, Samastipur, and Bhagalpur, where concentrations exceed permissible levels, posing carcinogenic risks and other health hazards. Districts such as Arwal, Aurangabad, and Gaya demonstrate higher calcium and magnesium levels, contributing to water hardness and associated health risks. The study emphasizes that while certain districts exhibit parameters within safe limits, widespread disparities necessitate a region-specific approach to water quality management.

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