Water Disaster induced Vulnerability using Groundwater Quality Assessment in Biharsharif, Nalanda, Bihar

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Abstract
The global climate change over the years gradually affected the water quality, leading to increased drought and flood risks and posing challenges for water management and resource availability. The water quality index (WQI) signifies the quality of water in terms of index number which communicates the information on overall water quality trends for the end users. In this study, nineteen groundwater samples were collected from hand pump, bore well and deep tube well of the Biharsharif township area during the pre- and post-monsoon seasons of the year 2023-24. In the present study, the quality of water was estimated by testing various physicochemical parameters namely, pH, TDS, TH, Calcium, Magnesium, Chloride, Nitrate, Sulphate and Fluoride and after that the quality index was analyzed in this study.

The WQI value of 110.9 is maximum and the value 38.56 is minimum in the study area. The computed WQI shows that 89.5% of groundwater samples were found as 'Very Good' to 'Good' category. On the other hand, only 10.5% samples fall in the poor category showing that the water is not suitable for direct consumption and needs a degree of treatment before its utilization. However, high values of WQI in the post-monsoon season of study area have been found to be mainly due to potential hazards leaching into the soil and mixes with the groundwater.

Keywords: WQI, groundwater quality, physicochemical analysis, pre-monsoon, post-monsoon, Biharsharif township.

Introduction

Over the past several decades, the frequency of heavy rainfall events has gradually increased due to global climate change and existing evidence suggests that this trend will continue, resulting in increased storm water runoff. Groundwater is one of the most important components and indispensable natural resources for sustaining the preparation of human life as well as environment that people always thought to be available in abundance and gift of nature throughout the world.

Groundwater is also considered as all-around solvent to dissolve various important minerals so that it is vital to the survival of ecosystem. In turn, ecosystem helps to regulate the quantity and quality of water necessary for the survival of all species and human life. The groundwater also plays vital role as a decentralized power source of drinking water for billions of rural and urban families in the world which cannot be overstated. Groundwater is the water present beneath earth's surface in soil pore spaces and in the fragment of rock formations. Over time, water from rainfall and through river penetrates usually into the ground and is stored in porous soils, aquifer and rocks. Groundwater is a gift of nature which has been used for various intentions, namely for domestic, irrigation, industrial and generating hydro-power.

People throughout the world have used groundwater as a prime natural sources of drinking water and even today more than half the number of world's people depends on groundwater for survival. The groundwater quality is very important to the society at large; therefore, it is important to ensure its high quality at all periods so that the public health is not compromised in a precious manner. Groundwater resources are affected by three major human activities. First one is extreme use of fertilizers, insecticides and pesticides in agricultural sector. The second one is unmanaged wastewater dumped into the earth surface and third one is utmost pumping and mismanagement of aquifers. The human activity of solid waste disposal in open ineffectual landfill area is one of the ultimate factors causing the groundwater polluted.

About 80% of all the diseases in human are caused by water as per World Health Organization (WHO). The rising rates of mortality are due to water borne diseases in India. The aim to access of safe drinking water remains a very important issue and needs immediate attention. Groundwater accounts for approximately 80 percent of the rural domestic water needs and 50 percent of the urban water needs in India. Its management plays a crucial role in farming production, poverty deduction and environmental sustenance. Most of the population in India is dependent on groundwater as the only source of drinking water. Water constitutes about 70% of the body weight of almost all the living organisms. About 97.2% of water on earth is salty and only 2.8% is present as fresh water from which about 30% constitute groundwater. Life is not possible on this earth without water.

The WQI is a single number for precise water quality by aggregating the measurement of different water quality parameters (such as pH, hardness, calcium, DO, TDS, EC, chlorides etc.). Usually, the lower score defines the better water quality and higher score as bad quality. Horton[15] has first introduced the concept of mathematical form of WQI, by selecting the different parameters of water in a simple manner. It was further improved by Brown et al[7] and then improved by Deininger (Scotish Development Department, 1975) respectively. WQI is one of the most productive tools to give information on the quality of any water body whether surface or non-surface water body. According to Foster[10], the vicious uses of natural resources and increased human being activities are a great threat to groundwater quality.

Groundwater quality assessment can be a complex process undertaking various parameters capable of causing multiple stresses on overall groundwater quality. Primarily, in this method, the ten important parameters such as pH, fluorides (F-), bicarbonate (HCO_3^-), total dissolved solid (TDS), total hardness (TH), calcium (Ca^{2+}), sulphate (SO_4^{2-}), magnesium (Mg^{+2}), chlorides (Cl^-), nitrates (NO_3^-) ions were taken for the assessment.

Disaster Vulnerability Assessment: Bihar's topography is marked by a number of perennial and non-perennial rivers of which, those originating from Nepal are known to carry high sediment loads that are then deposited on the plains of Bihar (Figure 1). A majority of the rainfall in this region is concentrated in the 3 months of monsoon during which the flow of rivers increases up to 50 times causing floods in Bihar. According to the Bihar Government's Flood Management Information Systems Cell, floods of Bihar can be divided into 4 categories namely:

Division of flood in Bihar	Types	Remarks
Class I	Flash Floods	floods occurring due to rainfall in Nepal, lead time is short (8 hours), receding of flood waters is fast.
Class II	River floods	Lead time 24 hours, receding of flood waters is 1 week or more.
Class III	Drainage congestion in river confluence	Lead time more than 24 hours, lasting full monsoon season (i.e. receding of flood water takes 3 months).
Class IV	Water logging	Permanent water-logged area.

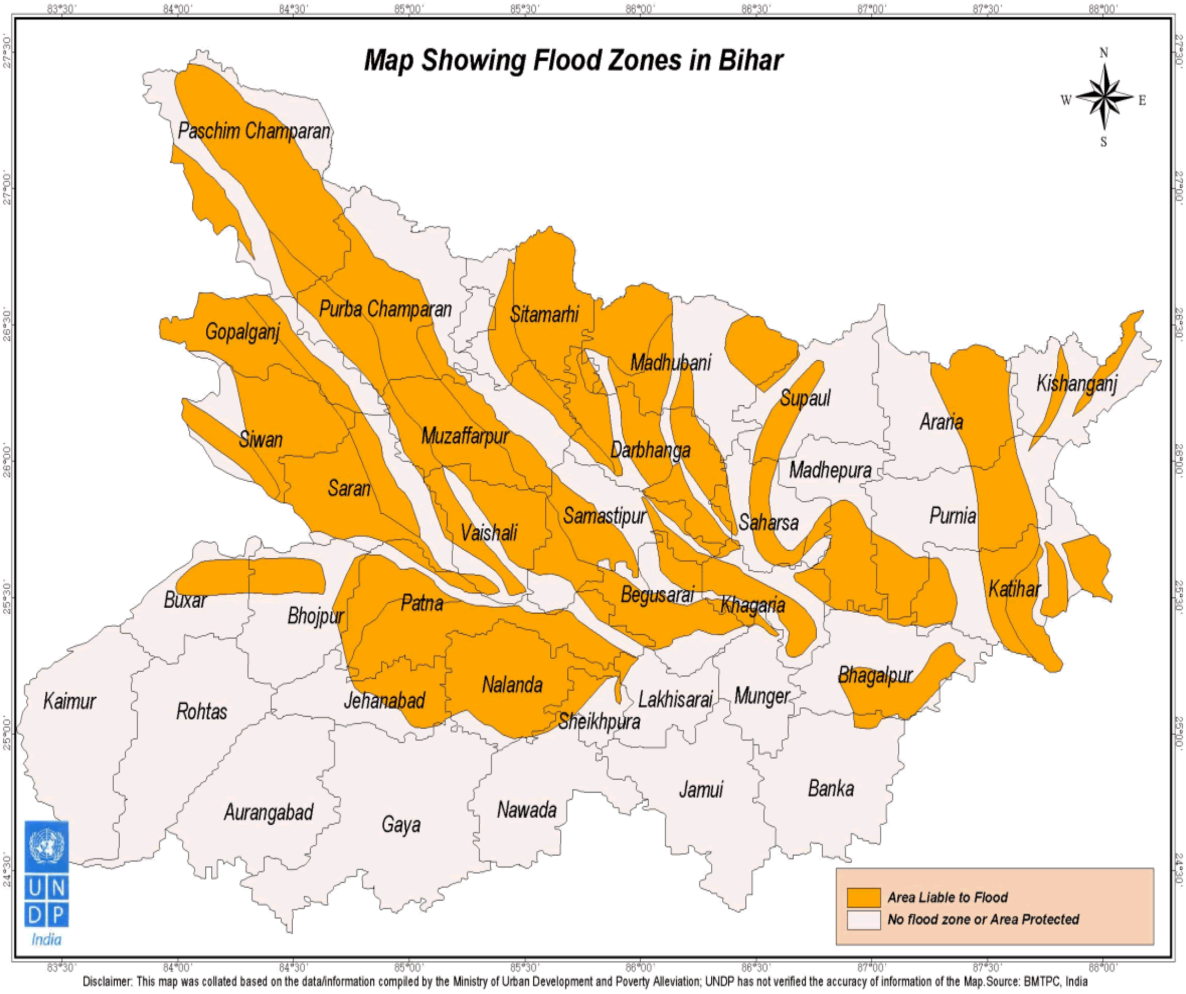

Figure 1: Flood zones in Bihar

As such, 73.63% of the geographical area of North Bihar is considered to be prone to floods. Out of 38 districts, 28 districts get flooded (of which 15 districts are worst affected) causing huge loss of property, lives, farmlands and infrastructure. During the 2008 Kosi floods, over 350,000 acres of paddy, 18,000 acres of maize and 240,000 acres of other crops were adversely affected, impacting close to 500,000 farmers. Historical flood and drought data from the Bihar State Disaster Management Authority (BSDMA) were analyzed. The potential impacts of these disasters on groundwater quality were modeled based on aquifer characteristics and floodwater intrusion patterns.

Table 1 shows the various flood events in district of Nalanda and Biharsharif region. The major flood outbreak in the region as flash flood and impact was also noticed. The area was submerged and affected many infrastructures, life of people and animals etc. The situation of the region was noticed as disaster in the region (BSDMA, Patna). Flooding significantly impacts water quality by introducing contaminants into drinking water sources, disrupting water treatment and sewage systems and increasing the risk of illness. Contaminated floodwater can carry pollutants like bacteria, chemicals and debris, making it unsafe for consumption and contact. Proper testing and disinfection of water sources are crucial after a flood to ensure safety. Flood events inject large quantities of suspended solids into rivers, causing turbidity to increase, affecting the aesthetics of the water body and endangering human health.

Here is a simulated time series graph showing mean hourly flood discharge (in cusecs) over a 48-hour period for the Falgu River near Biharsharif during a flood event in August 2024 as in fig. 2. The simulated time series of mean hourly flood discharge for the Falgu River near Biharsharif (Figure X) illustrates the typical behavior of river discharge during a monsoon-induced flood event. The discharge follows a diurnal cycle, peaking around midday to late afternoon, corresponding to peak runoff accumulation from upstream catchments. In this simulation, the discharge reaches a maximum of approximately 15,000–16,000 cusecs, exceeding the safe carrying capacity of nearby channels and causing localized overflow in low-lying urban and peri-urban areas.

Biharsharif, a municipal corporation city is the administrative headquarters of Nalanda district in Bihar State of India. A final report on city development plan for Biharsharif (2011) found that water quality falls in safe category. The city of Biharsharif does not have any treatment plant. Chandra et al[8] found that the city does not have problems relating the availability of groundwater, but poor water management and timely augmentation of dumping yard and leachate generation of water have led to adverse effect in groundwater quality. It also causes threats to surface and groundwater sources as the improper management to a high possibility to the use of contaminated potable water, so that people suffer from various water borne diseases. The city depends on the groundwater for its daily purpose through pipe water supply and individual hand pumps

Table 1
Major Flood Events in Nalanda District Impacting Biharsharif

Year	Event	Impact on Biharsharif
2014	Flash floods across Nalanda, Patna and Sheikhpura	Submerged low-lying areas, affected water infrastructure
2018	Overflow of Panchane River due to release from Teliya Dam	Inundation in Rahui and Harnaut blocks, Biharsharif outskirts impacted
2021	Monsoon-induced urban flooding	Waterlogging and contamination risk in densely populated wards

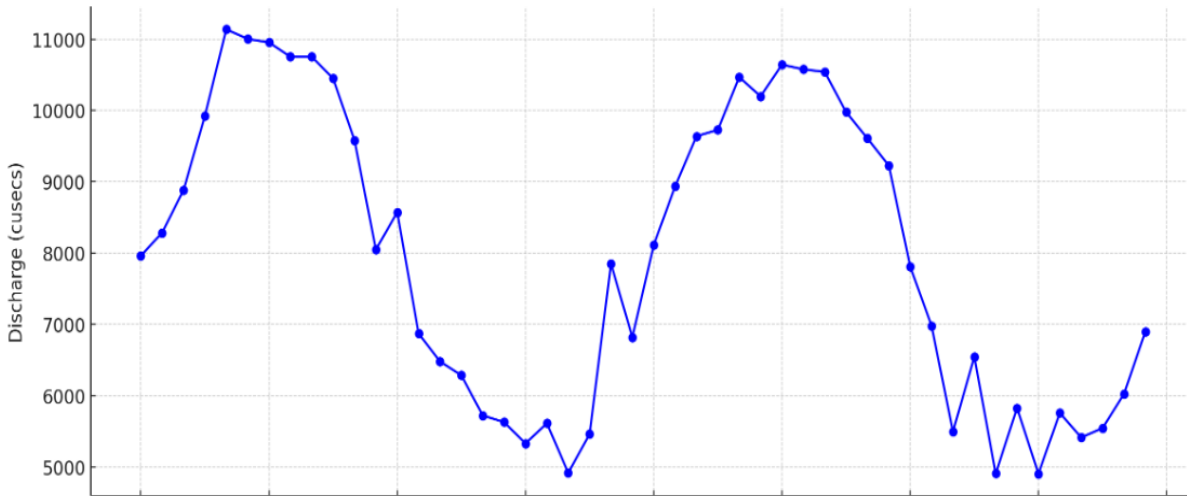

Figure 2: Stimulated time series mean hourly flood discharge Falgu River near Biharharif (August 2024)

The city has been facing the complexity of groundwater availability in recent times due to rapid urbanization, growth of population and industrialization. Due to massive demand of water in agriculture and domestic purpose, there is inadequacy in groundwater especially in urban area. The town is divided into seven water supply zones covering 46 multiple wards. According to CDP (2010-30), the gross water supply in the city is around 46.15 MLD but the projected water demand in 2030 and 2045 is 74.87 MLD and 109.7 MLD respectively. It has been reported that the quality of groundwater is not tested on regular basis. So, the method of WQI provides a better water quality based on several water quality parameters.

Review of Literature

The estimation of water quality index was studied by weighted arithmetic water quality index method. The results were compared with WHO and ISI standard and after that it was found that the pre-monsoon values are much suitable for drinking purpose in most of the stations whereas most of the stations are not suitable for drinking after monsoon. The pollution after monsoon is more than that of pre-monsoon. This study investigated the suitability of GW for drinking and farming purpose based on WQI estimation.

Srikanth et al[30] studied on access, monitoring and intervention challenges in the provision of safe drinking water in rural Bihar, India. The study focuses on the role of water quality monitoring and intervention that has a huge impact on protecting health problem in areas contaminated with arsenic and fluoride.

Foster et al[10] studied on protection of GW, especially linked with land management. This study aimed at studying the protection of groundwater based on scientific and practical application of land surface zoning. Pollutants are being added day by day to the groundwater system through human activity and natural processes. The analysis asks to increase awareness of risk and to promote public understanding of the problem of groundwater protection.

Hasim et al[14] studied a case study on physical characteristics of groundwater of Pecan, Pahang district. They estimated the physical characteristics of groundwater (temperature, pH, EC, TDS and salinity) and to identify the influence of several location of tube well. The result defines temp and pH for all samples having same values but for EC, salinity and TDS have significantly different values related to location of tube well. The overall result of Pekan tube well can be an evidence of saline water intrusion.

Tewari et al[31] observed the physico-chemical characteristics of ground water quality in the Allahabad city. The groundwater samples were collected from different locations of Allahabad city area by dividing into different zones. In this study they analyzed for pH, Conductivity, TH, Alkalinity, Sulphates, Fluoride, Sodium, Potassium and Chlorides etc. The sample location number PHSP-10 is showing higher values of TDS, TH, Ca, Mg and SO_4. Result indicates the need for periodic monitoring and GIS based study of groundwater in the sampling location.

Gupta and Rani[11] performed an experiment for understanding the characteristics of leachate from the landfill. Leachate and water samples were collected from Narela-Bawana (New Delhi) landfill location. Domestic wastes disposal is of primary concern in urban areas. Their study dealt with the determination of likely concentrations of hazardous pollutants in the groundwater over a period due to the discharge of such contaminants from residential area. Results indicate the likely contamination of groundwater due to solid waste released from residential area as well as from landfill.

Nagarajan et al[20] studied in a laboratory about leachate characteristics and observed that GW is polluted by solid waste generated from Chidambram town. The present land fill site is more than 5 decades old. Municipal, industrial, agricultural and domestic activities can all affect groundwater quality. Various types of contaminants may reach groundwater from several activities on the land surface which is threatened with residential area as well as environment.

Singh and Hussian[29] studied on WQI development for GW quality assessment of Greater Noida sub-basin. They carried out experimental work on various parameters of groundwater by collecting 47 groundwater samples from 25 blocks of Greater Noida city. The physicochemical and biological analysis of 11 parameters were subjected to develop water quality index. Currently, manufacturing industries have high demands for cooling water and water for cleaning purposes. The obtained value of WQI ranging from 53.64 to 267.82 indicates the very poor water quality in the area due to the number of industries increasing during the last decade. Analysis of results reveals that water quality index pertaining to the ground water of the sample location needs to be recognized. The sub-basin area also indicates alkali metals to go beyond a limit over the alkaline metals and temporary triumphs over permanent hardness.

Naveen et al[21] found that percolating water passing through waste becomes polluted and will have dissolved soluble compounds as well as suspended particles. The results showed that the highest metal concentrations that exists in the leachate was iron which is about 11.16 ppm. BOD5 and COD of the leachate are 1500mg/l and 10400 mg/l respectively. The groundwater quality of Nanganur region was studied for drinking purpose. Concentration of nitrate in groundwater ranged from 25 to 198 mg/l. The obtained WQI values ranged from 92 to 295. About 86% of GW samples were of poor quality for drinking purposes.

Result showed the health risk caused by larger intake of nitrate for infants. Therefore, health risk reduction procedure should be implemented.

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Gupta et al[11] observed that the industrial discharges, landfills, fertilizers and pesticide are possible sources of contamination of groundwater. They suggested that the analysis of the water quality is very important to preserve the natural ecosystem. Baba and Taylor[5] studied on GW contamination and its effect on health in Turkey under natural and anthropogenic sources. The result revealed that in recent years, there has been a significant growth of interest in environmental issues including groundwater quality.

Karthik et al[17] studied the physicochemical parameter of groundwater quality of Velliangadu village in the district of Coimbatore during pre and post monsoon season under seven groundwater samples. The result found that the TH, TDS and alkalinity are higher in post monsoon that the pre-monsoon water samples. pH of samples was found to be good for drinking as well as agricultural purposes. The presence of rock type in the area and the high number of fertilizers and pesticides applied in the agricultural field could be the cause of increase in physicochemical parameter values.

Mishra[19] observed the deterioration of ground water quality in recent years. Bihar is a largest State with high ground water potential, currently facing a severe water quality problem. He determined the steps to improve the rural health through safe drinking water supply. He also identifies that the drinking water in rural areas is not safe in most of the region. Out of 38 districts, groundwater sources of 80 blocks in 13 districts are affected by arsenic contamination whereas 22 districts are affected with excess fluoride and presence of iron in groundwater. After study, he concluded that efficient water management is required for preventing detonation of water quality such as improved sanitation, adequate attention to developed water quality database and strengthening the water testing laboratories.

Material and Methods

Water quality index: Water quality index is one of the most effective tools to provide a convenient means of reprising complex water quality data which can easily understand on the overall quality of water. It is useful as thumbnail indicator of surface as well as groundwater quality. The objective of an index is to convey the quality of water bodies for distinct uses such as drinking, irrigation and for other purposes. Horton[15] first introduced the mathematical form as WQI and was later improved by Brown et al[7].

WQI can be used in following purposes:
(1) To provide an overall status of the water quality.
(2) To study regulatory policies and environmental programs on water quality.
(3) To compare the water quality with different sources.
(4) To assist the policy makers to avoid subjective assessment.

Estimation of Water Quality Index: WQI is well known method to monitor the surface as well as ground water pollution and can be used in the water quality upgrading programs. It offers information of water quality to the concerned citizens. It thus, becomes an important tool for the assessment and management of groundwater. WQI is a technique of rating water quality that ensures sustainable safe use of water for drinking and various purposes.

For analyzing the GW samples, the water quality data of the analyzed samples was compared with std. of BIS 2012 (IS: 10500) was considered for the calculation of water quality index. In the present study, the WQI has been calculated in three steps. In the first step, each of 9 parameters (pH, TDS, TH, Ca, Mg, F, Cl, NO3 and SO4) has been assigned a weight (Wi) according to its relative importance in the overall quality of water for drinking purposes.

All concentrations are in mg/l, except pH. The maximum weight of 5 has been assigned to the parameter such as TDS, NO_3^-, Cl^-, F^- and SO_4^{2-} due to its major importance in water quality assessment. Total hardness is given as the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like Ca, Mg and pH were assigned weight between 1 and 5 depending on their importance in water quality determination. In the second step, the relative weight (Wi) is calculated from the following equations (Equations 1-4):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

where Wi and wi are the relative weight and weight of each parameter respectively and n is the number of parameters. In the third step, a quality rating scale (Qi) for each parameter was assigned by dividing its concentration in each water sample by its respective standard according to the guideline laid down in the BIS: 10500 (2012) and the result for the same is multiplied by 100.

$$Q_i = \frac{C_i}{S_i} 100 \quad (2)$$

where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l and Si is the BIS standard for each parameter in mg/l according to the guidelines of the BIS (10500:2012). For computing the WQI, the SI is first determined for each chemical parameter which is then used to determine the WQI as per the following equations:

$$SI_i = W_i \times Q_i \quad (3)$$
$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

The computed WQI values are categorized into five types such as “very good, good, poor, very poor and unfit”. The range of WQI for drinking purpose is given in table 2.

Standard groundwater quality parameter and their limits: The over exploitation of groundwater as well as post contamination of the distribution system due to intermittent water supply has impaired the water quality to such an extent that the pre-chlorination dose is essential to bring down the coliform count within the acceptable limits formulated by the CPHEEO, Govt. of India. The water quality norms are as per (IS: 10500-2012). Table 3 represents the drinking water standard. Single index may have variables from distinct ecological processes such as oxidization or mineralization. Currently, it is possible to tackle contaminated groundwater by using new WQI method. In this method it is used for various sources such as springs, streams, groundwater and black waters. Usually, the lower value of WQI alludes to better water quality and higher values to degraded quality.

Vishwakarma and Srivastava[33] studied on groundwater quality status by using water quality index method in Ujjain city, M.P, India and analyzed its physiochemical parameters. Water quality index rating was done in 54 wards and the results were compared with the WHO guideline for the quality of drinking water. The result shows that the 4% of samples represent "excellent water", 53% indicate "good water" and rest of the percentage is for "poor water" category, which recommends the use of appropriate technique to make water useful for drinking purpose. Research indicated that the groundwater of the selected location should be treated before its consumption to avoid adverse health effects on human being.

Krishan et al[18] observed groundwater quality assessment in Rajkot district, Gujarat, India. In this study they collected 27 samples from Rajkot district. The seven parameters were analyzed namely pH, TDS, TH, Fluoride, Chloride, Sulphate and Nitrate. The WQI values range from 27 to 98. The computed WQI reveals that 48.2% of water samples fall in the 'Fair' to 'Poor' groundwater category. On the other hand, 51.8% of water samples fall in the 'Good' to 'Excellent' category which indicates that water is not acceptable for direct consumption without treatment.

Ahmad et al[2] studied on Darbandikhan district, Kurdistan Region, Iraq around some villages with an objective of evaluation of groundwater quality for drinking purposes. The study was carried out in more than 60 km^2 over seven villages near Darbandikhan district using WQI by investigating different wells and springs.

The study spreads over two seasons namely fall and spring with 14 parameters such as pH, TDS, Nitrate, Chloride, Sulphate, Calcium, Magnesium, EC, Turbidity, Total hardness as $CaCO_3$, Phosphate, Sodium and Potassium. The observed values of these parameters were compared with WHO standards. The result show that the highest water quality was recorded at site Miradee (WQI=32.82) whereas lowest quality found at site Birke (WQI=11.77). These sampling were fit for drinking without proper treatment according to WHO standard from excellent to good water quality.

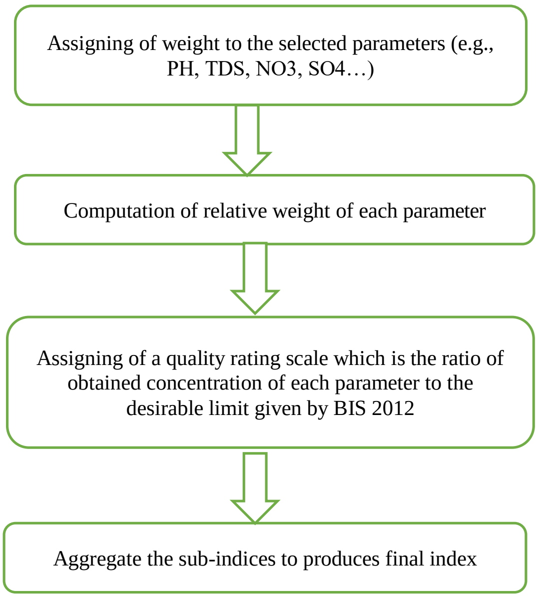

Figure 3: Flow chart for water quality index

Table 2
Range of water quality index specified for drinking water used in India

S.N.	WQI Range	Water Quality
1	<50	Very Good water
2	50-100	Good water
3	100-200	Poor water
4	200-300	Very Poor water
5	>300	Unfit for drinking purpose

Table 3
Drinking Water Standard

BIS (IS:10500)-2012					
S.N.	**Parameter**	**Unit**	**Desirable Limits**	**Max Permissible**	**WHO Desirable Limits**
1	pH	-	6.5 to 8.5	No Relaxation	6.5 to 9.2
2	E. Coli	Number/100ml	Absent	Absent	Absent
3	TDS	mg/l	500	2000	1200
4	Arsenic	mg/l	0.05	0.05	0.01
5	Fluoride	mg/l	1	1.5	1.5
6	Nitrate	mg/l	45	No Relaxation	50
7	Calcium	mg/l	75	200	-
8	Magnesium	mg/l	30	100	-
9	Sulfate	mg/l	200	400	500
10	Turbidity	NTU	5	10	10
11	Iron	mg/l	0.3	No Relaxation	0.3
12	Total Hardness	mg/l	200	600	500
13	Chloride	mg/l	250	1000	-
14	Alkalinity	mg/l	200	600	-
15	Color	Hazen	5	15	15

Kalra et al[16] studied on Koilwar block of Bhojpur, Bihar, India for the groundwater assessment. In this study there were 60 groundwater samples taken from the different villages from dug and bore wells. The 11 different physicochemical parameters were considered for calculating the WQI. Most of the parameters satisfy the WHO and ISI standards guidelines. WQI ranges from 40.65 to 69.57. Few parameters showed larger values and are not within the desirable limit of WHO standards.

The Bihar state can be deeply divided into three hydrogeological unit namely, unconsolidated/alluvial formation, semi-consolidated formations and consolidated/fissured formations. The main alluvial sediments are confined to entire substantial area of south of the Ganga River. These alluvial treats constitute prolific aquifers where the tube well can yield between ranges of 120 to 247 m^3/hr. The capability of these aquifer decreases due south in the marginal tract. In sub-tarai region, auto flow conditions happen. In the hard rock region of south Bihar, borewells located near fracture can yield between 10 to 50 m^3/hr. The overall stage of groundwater development is 39%. The groundwater quality is generally of good category at deeper levels (CGWB, New Delhi).

Study area

Biharsharif (also called as Bihar by local people) is the administrative headquarter of Nalanda. It is famous all over the world for the ancient international monastic university established in 5th century BC, which taught vedas, grammar, medicine, rhetoric and meta-physics. The total area covered by Biharsharif municipal area is about 23.5 sq. km and the average elevation of the city is 55 m above sea level. Geographically, Biharsharif is located within the mid-ganga basin, in the southern margin of the Gangetic plains. It is the district headquarters of Nalanda district in the eastern state of Bihar located at 25º 07'N latitude and 85º 31'E longitude. The town lies in the Hiranya Prabhat Parvat (recently known as Badi Pahari) on the bank of river Panchanan.

The river Panchana forms the physical boundary on the south western side. The city stands sixth in the population ranking of the cities in the State of Bihar and 28th in terms of area of the city. Biharsharif is well connected with other parts of the country by road. National highway 31 and 82 pass through the city and NH 110 terminates in the city. Geometrically, the NH 31 is the main axis of the city of Biharsharif. The city has population of 2,97,268 of which 1,55,216 are males and 1,42,052 are females as per report released by Census India. The population density of this city is 1006 per sq. km. The city is divided into 46 wards.

Biharsharif Municipal Corporation was constituted in the year 2007. People of this city mainly work in farming activities. The main source of water supply in the area is bore holes, tube wells, dug wells and manually operated hand pumps. The total potable water demand for the city of Biharsharif is met by underground water sources, which meet 90% of the total demand. The existing storage capacity of 3.18 ML seems adequate to support the present population of the city. The city of Biharsharif is divided into 7 water zones and there are more than 44 water bodies in and around the city. At present, the city is able to meet the demand of only 68 lpcd which is less than std. requirement. The area surrounding this city has been allowed with natural formations and it is referred to as the "Giver of knowledge".

The city experiences all the three season i.e. summer, winter and rain. The climate is reasonably cold in winters and hot during summers. The summer season usually starts from May and during that time the maximum temperature reaches to 43ºC whereas min. temperature reaches to 26ºC. Due to the Himalayan effect, the winter season which is generally during October to March, the temperature below 11ºC. The average annual rainfall is 1139 mm. In Biharsharif, the winds are mostly dry, warm and generally light throughout the year. The predominant wind direction in the city and surrounding area is in north east direction.

Sampling and Preservation: Groundwater samples were collected from different wards in Bihrsharif city namely, Asha Nagar, Surya Mandir, Khasganj, Sohsarai, Moghal Kua, Singar Hat, Badi Pahadi, Ramchandarpur, Gandhi Chowk, Durgasthan, Nalanda College, Baradari Masjid, Khandakpur, Sakunat, Khairabad, Mathuriya, Sogra College, Badi Dargah and Mangal Nagar as in figure 4. The samples were collected from hand pump, bore well and deep tube well. The samples were collected before rainfall (May-June, 2019) and after rainfall (September-October) from various locations. The hand pumps were continuously pumped prior to the sampling water. The GW samples were collected from various locations as mentioned in table 4 stored in high density plastic bottles and preserved in laboratory for further analysis.

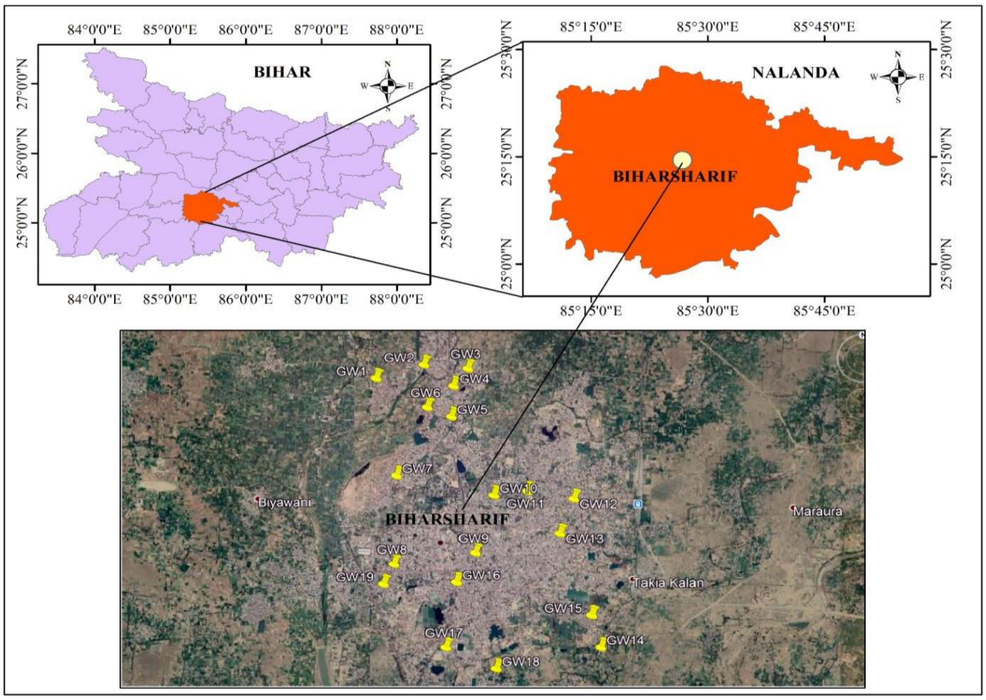

Figure 4: Groundwater sample location in the Biharsharif township area

Table 4
Details of the sampling site from different wards of Biharsharif city

Sample Code	Sampling Location	Ward Name	Source	Latitude	Longitude
GW1	Asha Nagar	6	D.T	25°13′1.80″N	85°30'21.09"
GW2	Surya Mandir	7	B.W	25°13′8.11″N	85°30'44.93"
GW3	Khasganj	9	H.P	25°13′6.42″N	85°31'4.50"
GW4	Devsharan Mahila College, Sohasarai	10	D.T	25°12′58.75″	85°30'58.21"
GW5	PHD Dept., Moghal Kua	18	H.P	25°12′45.22″	85°30'57.26"
GW6	Singar Hat	19	B.W	25°12′49.25″	85°30'46.51"
GW7	Govt. High School, Badi Pahari	20	D.T	25°12′19.27″	85°30'32.80"
GW8	Ramchandarpur Bus Stand	23	H.P	25°11′40.38″	85°30'31.62"
GW9	Gndhi Park	24	B.W	25°11′45.36″	85°31'8.00"
GW10	Nagar Nigam Durgasthan	26	B.W	25°12′10.64″	85°31'16.20"
GW11	Nalanda College	27	D.T	25°12′12.48″	85°31'31.26"
GW12	Baradari Masjid	29	B.W	25°12′9.12″	85°31'51.86"
GW13	Khandakpar	30	B.W	25°11′53.82″	85°31'45.69"
GW14	Sakunat Devi Asthan	31	D.T	25°11′3.85″	85°32'3.93"
GW15	Khairabad Boring	33	B.W	25°11′17.94″	85°31'59.85"
GW16	Laheri Thana, Mathuriya	38	B.W	25°11′32.5″	85°30'59.49"
GW17	Sogra College	44	D.T	25°11′3.84″	85°30'54.83"
GW18	Badi Dargah	45	B.W	25°10′54.54″	85°31'17.25"
GW19	Mangal Nagar	-	B.W	25°11′31.66″	85°30'26.91"

Table 5
Parameter and their methods

S. N.	Parameters	Unit	Test Methods & Instrument
1	pH	-	Digital PH meter
2	EC	µmho/cm	Digital conductivity meter
3	Turbidity	NTU	Digital turbidity meter
4	TDS	mg/l	Electrometric
5	TH	mg/l	Titrimetrically by std. EDTA
6	Fluoride	mg/l	Pocket Colorimeter
7	Sulfate	mg/l	UV VIS Spectrophotometer
8	Chloride	mg/l	Aquamate 8000 Spectrophotometer
9	Nitrate	mg/l	Aquamate 8000 Spectrophotometer
10	Calcium	mg/l	Titrimetric
11	Magnesium	mg/l	Titrimetric

Table 6
Relative weight of chemical parameters

Chemical Parameters	Standards (BIS)	Weight (wi)	Relative Wt (Wi)
pH	8.5	4	0.1081
TDS	500	5	0.1351
TH	300	2	0.054
Calcium	75	3	0.081
Magnesium	30	3	0.081
Sulphate	200	5	0.1351
Nitrate	45	5	0.1351
Chloride	250	5	0.1351
Fluoride	1	5	0.1351
		Σwi=37	ΣWi=1.0

Physico-chemical Analysis: Analysis was carried out for various parameter measured by using standard methods. Biharsharif city was chosen as study area whereas water samples were collected from 19 stations for pre- to post-monsoon season by using std. methods (APHA). The multivariate stastical analysis has been performed using standard methods as in table 5.

Results and Discussion

Groundwater is the major source of water supply in Biharsharif town. The competitive advantage of this city is in its primary agriculture activities. The city acts as a key centre for distribution of agri-products for nearby places. Most of the wastewater from the city is discharged directly to the natural water bodies due to the insufficient treatment. The pollutants also reach the GW aquifers, making it unfit for human being.

Variation of physiochemical parameters around Biharsharif township area, Nalanda, Bihar: Based on study done in laboratory, results of groundwater samples are analyzed for the physicochemical and WQI for assessing the groundwater quality and its suitability for various purposes.

pH: No health-based instruction is proposed for pH although pH usually has no influence on consumers, it is one of the most important water quality parameters. pH control is necessary at all stages of groundwater treatment to ensure clarification and disinfection. The pH of water must be controlled to reduce the corrosion effect of water. Failure to corrosion can result in the contamination of groundwater and adverse effect on its taste. The optimum pH required is usually in the range of 6.5-8.5. Utmost value of pH can result from accidental spills and another various disease. The pH value of collected samples in the present study has been analyzed and varies in the range of 6.46-8.34 for both pre and post monsoon (Figure 5). Only one sample collected from location GW3 is obtained as a higher value of pH.

Turbidity: Turbidity in groundwater is caused by particulate matter because of inadequate filtration of sediment. The turbidity of drinking water is less than 5 NTU and is usually acceptable to human being. Particulates can protect micro-organisms also from the effect of disinfection. In all cases where water is disinfected, the turbidity must be low so that disinfection can be effective. Turbidity indicates problems with treatment processes particularly coagulation, sedimentation and filtration. Turbidity of collected samples varies in the range of 1.0-4.8 (Figure 6) for both pre and post monsoon.

Total Dissolved Solid: TDS contain inorganic salts and small quantity of organic matter that are dissolved in water. TDS in groundwater appears from natural sources, urban runoff and sewage.

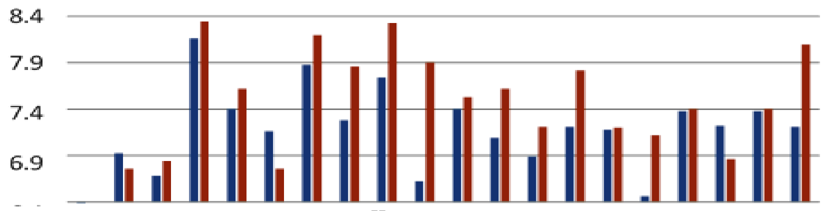

Figure 5: Variation of p^H in samples of all the locations

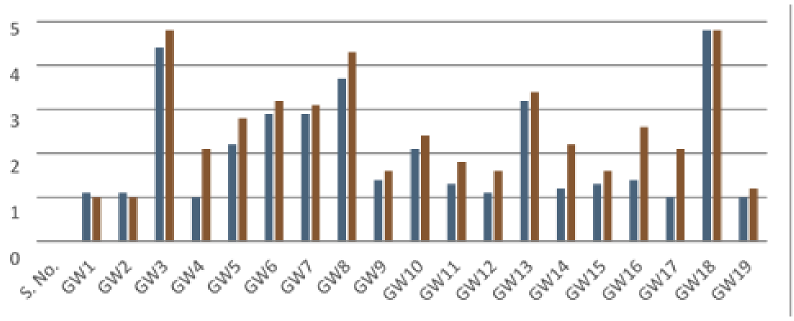

Figure 6: Variation of turbidity in all samples of different locations

Amount of TDS concentration may vary in different region owing to variations in the solubility of minerals. Generally, the presence of high levels of dissolved solids in water may be objectionable to consumers. Drinking water with low concentrations of TDS may also be unsatisfactory because of its bad taste. The acceptable limit of TDS prescribed by BIS is 500 mg/l and 2000mg/l as the permissible limit. In present study, the TDS concentration of GW samples lies in the range of 214-1040mg/l. It is concluded that TDS of all the collected samples is within the permission limit. The TDS concentration of sample number GW3 was found to be 1040 mg/l in post monsoon season which is higher than all the collected sample. The variation of total dissolved solids in all the samples is presented in figure 7.

Total Hardness: Hardness in fresh water sources is caused by dissolved calcium and magnesium salts. It is relatively expressed as the equivalent quantity of $CaCO_3$. Total hardness above about 200 mg/l can result in scale deposition in the treatment works within buildings. Water with hardness less than 100 mg/l may have a low buffering capacity and will be more corrosive for distribution system. The acceptable limit of total hardness is 200 mg/l and 600 mg/l as the permissible limit. However, the degree of hardness in drinking water may affect its acceptability to the consumer in terms of taste. The hardness of drinking water samples in the study area is found to be in the range of 160-510 mg/l as $CaCO_3$, while 16% of total samples were found to be within the desirable limit of 200 mg/l for both pre and post monsoon season. The variation of total hardness in all the samples from different location is depicted in figure 8.

Calcium: Analysis of calcium has been accomplished in all the groundwater samples in present study. The acceptable limit of Ca by BIS is 75 mg/l and 200 mg/l as permissible limit for drinking water. The concentration of Ca in all the collected samples of the study region lies in the range of 40-110 mg/l. The concentration of all the groundwater sample is well within the permissible limit. Sample GW3 was found to be above the desirable limit of 75 mg/l. Calcium variation in all the samples of different locations is presented in figure 9.

Magnesium: Magnesium is another weighty parameter that has been assessed in all the samples calculated in the present study. The limit of BIS for the Mg concentration is 30 mg/l as acceptable and 100 mg/l as a permissible limit for drinking water. The magnesium concentration of all the samples has been found to be in the range of 17-90 mg/l. Only 11% of the total samples have been found to be outside the acceptable limit (Figure 10).

Chloride: Some frequent chloride compounds found in drinking water are NaCl, KCl and $MgCl_2$. Chloride in groundwater originates from sewage and industrial effluents containing de- icing salt. The main source of chloride for human exposure is the addition of salt to food. Extreme chloride concentrations increase rates of corrosion. However, based on taste threshold, it was confirmed that chloride concentrating more than about 250 mg/l can give rise to detectable taste in water. The concentration of chloride in the collected GW samples is in the range of 30-120 mg/l. All the collected pre-monsoon and post- monsoon samples were well within the acceptable limit prescribed by BIS (Figure 11).

Nitrate: Nitrate is found naturally in the controlled environment. It is an important nutrient for plant kingdom and a part of the nitrogen cycle. Nitrate is usually present in significant concentrations in drinking water because of leaching from natural vegetation. The composition of nitrates with other nitrogenous compounds through the action of bacteria in the digestive system results in the formation of nitrosamines, which can become carcinogenic. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, but groundwater concentrations relatively show slow changes.

In general, the most important source of human exposure to nitrate is through vegetables and through meat in the diet. When nitrate concentration is present in large quantities in drinking water, it causes potential health hazard. The maximum limit of nitrate as per BIS for water is 45 mg/l. The concentration of nitrate in collected sample ranges between 1.2 to 5.2 mg/l and all collected pre- and post-monsoon sample were found to be well within the permissible limit. Figure 12 shows the nitrate variation in all the samples at different locations.

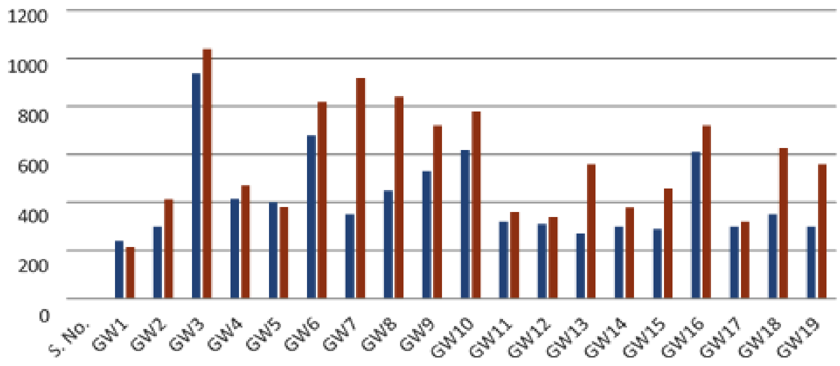

Figure 7: Variation of total dissolved solids in all the samples

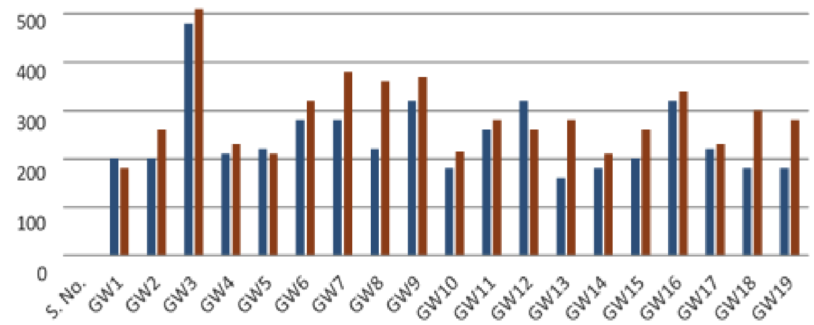

Figure 8: Variation of total hardness in all the samples from different location

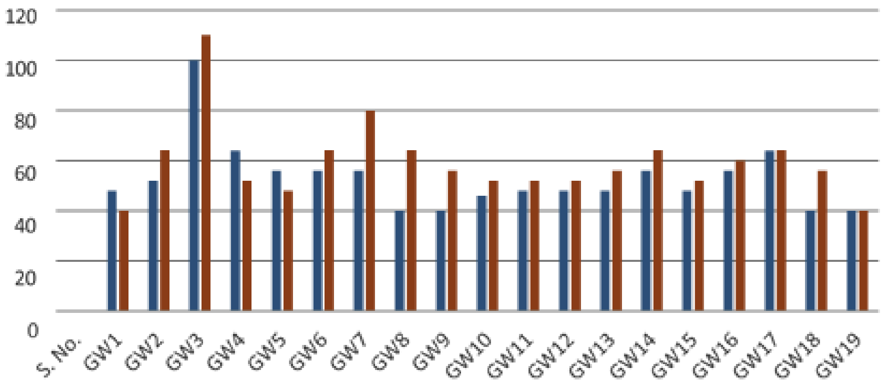

Figure 9: Calcium variation in all the samples of different locations

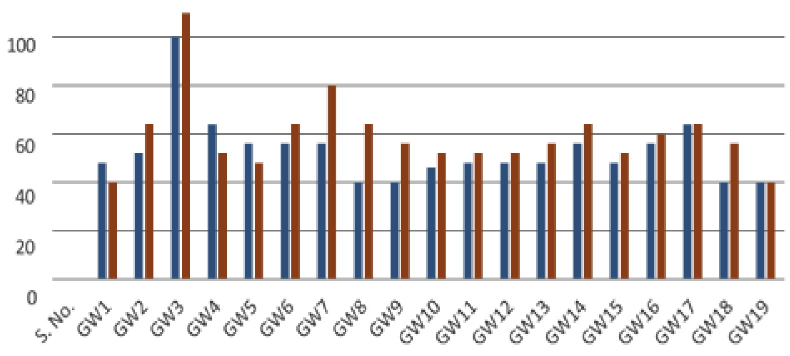

Figure 10: Magnesium variation in all the samples of different locations

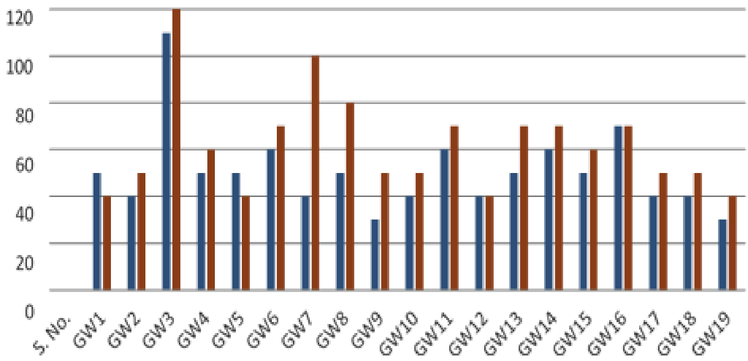

Figure 11: Variation of chlorides in all the samples from different locations

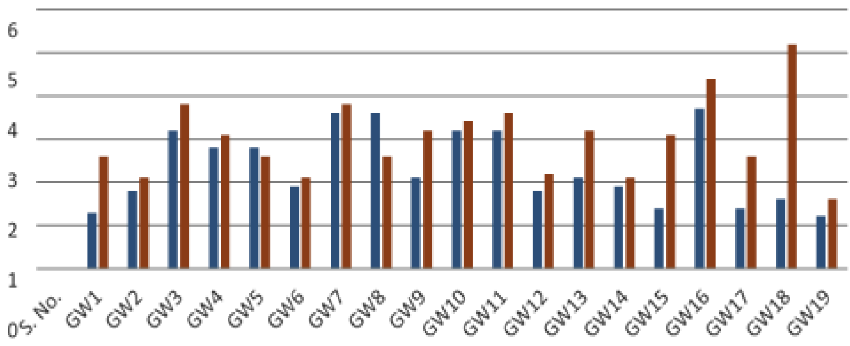

Figure 12: Nitrate variation in all the samples at different locations

Sulphate: Sulphate occurs naturally in numerous well-oxygenated waters. It discharged into water from industrial waste and through atmospheric deposition. The presence of sulfate in drinking water may also cause noticeable tastes at concentration above 250 mg/l and may contribute to the corrosion of distribution systems. Very high levels of sulfate might cause a laxative effect for consumers. Sulphate concentration of collected samples in the study area lies in the range of 2.6-9.8 mg/l within the acceptable limit prescribed by BIS. Figure 13 represents the sulphate variation in all the samples of different locations.

Fluoride: Fluoride is a common element that is found in all-natural type of waters at different concentrations. It is widely distributed in the earth's crust as a mineral, such as fluorspar and cryolite. Virtually all foodstuffs contain at least traces of fluorine. All vegetation contains some fluoride, which is absorbed from soil and water. These can be available in the form of tablet, mouthwashes, toothpastes and gels for local application. Total daily fluoride exposure can vary markedly from one region to another. The BIS referred to fluoride, stating that concentrations, in drinking water more than 1.0-1.5 mg/l of fluorine per liter may give rise to dental fluorosis in some children and much higher concentrations may eventually result in skeletal damage in both children and adults.

To prevent the development of dental caries in children, a number of communal water supplies are fluoride to bring the fluorine concentrations to 1.0 mg/l. The fluoride concentrations of all collected GW sample are in the range of 0.40 to 1.24 mg/l for both pre- and post-monsoon. It is found that fluoride concentration in 84% of total samples is well within the desirable limit prescribed by BIS. Fluoride variation in all the sample of different locations is presented in figure 14.

Computation of WQI

Water quality index is an important factor for public health issues to give information on the quality of any water body. The WQI was calculated to assess the quality of groundwater of Biharsharif city for the pre- and post-monsoon. The computed water quality index values of collected GW samples ranged from 38.56 to 100.55 in the pre-monsoon season and from 40.34 to 110.9 in the post-monsoon respectively. The highest values of WQI were collected for the samples from the Khasganj, Ramchandarpur and Badi Pahadi sampling locations (Table 7). This may be due to the urban expansion and development. The highest WQI values in the groundwater of the Biharsharif township area were found in the post-monsoon season as compared to pre-monsoon season. The higher values of WQI were observed due to higher concentration of TDS, Cl^-, SO_4^{2-}, NO_3^- and F^- in the groundwater samples during pre- and post-monsoon seasons respectively. The highest values in the collected samples may be attributed due to the natural and human activities of the study site. However, higher values of WQI in the post-monsoon season of the study area indicate dilution effect. Among all of the GW samples, the percentage of water quality index categories was very good (63.15%), good (31.57%) and poor (5.26%) in the pre- monsoon season. However, in the post-monsoon season the percentage of WQI categories is very good (36.84%), good (57.89%) and poor (5.25%).

These results indicate that the groundwater is moderately contaminated and is not suitable for direct drinking uses. The pictorial depiction of GWQI values is presented in figure 15. The WQI values for the groundwater during pre- and post-monsoon season of the Biharsharif township area are presented in table 7.

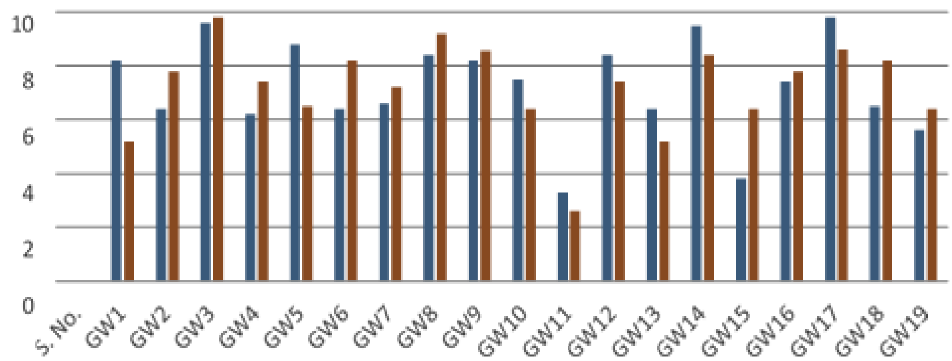

Figure 13: Sulphate variation in all the samples of different locations

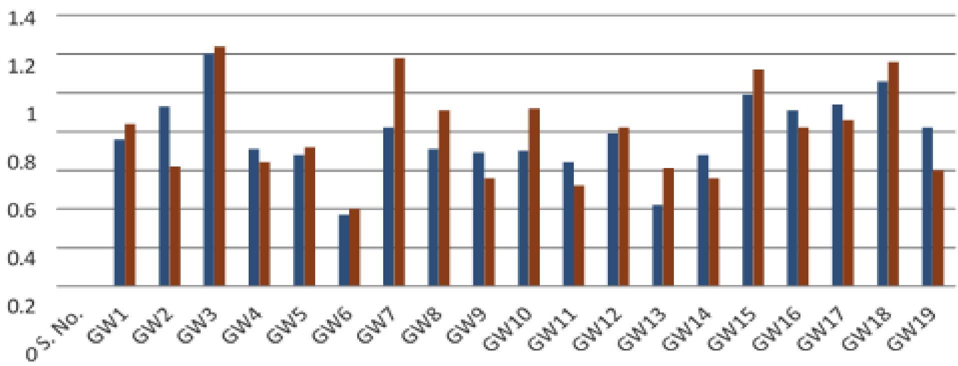

Figure 14: Fluoride variation in all the sample of different locations

Table 7
Water quality index values for the groundwater during pre and post-monsoon season of the Biharsharif township area

S. N.	Location	WQI values pre-monsoon	Description	WQI values post-monsoon	Description
GW1	Asha Nagar	42.56	Very Good	40.34	Very Good
GW2	Surya Mandir	46.08	Very Good	49.06	Very Good
GW3	Khasganj	100.55	Poor	110.9	Poor
GW4	Sohsarai	51.02	Good	52.2	Good
GW5	Moghal Kua	48.6	Very Good	45.64	Very Good
GW6	Singar Hat	54.12	Good	57.41	Good
GW7	Badi Pahadi	51.42	Good	92.2	Good
GW8	Ramchandarpur	53.12	Good	80.9	Good
GW9	Gandhi Park	48.72	Very Good	60.23	Good
GW10	Nagar Nigam	58.34	Good	62.94	Good
GW11	Nalanda College	45.41	Very Good	48.34	Very Good
GW12	Baradari Masjid	47.42	Very Good	49.26	Very Good
GW13	Khandakpar	38.56	Very Good	56.25	Good
GW14	Sakunat devi asthan	45.56	Very Good	48.87	Very Good
GW15	Khairabad Boring	47.57	Very Good	56.91	Good
GW16	Mathuriya	60.77	Good	64.38	Good
GW17	Sogra College	49.91	Very Good	50.95	Good
GW18	Badi Dargah	47.56	Very Good	64.47	Good
GW19	Mangal Nagar	42.05	Very Good	49.86	Very Good

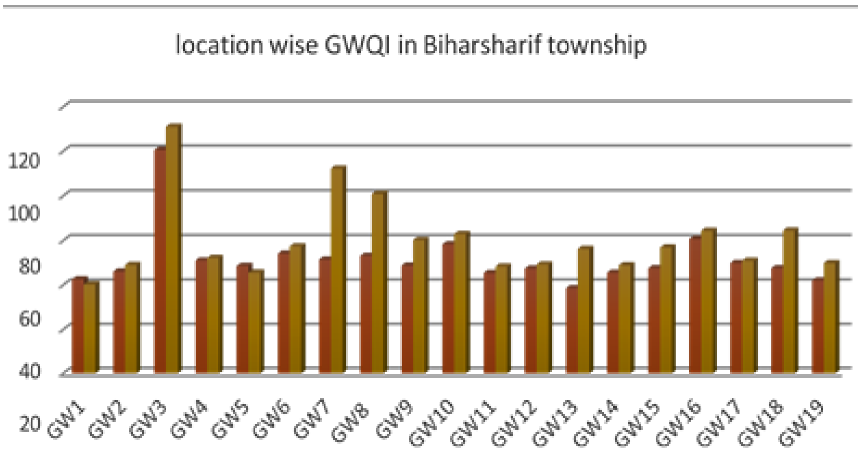

Figure 15: Pictorial Depiction of GWQI Values

Conclusion

This study presents a comprehensive assessment of groundwater quality in Biharsharif Township, with a focus on its vulnerability to water-related disasters such as floods and droughts. The findings reveal a concerning degradation of groundwater quality, with elevated levels of TDS, nitrates and microbial contamination in several locations particularly in areas with dense population and agricultural activity. Seasonal variation, especially in post-monsoon, further underscores the influence of surface water dynamics on subsurface water quality. The following conclusions were observed:

1. The physicochemical parameters for pre- and post-monsoon season were observed and WQI computed for 19 samples ranges was found to in the range of 38-111.
2. It has been observed that 89.5% of groundwater samples were found in very good to good water category around the study area and all the parameters are well within the acceptable limit prescribed by BIS (2012) for drinking water.
3. Only one sample of location GW3 from Khasganj has been observed to be of poor category showing that the water is not suitable for direct consumption and needs a degree of treatment before its utilization.
4. The pictorial depiction of GWQI clearly explains that the pre-monsoon values are much suitable for drinking purpose in most of the study area.
5. It was observed that the pollution after monsoon is more than that of pre-monsoon due to dilution effect of pollutant.
6. The TH, TDS, Chloride and Fluoride are found to be higher in post-monsoon water samples than the pre-monsoon water samples.
7. Continuous monitoring of groundwater in the city to protect water disaster in future from any possible contamination due to growth of population, urbanization and industrialization should be emphasized.

Floods could significantly exacerbate contamination through surface water intrusion into shallow aquifers. These dual threats necessitate disaster-resilient infrastructure such as elevated wells, improved drainage and protective aquifer barriers. Identifying waste disposal from different wards will help to enhance the water quality. So, proper inspection should be observed to lower groundwater levels to prevent uncontrolled sewage discharge.

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