RESEARCH ARTICLE

# Characteristics of Groundwater Quality in the Aquifer of Indo-Nepal Border of Balrampur City

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## Abstract

The study deals with the groundwater quality of aquifers at the foothills of Shivalik at the Indo-Nepal border of Balrampur. Here, the water samples were collected from those areas where industrial and municipal wastewater leachate were mixed with the groundwater. The groundwater is used as potable water for drinking and other purposes, like irrigation and farming. The analysis has been done especially during the summer and winter season. In this season, the groundwater quality is seriously affected by various types of pollutants that are discharged from industrial sources and leached down and mixed with the groundwater after percolation. The result shows that groundwater quality is affected by the continuous contamination of pollutants.


**Keywords:** Foothills, Groundwater, Leachate, Percolation.

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## Introduction

Life cannot exist without water because it is a major component of all living beings. It is important, both physiologically and economically, as it plays an essential role in temperature control and also is the medium, in which organisms exist. The rapid pace of industrialization in India has created problems with water. Therefore, the three types of water occur in nature, *i.e.*, surface water, rainwater, and groundwater. Rainwater and surface water are mostly running water and rarely used for commercial purposes. Groundwater is the primary source of potable water. Besides these, it is also used for domestic purposes. Groundwater is about 20% of the world's resources of freshwater and is used by industries. Only about 1% of all freshwater is available in rivers, ponds, and lakes. Only about 1% of all freshwater available in rivers, ponds, lakes, out of which 0.03%, water is required for the survival of many forms of animals and plant life on the earth's surface.

Over the last 150 years, there has been a growing intensification of agricultural activities in the Indo-Gangetic plains. This started with the introduction of large surface water irrigation in the 19th century and was followed by the introduction of agrochemicals in the mid 20th century and rapid growth in groundwater irrigation and urban development in the last 50 years. Groundwater dynamics reflect a complex natural process, which is influenced by various factors, *e.g.*, climate, geology, and topography (Wang *et al.*, 2012). Climatological conditions cause temporal fluctuations of groundwater to exhibit periodic and seasonal cycling (Yu *et al.*, 2016). Groundwater is now heavily exploited for irrigation, industry, and drinking water, and demands on this resource are increasing rapidly.

Chemical properties of groundwater can be used as environmental tracers to enable conclusions to be drawn about the water's origin, residence time, and hydro-geochemical evolution (Edmunds *et al.*, 2001). Groundwater cycles mainly occur in a vertical direction, with climatic (precipitation and evaporation) and human factors (surface water irrigation and groundwater exploitation) being considered factors of groundwater dynamics (Du *et al.*, 2013). For example, tracers, such as, major elements and ratios (*e.g.*, $NO_3$, Ca/Mg, $NO_3$/Cl, Cl, and Cl/Br) and trace elements, *e.g.*, Sr, Li, Rb, Mo, U, As, Zn, B) are used as tracers in hydro-geochemical investigations characterize anthropogenic and geogenic sources of contamination (Edmunds & Savage, 1991).

Groundwater depletion has been widely studied on the Indo-Nepal border, but water quality concerns are still poorly constrained. Salinity, nitrate, chloride, and lead concentrations are significantly higher in the shallow (0–50 meters) groundwater system due to anthropogenic contaminant loading from agricultural and urban sources. The widespread occurrence of groundwater with the aquifer system means that denitrification potential is limited and also enhances the mobility of selenium and uranium in groundwater. Groundwater is crucial for humans, especially in developing countries. The impact of groundwater use is positive and includes benefits, such as, increased productivity, food security, job creation, livelihood diversification, and general economic and social improvement. In the long run, the impact of groundwater extraction might be negative especially in overexploitation situations, such as, permanent lowering of the water table, deterioration of water quality, and saline intrusion in the coastal areas. Recent studies

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have mostly focused on long-term reduction in groundwater table because of global climate change, overexploitation, and other human activities. However, short- or mid-term fluctuations of the groundwater table attributed to climate variation are also a considerable problem (Apaydin, 2010).

The Indo-Nepal border aquifer is laid down in the Gangetic plain alluvium running across the border of Uttarakhand, U.P. and Bihar are under the safe category. It is largely recharged from the Bhabar zone of the Himalayan foothills, which is partly in the part of Nepal. Bhabar zone is generally permeable and unconfined in nature. Tarai zone is separated by the spring line from the Bhabar zone and consists of alternating layers of sand, silt, clay, and gravel deposits of varying thickness (Khan & Tater, 2006). The Tarai belt along with the Indo-Nepal border is known for its artesian condition for auto flowing wells, which forms extensive and profile aquifers.

## Materials and Methods

Barhni is a town and Nagar Panchayat in Siddharthnagar District in Uttar Pradesh, India. Barhni is situated near 27.4957°N and 82.7915°E with the GPS coordinates. It is situated at the Indo-Nepal border of India. We collect groundwater samples from different sites of the region which are given below:

a) Barhni Bazar,
b) Akrahra, and
c) Basantpur.

It is adjacent to the Nepal border from Krishnanagar. Nepalese and Indian nationals cross the border with no restrictions; however, there is a customs checkpoint for goods. Barhni is directly connected to Siddharthnagar, Gonda, Lucknow, Kanpur, and Kolkata.

## Result and Discussion

The analytical results of the groundwater of the present study are shown in Table 1 (physicochemical parameters of water samples). All the groundwater samples collected from drinking sources were compared with drinking water standard Bureau of Indian Standards (BIS)-10500 and World Health Organization (WHO) guidelines. Nepal has four major river systems with Mahakali as a westernmost border river with India. This river system has been poorly studied so far as its water quality is concerned. Only five sites were considered for water quality studies, which showed pollution levels from slight to moderate. The water chemistry of the Mahakali river at Pancheshwar has also been studied for pH, total dissolved solid (TDS), dissolved oxygen (DO), and biochemical oxygen demand (BOD) levels. It is very essential and important to test the water before it is used for drinking, domestic, agricultural, or industrial purposes. Water must be tested with different physicochemical parameters. Water does contain different types of floating, dissolved, suspended, and microbiological, as well as, bacteriological impurities. Some physical tests should be performed for testing of its physical appearance, such as, temperature, pH, turbidity, TDS, etc., while chemical tests should be performed for its BOD, chemical oxygen demand (COD), dissolved oxygen, alkalinity, hardness, and other characters.

### Temperature

In an established system, the water temperature controls the rate of all chemical reactions and affects fish growth, reproduction, and immunity. Drastic temperature changes can be fatal to fish. The rates of biological and chemical processes depend on temperature. Aquatic organisms from microbes

Table 1: Physicochemical parameters of water samples

| *Parameter* | *Unit* | *Standard limit* | *Site 1* | *Site 2* | *Site 3* |
|---|---|---|---|---|---|
| Temperature | °C | 40 | 27 | 29 | 30 |
| pH | - | 7 | 7.2 | 7.3 | 7.5 |
| Colour | Hazen | - | Transparent | Transparent | Light yellow |
| Odor | - | - | Odorless | Odorless | Odorless |
| Turbidity | NTU | 4 | 3.8 | 3.5 | 3.1 |
| Salinity | mg/l | 70 | 15 | 21 | 28 |
| Alkalinity | mg/L | 120 | 60 | 72 | 88 |
| EC | **μS/cm** | 40 | 180 | 240 | 230 |
| Total hardness | mg/L | 300 | 70 | 90 | 120 |
| Calcium | mg/L | 75 | 73 | 75 | 80 |
| TDS | mg/L | 500 | 58 | 65 | 70 |
| TSS | mg/L | 10 | 4.4 | 4.8 | 5.2 |
| COD | mg/L | 2.72 | 0.75 | 1.03 | 1.05 |
| DO | mg/L | 14.6 | 11.2 | 11.8 | 10.09 |
| BOD | mg/L | 30 | 16 | 20 | 22 |
| Nitrate | mg/L | 45 | 28 | 35 | 38 |
| Sulphate | mg/L | 200 | 74 | 120 | 140 |
| Phosphorous | mg/L | 0.3 | 0.75 | 0.83 | 0.85 |
| Sodium | mg/L | 200 | 30 | 42 | 58 |
| Chloride | mg/L | 250 | 120 | 140 | 160 |

to fish are dependent on certain temperature ranges for their optimal health. Temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases), the rate of photosynthesis by aquatic plants, the metabolic rates of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, and diseases. Causes of temperature change include weather, removal of shading stream bank vegetation, impoundments, discharge of cooling water, urban stormwater, and groundwater inflows to the stream (Spellman & Drinan, 2012).

## pH

The pH of water is governed by $CO_2$, $CO_3$, and $HCO_3$. pH is most important in determining the corrosive nature of water. The lower the pH value, the higher is the corrosive nature of water. The reduced rate of photosynthetic activity and the assimilation of carbon dioxide and bicarbonates are ultimately responsible for increased pH the low oxygen values coincided with high temperature during the summer month. Various factors bring about changes in the pH of water. The higher pH values observed suggests that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physicochemical condition. The pH of water samples of different sites is a bit variable. It ranges from 7 to 7.5. All the water samples were within the permissible limit for drinking prescribed by WHO (2011) and BIS (2012). The average value of pH indicates that groundwater is an alkaline type.

## Salinity

The salinity of groundwater is mainly influenced by the ion exchange process and seepage of agricultural fertilizers in the study area. But here, the use of fertilizers is less than other places, therefore, it ranges from minimum salinity is 15 and its maximum value is 28 mg/L.

## Alkalinity

Alkalinity refers to the capacity of neutralization of water. The bicarbonate contributes to the major portion of alkalinity. The bicarbonate concentration is due to the reaction of $CO_2$ with the soil and it releases bicarbonate into water (Tyagi *et al*., 2009). The alkalinity ranges from 60 to 88 mg/L. The bicarbonate concentration also depends on the oxidation and decomposition process.

## Electrical Conductivity (EC)

The EC is the amount of salts present in water. The EC value of water ranges from 180 to 240 mS/cm. Conductivity shows a significant correlation with parameters, such as, temperature, pH value alkalinity, total hardness, calcium, total solids, total dissolved solids, and chemical oxygen demand, chloride, and iron concentration of water. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water (Gupta & Paul, 2010). Streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Groundwater inflows can have the same effects depending on the bedrock they flow through. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity. Electrical conductivity is controlled by two main factors, which include rock water interaction and residence time of water in the rock (Eaton, 1950). The EC value of groundwater is generally varied from 2 to 10 times greater than the tank eater. An excess amount of EC in human beings causes gastrointestinal irritations (Singh *et al.,* 2008). According to WHO (2011) and BIS (2012) standard, the desirable limit for EC in drinking water is 1,500 mS/cm.

## Total Hardness

The total hardness of groundwater ranges from 70 to 120 mg/L. The alkaline earth metals, such as, calcium and magnesium in the groundwater are the reason for the hardness of water (Krishnakumar *et al.,* 2015). As per the WHO standard, the desirable limit is 100 mg/L and the allowable limit is 300 mg/L. Increased water hardness in health causes urolithiasis anencephaly, prenatal, mortality, cancer, and cardiovascular diseases (Durvey *et al.,* 1991; Agarwal & Jagetai, 1997). Excessive hardness of water causes yellowing of fabrics and forms scales in pipe, boilers, and water heaters, and too low hardness may also be corrosive.

## Biochemical Oxygen Demand (BOD)

The BOD is a measure of the dissolved oxygen consumed by microorganisms during the oxidation of reduced substances in waters and wastes. BOD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of the high BOD are the same as those for low dissolved oxygen aquatic organisms, which become stressed, suffocate, and die. Sources of BOD, include leaves and woody debris, dead plants and animals, animal manure, effluents from pulp and paper mills, wastewater treatment plants, feedlots and food-processing plants, failing septic systems, and urban stormwater runoff. The discharge of wastes with high levels of BOD can cause water quality problems, such as, severe dissolved oxygen depletion and fish death in the receiving water bodies (Penn, 2003). Chlorine can also affect BOD measurement by inhibiting or killing the microorganisms that decompose the organic and inorganic matter in a sample. In chlorinated waters, such as, those below the effluent from a sewage treatment plant, it is necessary to neutralize the chlorine with sodium thiosulphate (APHA, 2016).

## Chloride

Chlorine may be due to the natural and anthropogenic sources, which form the basis of chloride. The main source of chloride is due to sedimentary rocks (evaporates). The natural source, which includes, weathering leaching and anthropogenic activities that include inorganic fertilizers. Chloride is also due to seawater intrusion in the coastal area (Brien & Majewski, 2002). Chloride plays a vital role in indicating the pollution sources. Usually, the chloride greater than 100 mg/L will impart a salty taste to water. The desirable limit of WHO and BIS standards in drinking water is 250 mg/L. The highest value of chloride is 160 mg/L and the minimum value is 120 mg/L. Rainwater that leaches into groundwater is also the reason for the increase in chloride concentration of groundwater (Hounslow, 1995). An excess amount of chloride will retard plant growth. High chloride in water will corrode the metal pipes, through which water is transported.

## Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

The mineral concentrations dissolved in water determine the amount of dissolved solids in water. The lowest TDS value in the water sample is 65 mg/L and the highest TDS is 70 mg/L. The desirable limit prescribed by WHO is 500 mg/L, which is the same as BIS also. Agricultural activities and saltwater intrusion from the sea is the reason for the increase in TDS in the study area. The TDS concentration may also be increased due to the incursion of solid wastes. The domestic wastes from the houses also one of the reasons for the increase in the study area. TDS in water is due to its ability to dissolve minerals concentration during its course of flow in the soil profile or saturated zone since water is a universal solvent (Sankaran *et al.,* 2015). Solids are found in streams in three forms, suspended, volatile, and dissolved. Suspended solids include silt, stirred-up bottom sediment, decaying plant matter, or sewage-treatment effluent. Suspended solids will not pass through a filter, whereas dissolved solids will. The TDS concentration in a body of water is affected by various factors (APHA, 2016). Fertilizers from fields and lawns can add a variety of ions to a stream. Increases in TDS can also result from runoff from roads that have been salted in the winter. Organic matter from wastewater treatment plants may contribute to higher levels of nitrate or phosphate ions. If TDS levels are high, especially due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of animals. Volatile solids are those solids in water or other liquids that are lost on the ignition of dry solids at 1,020°F (550°C). It is a water quality measure obtained from the loss on ignition of total suspended solids. It has great importance in water and wastewater treatment. It normally represents the amount of organic solids in water. It helps assess the amount of biologically inert organic matter, such as, lignin in the case of wood pulping waste liquids. A volatile solid is a substance that can easily transform from its solid phase to the vapor phase without going through a liquid phase. In domestic wastewater, solids are about 50 percent organic, which in turn contaminates the ground and freshwater. These solids are generally from plants, dead animal matter, and synthetic organic compounds. They can be ignited or burned. Because the organic fraction can be driven off at high temperatures, they are called volatile solids.

## Sulfate

The sulfate ions usually occur in natural waters. Many sulfate compounds are readily soluble in water. Most of them originate from the oxidation of sulfide ores, the solution of gypsum and anhydrite, the presence of shale, particularly those rich in organic compounds, and the existence of industrial wastes. Sulfate present in the groundwater is due to both the natural and anthropogenic sources. Fertilizers' application to the irrigation field also results in an increase in sulfate concentration in the study area. A higher concentration of sulfate leads to respiratory problems in human beings (Rao, 1993). The minimum concentration is 74 mg/L and the maximum concentration is 140 mg/L. All the samples were analyzed within the limit prescribed by both the BIS (2012) and WHO (2011) standards.

Atmospheric sulfur dioxide formed by the combustion of fossil fuels and emitted by the metallurgical roasting processes may also contribute to the sulfate compounds of water. Sulfur trioxide ($SO_3$) produced by the photolytic oxidation of sulfur dioxide comes with water vapors to form sulphuric acid, which is precipitated as acid rain or snow. Sulfur-bearing minerals are common in most sedimentary rocks. In the weathering process, gypsum (calcium sulfate) is dissolved and sulfide minerals are partly oxidized, giving rise to a soluble form of sulfate that is carried away by water. In the humid region, sulfate is readily leached from the zone of weathering by infiltrating waters and surface runoff but in semiarid and arid regions, the soluble salts may accumulate within a few tens of feet of the land surface (APHA, 2016).

## Calcium

The cationic ion calcium concentration is mainly due to the weathering of rocks and minerals (Brindha & Kavitha, 2015). Calcium, in the form of the $Ca^{2+}$ ion, is one of the major inorganic cations, or positive ions, in saltwater and freshwater. It can originate from the dissociation of salts, such as, calcium chloride or calcium sulfate, in water. Most calcium in surface water comes from streams flowing over limestone, $CaCO_3$, gypsum, $CaSO_4 \cdot 2H_2O$, and other calcium-containing rocks and minerals. Calcium carbonate is relatively insoluble in water but dissolves more readily in water containing significant levels of dissolved carbon dioxide. The concentration of calcium ions ($Ca^{2+}$) in freshwater is found in a range of 0 to 100 mg/L, and usually has the highest concentration of any freshwater cation (Abboud, 2014). A level of 50 mg/L is recommended as the upper limit for drinking water. High levels are not considered a health concern; however, levels above 50 mg/L can be problematic due to the formation of excess calcium carbonate deposits in plumbing or decreased cleansing action of soaps. If the calcium ion concentration in freshwater drops below 5 mg/L, it can support only sparse plant and animal life, a condition known as oligotrophic. Typical seawater contains $Ca^{2+}$ levels of about 400 mg/L. It exists mainly in the form of bicarbonates and also in the form of sulfate and chloride. It is directly proportional to the hardness of water (Krishnakumar *et al.,* 2015). The calcium ranges between 73 and 80 mg/L. As per BIS (2012) standard classification, desirable limit for calcium is 75 mg/L. Excess calcium results in abdominal ailments and it causes encrustation and scaling.

## Sodium

Sodium is the dominant ion among the cations. The sodium concentration ranges between WHO (2011) prescribed the desirable limit sodium concentration in drinking water should be within 200 mg/L. The higher concentration of sodium causes heart diseases, nervous and kidney disorders. Increased sodium content in groundwater is mainly due to anthropogenic pollution, which prevails in the study area. Sodium plays a major role for irrigation purpose because plant growth is directly influenced by sodium concentration.

### Phosphorus

Phosphorus is an essential nutrient for the plants and animals that make up the aquatic food web. Since phosphorus is the nutrient in short supply in most freshwaters, even a modest increase in phosphorus can, under the right conditions, set off a whole chain of undesirable events in a stream including accelerated plant growth, algae blooms, low dissolved oxygen, and the death of certain fish, invertebrates and other aquatic animals. There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations. Phosphorus has a complicated story. Pure, “elemental” phosphorus (P) is rare. In nature, phosphorus usually exists as part of a phosphate molecule ($PO_4$). Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in a plant or animal tissue. Phosphate that is not associated with organic material is inorganic. Inorganic phosphorus is the form required by plants. Animals can use either organic or inorganic phosphate. Both organic and inorganic phosphorus can either be dissolved in the water or suspended attached to particles in the water column (Spellman, 2014).

### Nitrate and Ammonia

Both nitrate ($NO_3$-N) and ammonia ($NH_4$-N) concentrations are highly variable during lake seasonal cycles. For deep stratified lakes, nitrate is higher during mixing events and usually decreases in late summer and fall. For the trophogenic zone of shallow lakes, both concentrations would be lower during periods of water column stability and they will increase during vertical mixing events. $NH_4$-N is generated by heterotrophic bacteria as the primary nitrogenous end product of the decomposition of organic matter and is readily assimilated by plants in the trophogenic zone (Wetzel, 2001). $NH_4$-N concentrations are usually low in oxygenated waters of oligotrophic to mesotrophic deep lakes because of utilization by plants in the photic zone and nitrification to N oxidized forms. At relatively low dissolved oxygen, nitrification of ammonia ceases, the absorptive capacity of the sediments is reduced and a marked increase of the release of $NH_4$-N from the sediments then occurs.

## Conclusion

Although some parameters are within the desirable limit in the study, but water is unfit for drinking purposes. Temperature, salinity, alkalinity, turbidity $SO_4^{-2}$, $NO_3^-$, and $Na^+$ are within the limit, but $Ca^{+2}$ and EC levels are beyond the WHO permissible limit. The data indicate that chloride and EC contents were in the range of 120 to 160 mg/L and 180 to 240 mg/L, respectively. It was concluded that aquifiers of Indo-Nepal border are continuously contaminated through the industrial polutants.

Some effective initiatives are, therefore, required:

- Intensive chloride and EC in all existing hand pumps (both rural and urban).
- Establishing permanent quality surveillance/monitoring stations.
- Study to assess the risk of chloride percolation to deeper aquifers, if gets overexploited.
- Monitoring of ground water-based irrigation supplies.
- Evaluating prospects of bio-remediation for chloride removal.

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