Assessing Groundwater Level and Water Quality in Bhaktapur Municipality: A Pre-Monsoon and Post-Monsoon Analysis

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ABSTRACT

Groundwater is a crucial natural resource for sustaining human life, agriculture, and ecosystems worldwide. In many Asian countries, including Nepal, groundwater has emerged as a dependable source of water, particularly in areas where surface water is scarce or unreliable. For instance, in Bhaktapur Municipality (BM), Nepal, groundwater has been contributing around 50–60% of the total water supply. However, over the past few years, extensive extraction, alterations in the land use pattern, and other anthropogenic interventions have posed serious threats to this highly valuable resource. As such, groundwater monitoring is an essential primary step for understanding the status of the groundwater resource. Meanwhile, the Water Quality Index (WQI) is an effective tool that can turn complex water quality data into simplified information that is understandable and usable by the public. This study aimed to understand the groundwater levels and further comprehend the groundwater quality using the WQI of the BM. The groundwater level data and water samples were collected from 24 spatially distributed wells of the BM in the post-monsoon of 2021 and the pre- and post-monsoon of 2022. Laboratory analysis was carried out to determine the nine physico-chemical water quality parameters, and the obtained parametric values were compared with those of the World Health Organization (WHO) and the National Drinking Water Quality Standard (NDWQS). The results show deeper groundwater levels in the core area than the periphery, and the water quality getting poorer from post-monsoon 2021 to post-monsoon 2022. The EC, TDS, pH, phosphate, chloride, and hardness of most of the samples were within the permissible limits of

WHO and NDWQS, whereas the turbidity, ammonia, and alkalinity of many samples exceeded the permissible limits. Average WQI revealed that the majority of the samples were unsuitable for drinking and suitable only for household and irrigation purposes. This study provides insights into managing water demands, addressing issues of water scarcity, and highlighting the urgent need for additional research and policymaking to improve drinking water quality and the sustainability of groundwater management in BM.

Keywords: Groundwater, Drinking water, Water Quality Index (WQI)

Introduction

Water is essential for human survival and economic growth. While water is abundant on Earth, usable freshwater resources are relatively limited. Groundwater, which makes up 0.4% of the total amount of water on Earth, is the most accessible source of freshwater (Kemira Kemwater, 2003). Due to natural filtration and low levels of pollutants, groundwater is considered a reliable source of freshwater (Ganesh et al., 2018). However, overexploitation driven by increasing water demand has posed serious challenges to the sustainability of groundwater globally. Anthropogenic factors, such as the use of pesticides and agricultural fertilizers, sewage leakage, and waste disposal leaching, contribute to groundwater contamination (Wekesa & Otieno, 2022).

Situated among the majestic Himalayas, Nepal is bestowed with abundant water resources, including tremendous underground reservoirs that hold enormous potential. Groundwater plays an eminent role in meeting the water needs of both rural and urban communities, particularly in urban areas like Kathmandu Valley (KV), where surface water sources are limited or inaccessible (Margot and Gun, 2013). Groundwater extracted from wells and stone-spouts has been an important source of water in Kathmandu valley, providing 50-70 % of the total water supply and meeting the optimum requirements for drinking water (Chapagain et al., 2009). Groundwater is used for various purposes, including domestic use, agriculture, and industrial activities in KV (Karki et al., 2020). At present, the groundwater resources of KV face severe challenges both in terms of quality and quantity as a result of diverse anthropogenic interventions.

The groundwater resources in Bhaktapur Municipality (BM) of KV have experienced intensified degradation in both quantity and quality. This degradation has been attributed to factors such as extensive groundwater extraction, land use modifications, inadequate management practices, and various human activities (Ganesh et al., 2018). The daily groundwater extraction rate in Kathmandu valley was approximately 80 MLD in 2011 (Ganesh et al., 2018), and this figure is expected to rise further due to rapid population growth indicated by the National Population and Housing Census 2021. The changing land-use patterns have also hindered groundwater recharge, exacerbating the already critical issue of groundwater depletion. Additionally, mismanagement of wells and pollution contribute to the deterioration of groundwater quality. Furthermore, the lack of systematic and reliable information regarding well statistics, groundwater quality and quantity, current groundwater use practices, and aquifer types throughout the valley adds to the challenge (Pandey et al., 2010). Therefore, it is crucial to monitor groundwater and assess its quality and quantity in order to manage and use groundwater resources sustainably.

There are many approaches to assessing water quality. A comparative study of experimentally determined values for various water quality parameters with standard values can facilitate assessing the extent of deviation from the desired or safe levels. However, effectively conveying the outcomes of these analyses, including multiple water quality parameters, to the general public and policymakers can be challenging. In such a case, the Water Quality Index (WQI) is an effective tool that can provide a quantitative assessment of the overall quality of the water and its suitability for specific purposes or usage in a simplified manner that is understandable and usable by the public. WQI is a solitary number that rates the water quality by totaling different water quality parameters (Rao et al., 2019).

The objective of this study is to examine the spatial variation of groundwater levels in BM in relation to land use patterns. It aims to assess various physio-chemical water quality parameters and determine the degree of deviation from safe levels to identify potential health risks associated with BM's groundwater. Additionally, the study calculates the Water Quality Index (WQI) to evaluate its spatio-temporal variation and the suitability of groundwater for various uses.

2. Study Area

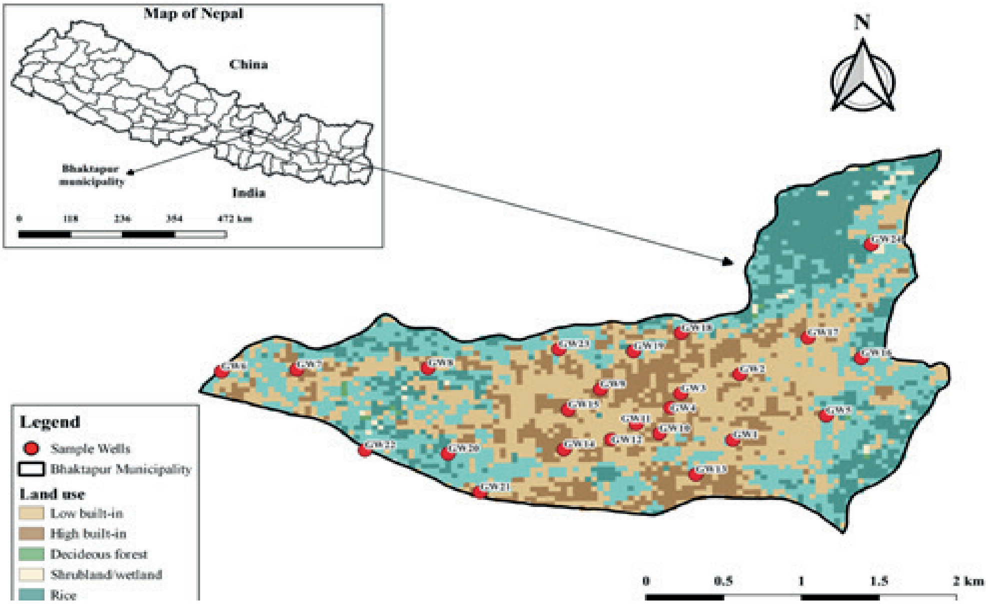

Figure 1. Study Area showing sample wells.

BM is one of the four municipalities of Bhaktapur district in central Nepal. It has an area of 6.9 km2, extending at the geographical coordinates of 85°21' - 85°31' E longitude and 27°36' - 27°44' N latitude (Kawan et al., 2019). The average altitude of BM is 1,400 m above sea level. The climate of BM is a monsoon-influenced humid subtropical climate, with mean daily temperatures ranging between 2 ˚C to 15 ˚C in winter and 19 ˚C to 27 ˚C in summer and an annual rainfall of about 1500 mm (Thakur et al., 2015). The geological structure of BM is characterized as weak, with numerous fault lines and a loose soil composition (Chapagain et al., 2010; Thakur et al., 2015). The soil of BM consists of sticky clay in the topsoil, along with coarse and fine sand, clay, cobbles, boulders, and pebbles on hard rocks such as granite, quartzite, and basalt (BDC, 2011). According to the National Population and Housing Census 2021, BM has a population of 79,136. The water sources in BM include Kathmandu Upatyaka Khanepani Limited (KUKL), rivers, tunchhi (wells), and hiti (stone-spouts). Ninety percent of households use tap water as the primary source of drinking water (Ganesh et al., 2018).

3. Materials and Methods

3.1. Groundwater Sampling

Samples were collected from 24 private or public wells in October 2021 (post-monsoon), May 2022 (pre-monsoon) and November 2022 (post-monsoon). The groundwater-level from ground level to water level was measured using a measuring tape. These data were recorded using an Android application called Open Data Kit (ODK) Collect. One liter water sample was collected for laboratory analysis for each well.

3.2. Determination of physio-chemical parameters

The physio-chemical parameters such as temperature, pH, EC and TDS were measured using sensor-based instruments in the field. Similarly, laboratory analyses for other parameters such as turbidity, ammonia, phosphate, alkalinity, chloride, and hardness were carried out in the S4W-Nepal laboratory. A turbidity meter was used for the determination of turbidity. Alkalinity was determined by titration of the samples with dil. HCl in the presence of phenolphthalein and methyl orange indicators. Chloride was determined by argentometric titration using a silver nitrate titrant. And hardness was determined by colorimetric titration with an EDTA solution. The phosphate and ammonia were tested using the ENPHO water test kit. The determined values of these parameters were compared with the guidelines set by WHO-2017 and National Drinking Water Quality Standards (NDWQS)-2005. Table 1 summarizes the measured categories of parameters and their permissible limits as published by WHO and NDWQS.

Table 1. Permissible limits of various parameters as per WHO-2017 and NDWQS-2005

Parameters	Units	Permissible limits		Measuring method (Silwal et al., 2021)
		WHO	NDWQS	
pH	-	6.5-8.5	6.5-8.5	pH meter
Turbidity	NTU	1.5	5(10)	Turbidity meter
TDS	mg/l	1000	1000	TDS-meter
EC	µS	-	1500	EC-meter
Hardness	mg/l as CaCO3	500	500	Colorimetric titration
Alkalinity	mg/l	100-300	500	Double end-point titration
Chlorides	mg/l	250	250	Argentometric titration
Ammonia	mg/l	1.5	1.5	ENPHO test kit
Phosphates	mg/l	1	-	ENPHO test kit

3.3. WQI calculation

The Weighted Arithmetic Index method (Brown et al., 1972) was used for the calculation of WQI. The steps for the calculation of WQI were as follows::

Firstly, the unit weight (Wn) factors for each parameter were calculated using the formula:

$$\text{Wn} = \frac{k}{Sn}$$

Where,

$$k = \frac{1}{\sum 1/Sn}$$

Sn = Standard desirable value of the nth parameter

On summation of all selected parameters unit weight factors, $\sum \text{Wn} = 1$ (unity)

Then, the Sub-index (Qn) value was calculated using the formula:

$$\text{Qn} = \left| \frac{Vn - Vi}{Sn - Vi} \right| \times 100$$

Where,

Vn = Measured value for the nth parameters

Sn = Standard desirable value of the nth parameters

Vi = Ideal value of the parameters in pure water, which is generally zero for most parameters except pH, i.e. 7

The overall WQI was calculated using the formula:

$$\mathrm{WQI} = \frac{\sum \mathrm{W}n \times Qn}{\sum \mathrm{W}n}$$

After determining the Water Quality Index (WQI) for each sample using the aforementioned method, the water quality was categorized into five ranks: excellent, good, poor, very poor, and unsuitable for drinking (Table 2). This categorization simplifies the assessment of overall water quality in each location.

Table 2. Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WQI value	Rating of water quality	Grading
0 - 25	Excellent water quality	A
26 - 50	Good water quality	B
51 - 75	Poor water quality	C
76 - 100	Very Poor Quality	D
Above 100	Unsuitable for intended purpose	E

4. Results and Discussion

4.1 Groundwater level

The groundwater levels represented by the map show similar spatial variation in both years. Variations in groundwater levels across the BM might be attributable to land use and population density (Ganesh et al., 2018). The average groundwater levels of the wells show that 62.5% of the sample wells have a water depth of 4 m below ground level, 29.17% have a water depth less than 8 m, and 4.17% have a water level greater than 8m below ground level. The groundwater level was deeper in the wells of the central part of BM, whereas a shallower groundwater level was observed around the periphery of the municipality. The deeper groundwater level in the core area with built-in land-use can be associated with sealed ground cover, reducing groundwater recharge and higher rate of groundwater extraction (Prajapati et al., 2021). Shallow groundwater levels were observed at wells located close to agricultural land, where there is more groundwater recharge and less impact from anthropogenic stresses.

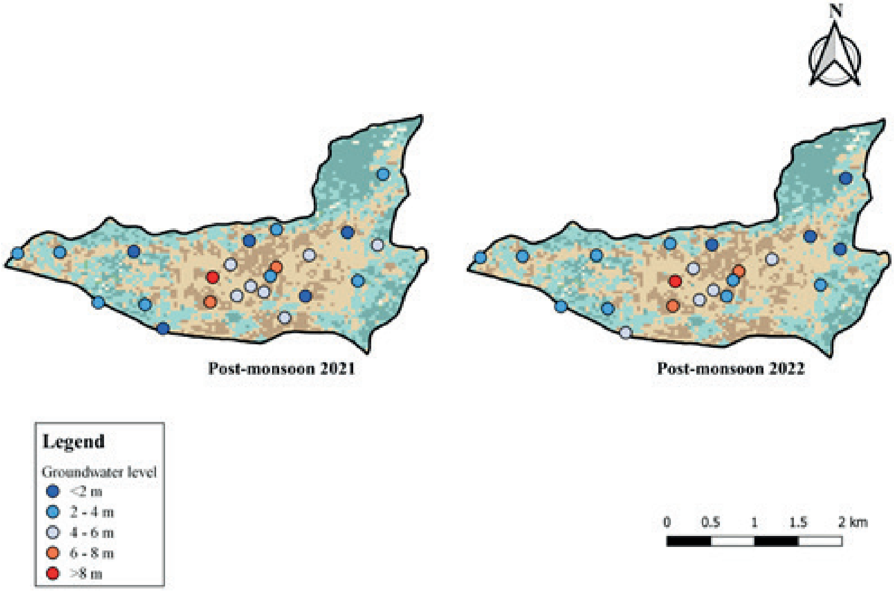

Figure 2. Spatial variation of groundwater levels in post-monsoon 2021 and post-monsoon 2022.

4.2 Water Quality Parameters

It was observed that the EC, TDS, pH, phosphate, chloride, and hardness of most of the samples were within the permissible limits of WHO and NDWQS, whereas the turbidity, ammonia, and alkalinity of many samples exceeded the permissible limits.

a. Hydrogen ion concentration (pH)

Water in its pure state is neutral, so the pH of water can indicate the presence of acidic or alkaline substances. The pH of the samples ranged between 7.9 and 6.11. The pH values in the pre-monsoon were higher in samples from the pre-monsoon of 2022, which might be due to the high temperature in the pre-monsoon (Rao and Krishna, 2019). The standard limits set by WHO and NDWQS for pH are 6.5–8.5. The distribution of pH values denoted that 47.83% of the groundwater samples were a bit acidic in the post-monsoon 2021, which tends to be corrosive in nature (Singh and Hussian, 2016). None of the samples from 2022 exceeded the standard limits.

b. Turbidity

Turbidity is caused by algae, particles of soil, metals, or organic or inorganic matter suspended or dissolved in water that scatter light, making the water appear cloudy or murky. The concentration of turbidity in the samples ranged from 0 to 62.8 NTU. 5 NTU is the acceptable turbidity as per NDWQS, and 10 NTU is the standard limit if an alternate source of potable water is unavailable. Most of the samples exceeded the permissible limits. 43.48%, 91.67%, and 33.33% of the samples exceeded the permissible limits in post-monsoon 2021, pre-monsoon 2022, and post-monsoon 2022. This must be due to the low volume of water in the pre-monsoon (dry season) and the higher concentration of dissolved or suspended particles (Pradeep et al., 2012).

c. Total Dissolved Solid (TDS)

TDS is the measure of the inorganic minerals such as bicarbonates, chlorides, sulfates, potassium, calcium, sodium, and their salts, along with some organic components, dissolved in water. The TDS of the samples ranged from 88 to 785 mg/l. The permissible limit for TDS set by WHO and NDWQS is 1000 mg/l, but TDS above 500 mg/l might cause undesirable taste and gastrointestinal irritation (Selvakumar et al., 2017). All the samples were found to be within the permissible limits of 1000 mg/l, but 26.09%, 20%, and 23.81% of samples had TDS above 500 mg/l in post-monsoon 2021, pre-monsoon 2022, and post-monsoon 2022, respectively. There was no drastic difference in the TDS of samples from post-monsoon 2021, pre-monsoon 2022, and post-monsoon 2022.

d. Electrical Conductivity (EC)

Electrical conductivity refers to the ionic strength of water and is an important factor in the quality of groundwater. Natural weathering and various anthropogenic sources can contribute to high EC. The EC of the analyzed samples over the study period ranged from 180 to 9444 µS. NDWQS has mentioned that the permissible limit of EC in drinking water is 1500 µS/cm. All the samples were within the standard limit in post-monsoon 2022, and only one of the samples in both post-monsoon 2021 and pre-monsoon 2022 exceeded the guidelines. The average EC of all the wells except one was within the permissible limit.

e. Total Hardness

The hardness of groundwater is mostly due to the occurrence of calcium and magnesium salts (Pant 2011). The hardness of the groundwater samples was between 0 and 452 mg/l. As per the WHO guidelines, water with a hardness between 0 and 60 mg/l is considered soft, 61 to 120 mg/l is moderately hard, 121 to 180 mg/l is hard, and above that is considered very hard water. The average hardness of the samples suggests that 12.5% of the wells had moderately hard water, 25% had hard water, and 62.5% had very hard water. According to WHO and NDWQS, the permissible limit of hardness for potable water is below 500 mg/l. Although none of the samples crossed the permissible level, very hard water might not be desirable for certain domestic uses due to its tendency to form scale deposits and difficulty in forming lather with soap (Rubenowitz and Hiscock, 2012).

f. Alkalinity

Alkalinity is a measure of water's ability to neutralize acids or resist changes that cause acidity, maintaining a stable pH. The presence of hydroxide, bicarbonate, and carbonate compounds of potassium, calcium, and sodium contributes to alkalinity (Devi and Prem Kumar, 2012). Total alkalinity between 90 and 740 mg/l. NDWQS has prescribed 500 mg/l as the permissible concentration for alkalinity in drinking water. 4.17% of the samples exceeded this limit in the post-monsoons of 2021 and 2022, and 8.33% of samples exceeded this limit in the pre-monsoon of 2022. WHO recommends alkalinity between 100-300 mg/l in drinking water. The average alkalinity of the samples shows that 29.67% of the wells exceed the WHO guidelines. High alkalinity in water can affect the taste of water and cause negative effects on human health, such as metabolic alkalosis (Rao et al., 2019).

g. Chloride

Chlorides are essential electrolytes that are necessary for balancing the quantity of cell fluids and maintaining blood volume and pressure (Rao et al., 2019). The chloride content in the samples was between 14.2 and 234.3 mg/l throughout the study period. NDWQS and WHO have set 250 mg/l as the standard limit for chloride. High concentrations of chlorides can make water saltier, and high chloride intake can result in hyperchloremia, hypertension, renal stones, and osteoporosis (McCarthy, 2004). The concentration of chlorides in none of the analyzed samples was greater than the permissible limits.

h. Ammonia

Ammonia is a common contaminant in groundwater that can result from the degradation of naturally occurring organic matter or anthropogenic sources. The ammonia content in the samples was between 0 and 3 mg/l throughout the study period. WHO and NDWQS have set 1.5 mg/l as the standard limit for ammonia. The existence of ammonia in water beyond this limit denotes organic pollution (Thakur et al., 2015). 66.67% of the samples exceeded the guidelines in post-monsoon 2021, whereas 41.67% exceeded the guidelines in pre- and post-monsoon 2022. Ammonia indicates organic pollution and is considered toxic for the human body (Thakur et al., 2015).

i. Phosphate

Dissolution of minerals in overlying soil, infiltration of agricultural fertilizers, and leakage of septic systems are the major sources of phosphates in groundwater (Fuhrer et al., 1999). The range of phosphate concentrations in the samples was found to be between 0 and 1 mg/l, which is not concerning because the WHO-permitted limit for phosphate is 1 m/l. NDWQS has not set any guidelines for phosphates. Lower concentrations of phosphate in water are not toxic, but extremely high concentrations of inorganic phosphates can cause digestive problems (Olanbiwonnu and Holden, 2018).

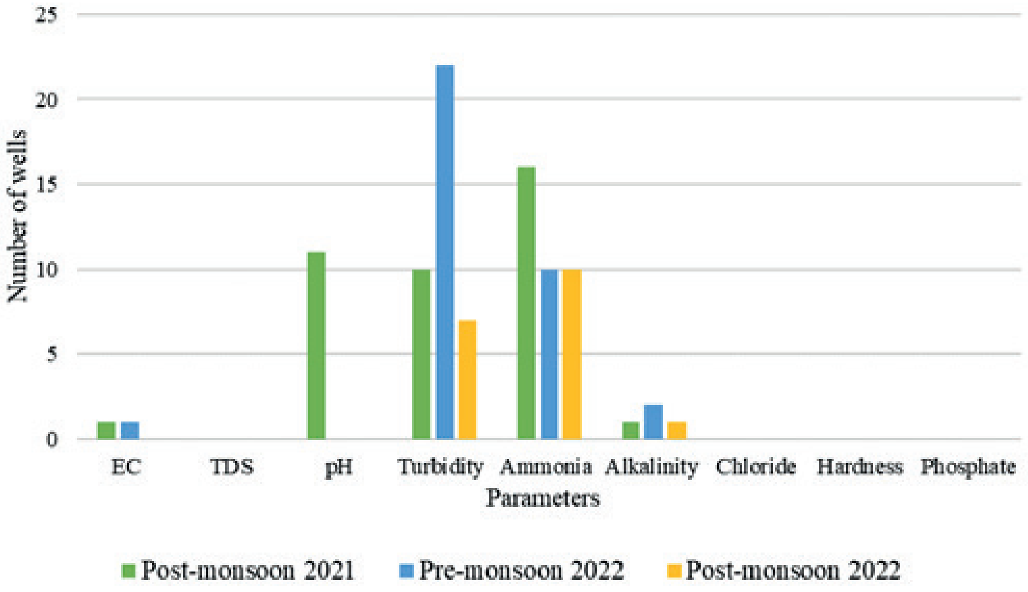

Figure 3. Number of wells that exceeded NDWQS guidelines.

4.4 Water Quality Index

The WQI values of groundwater from 24 monitoring sites during the period of study are represented in Fig. 4. The lowest WQI value, i.e., 13.39, was observed in site GW20 during pre-monsoon 2022, whereas the highest value, i.e., 1091.49, was found in site GW10 during post-monsoon 2022. The WQI values of the samples from pre-monsoon 2022 were comparatively lower than those of the samples from post-monsoon 2021 and 2022. This can be linked to the recharge of contaminants such as pesticides, fertilizers, and other chemicals from agricultural run-off and possible septic leakage during the wet season. Although there is a tendency for dilution of contaminants during post-monsoon, negative effects on the dilution occur in various chemical and nitrogen parameters during the wet seasons (Shakya et al., 2019).

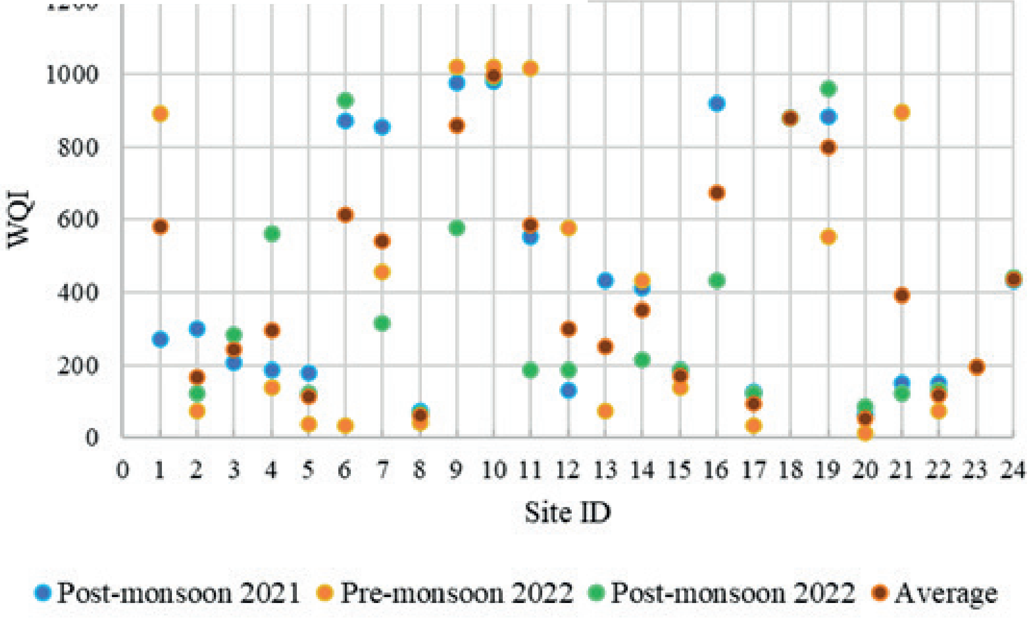

Figure 4. Temporal variations of WQI values in groundwater samples of study area during post-monsoon 2021, pre- and post-monsoon 2022, including average WQI values.

The WQI values in post-monsoon 2021 show that 21 wells had water in 'E' category, and the remaining had water in the 'C' category. In pre-monsoon 2022, one well had excellent water quality 'A', 4 wells had good water quality 'B', 3 wells had poor water quality 'C' and the remaining wells had water unsuitable for drinking 'E'. There was one well in the 'C' and 'D' categories each, and the remaining wells were in the 'E' category in post-monsoon 2022. The average WQI values of the sampling wells during the study period reveal that 22 wells fall under grade 'E', i.e., unsuitable for drinking. The remaining two wells were in category 'C', i.e., poor.

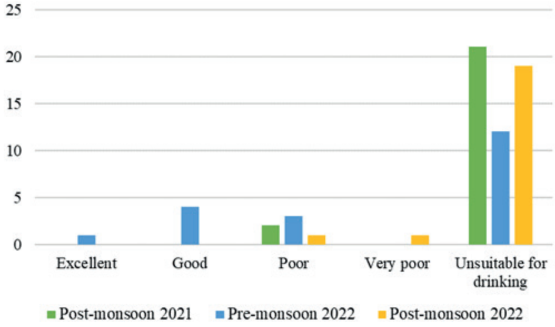

Figure 5. Water quality status of wells in BM during the study period.

Fig. 6 depicts the spatio-temporal variation of WQI in Bhaktapur Municipality over the duration of the study. Various factors such as altitude, soil type, land use patterns, groundwater use practices, and degree of contamination might be responsible for these variations (Silwal et al., 2021). The maps show that all the wells in the core area of the municipality had water unsuitable for drinking, i.e., in the 'E' category, throughout the study period. The poor water quality observed at these sites with built-in land use can be attributed to excessive groundwater extraction, infiltration of sewage into groundwater, and inadequate well maintenance (Kayastha et al., 2014). Similarly, two wells, GW7 and GW21, outside the core area fall in the 'E' category. These sites, characterized by a combination of built-in and agricultural land use, can be linked to sewage disposal, contamination from agricultural activities, and mismanagement of the well (Kayastha et al., 2014).

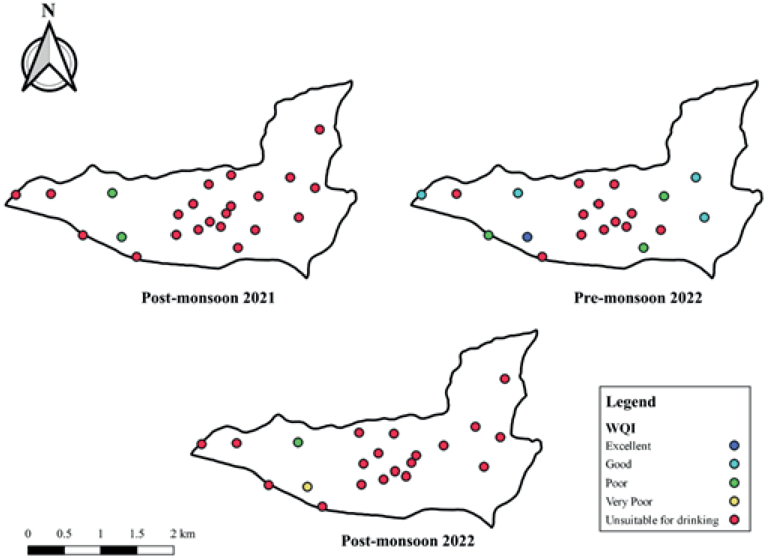

Figure 6. Spatio-temporal variation of WQI in BM during post-monsoon 2021, pre-monsoon 2022 and post-monsoon 2022.

This shows that the overall quality of groundwater in Bhaktapur municipality is not good. The increase in Water Quality Index (WQI) values in these areas is mainly due to human activities that negatively impact the water. These activities include leakages from sewage systems and septic tanks, inadequate upkeep and cleanliness of wells and nearby areas, excessive use of groundwater, runoff from urban areas, and the seepage of pollutants from agricultural activities (Thakur et al., 2015).

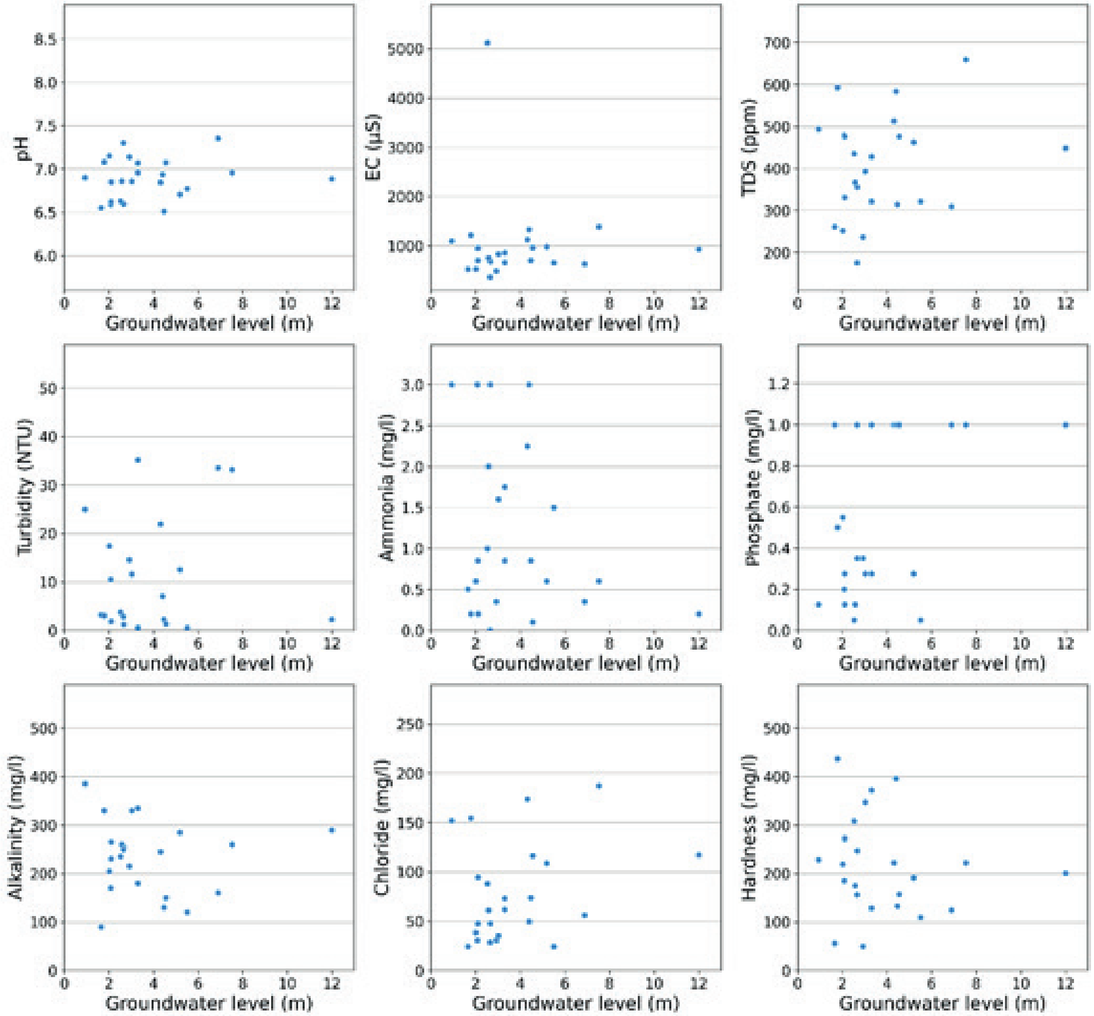

Figure 7. Scatter plot of average parameter values of each sampling site as a function of groundwater level (m)

Table 3. Correlation between water quality parameters and groundwater level

Parameters	Correlation with groundwater level
EC	-0.0402
pH	-0.2565
TDS	-0.1540
Turbidity	0.2433
Ammonia	0.1414
Phosphate	-0.3197

Alkalinity	-0.0620
Chloride	0.2091
Hardness (mg/l)	0.2954

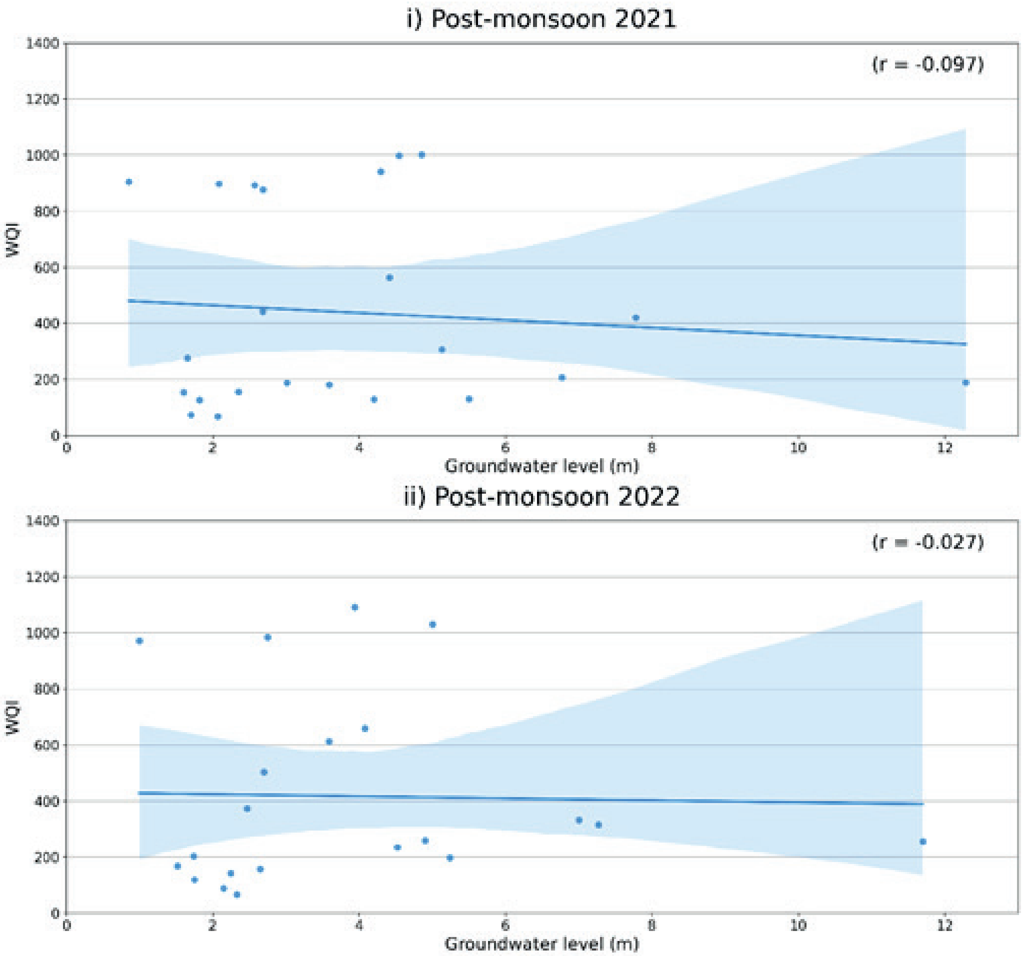

Figure 8. Regression plot of Water quality index values of each sampling site as a function of groundwater level (m) in post-monsoon 2021 and post-monsoon 2022.

The correlation between fluctuation of WQI values and the groundwater level from ground level to water i.e. -0.097 and -0.027 in post-monsoon of 2021 and 2022, respectively as showm in Figure 8. Therefore, there was a low negative correlation between watqr quality and water quantity.

5. Conclusions

The study provides an overview of the present condition of groundwater in BM. Deeper groundwater levels were found in the wells in the center of BM, while shallower levels were found in the periphery. Most of the samples' EC, TDS, pH, phosphate, chloride, and hardness were within the WHO and NDWQS guidelines; however, many samples had turbidity, ammonia, and alkalinity levels that were higher than the permissible limits. The WQI values indicate better water quality in the pre-monsoon than in the post-monsoon. Based on the average WQI values, the water from most of the sample wells was classified as unfit for drinking. The water quality index values were comparatively higher for the wells in the built-in areas. The water quality of Bhaktapur Municipality's groundwater has significantly deteriorated due to various human activities, making it unsuitable for consumption. The results of this study suggest the need for effective groundwater resource management strategies, including regular monitoring of the resource and protection of groundwater recharge areas. Furthermore, the study highlights potential measures to improve groundwater quality, such as preventing leakage from septic and sewage lines, reducing the use of chemical fertilizers in agricultural areas, and maintaining wells with proper sanitation. This research can serve as a valuable reference for developing management plans and conducting similar assessments in the future.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

Brown, R.M., McClelland, N.I., Deininger, R.A., & O'Connor, M.F., (1972). A water quality index—crashing the psychological barrier. In *Indicators of Environmental Quality: Proceedings of a symposium held during the AAAS meeting in Philadelphia, Pennsylvania, December 26–31, 1971* (pp. 173-182). Springer US.

Central Bureau of Statistics (2023) *National Population and Housing Census 2021 Results*.Thapathali, Kathmandu, Nepal: CBS Retrieved from https://censusnepal.cbs.gov.np/results

Chapagain, S. K., Pandey, V. P., Shrestha, S., Nakamura, T., & Kazama, F. (2010) Assessment of Deep Groundwater Quality in Kathmandu Valley Using Multivariate Statistical Techniques. *Water, Air, & Soil Pollution*. 210(1-4), 277–288. Available from DOI: 10.1007/s11270-009-0249-8. Retrived from https://www.researchgate.net/publication/227217168_Assessment_of_Deep_Groundwater_Quality_in_Kathmandu_Valley_Using_Multivariate_Statistical_Techniques

Department of Water Supply & Sewerage (2005). Ministry of Physical Planning and Works *National Drinking Water Quality Standards and Directives, 2005*. Maharajgung, Kathmandu, Nepal: DWSS Retrieved from https://doc-10-38-docs.googleusercontent.com/docs/securesc/f3775kt7rmtbtfoooc

Devi, S., & Premkumar, R. (2012), Physicochemical Analysis of Groundwater samples near Industrial Area, Cuddalore District, Tamilnadu, India. *International Journal of ChemTech Research* 4(1), 29-34.

Fuhrer, G.J., (1999). *The quality of our nation's waters: nutrients and pesticides,* Department of Interior.

Ganesh, R., Koju, R., & Prajapati, R. (2018). Assessment of Groundwater Quality and Water Table Mapping of Bhaktapur Municipality. *Journal of Science and Engineering*. 5, 43-50 URL: https://www.nepjol.info/index.php/jsce/article/download/22371/19043/70220

Gillberg, L., Hansen, B., Karlsson, I., Enkel, A.N., & Palsson, A. (2003). About water treatment. *Kemira Kemwater*, 171, pp.195-199. Retrieved from http://pages.kemira.com/rs/784-UGU-140/images/kemira-water-handbook-about-water-treatment-2020.pdf

Karki, S., Poudel, P. B., & Niraula, R. (2020). Groundwater availability, use and management in Bhaktapur Municipality, Nepal. *Journal of Hydrology: Regional Studies*, 30, 100733. Retrieved from https://doi.org/10.1016/j.ejrh.2020.100733

Kawan, C.K., Maskey, P.N., & Motra, G. (2019) Spatial Variation of Silt and Clay Sediment Deposit in Bhaktapur City. *Journal of Science and Engineering*. 7, 34-42 Retrieved from https://www.nepjol.info/index.php/jsce/article/download/26788/22162/80142

Kayastha, S.P. (2014) Heavy Metal Pollution of Agricultural Soils and Vegetables of Bhaktapur District, Nepal. *Scientific world*. 12(12), 48-55.

Margat, J., & Gun, J. V. D. (2013) *Groundwater around the World: A Geographic Synopsis*. E.H. Leiden, The Netherlands: CRC press Retrieved from https://books.google.com.np/books?hl=en&lr=&id=2qFWeXvPGVEC&oi=fnd&pg=PP1&ots=AvJbHLxdac&sig=e7XrX8pIS2MFpK7_2TlMtdtN8jg&redir_esc=y#v=onepage&q&f=false and https://sci-hub.st/10.1007/s12665-009-0263-6

McCarthy, M.F. (2004) Should we restrict chloride rather than sodium? *Med Hypotheses* 63, 138–148

Olanbiwonnu, T., & Holden, R.M. (2018). Inorganic phosphate as a potential risk factor for chronic disease. *Cmaj, 190*(26), E784-E785.

Pandey, V.P., Chapagain, S.K., & Kazama, F. (2010). Evaluation of groundwater environment of Kathmandu Valley. *Environ Earth Sci,* 2010, 1329–1342 Retrieved from https://sci-hub.st/10.1007/s12665-009-0263-6

Pant, B.R. (2011). Ground water quality in the Kathmandu valley of Nepal. *Environmental monitoring and assessment*, 178, pp.477-485. Retrieved from https://www.researchgate.net/publication/46382695_Ground_Water_Quality_in_the_Kathmandu_Valley_of_Nepal#:~:text=commercial%20fish%20food.-,...,the%20Kathmandu%20Valley.%20...

Pradeep, V., Deepika, C., Urvi, G., & Hitesh, S., (2012). Water quality analysis of an organically polluted lake by investigating different physical and chemical parameters. *Int. J. Res. Chem. Environ*, 2(1), pp.105-111.

Prajapati, R., Upadhyaya, S., Talchabhadek, R., Thapa, B.R., Ertis, B., Silwal, P. & Davids, J.C. (2021) Investigating the nexus of groundwater levels, rainfall and land-use in the Kathmandu Valley, Nepal. *ScienceDirect*. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352801X21000400

Rao, V.D., Rao, M.V.S., & Krishna, M.P.S. (2019). Evaluation of Groundwater Quality in Pre-monsoon and Post-monsoon Seasons of a Year Using Water Quality Index (WQI). *Rasayan J. Chem.*, 12(4), 1828-1838 Retrieved from https://rasayanjournal.co.in/admin/php/upload/777_pdf.pdf

Rubenowitz-Lundin, E., & Hiscock, K.M. (2012). Water hardness and health effects. In *Essentials of Medical Geology: Revised Edition* (pp. 337-350). Dordrecht: Springer Netherlands. Retrieved from https://www.researchgate.net/publication/278692828_Water_Hardness_and_Health_Effects

Selvakumar, S., Chandrasekar, N., & Kumar, G. (2017). Hydrogeochemical characteristics and groundwater contamination in the rapid urban development areas of Coimbatore, India. *Water Resources and Industry*, 17, 26-33.

Shakya, B.M., Nakamura, T., Kamei, T., Shrestha, S.D., & Nishida. K. (2019). Seasonal Groundwater Quality Status and Nitrogen Contamination in the Shallow Aquifer System of the Kathmandu Valley, Nepal. *Water* 2019, 11, 2184; doi:10.3390/w11102184

Silwal, P., Prajapati, R., Thapa, B.R., Talchabhadel, R., Kafle, A.S., & Davids, J.C. (2021). Assessment of groundwater quality by using Water Quality Index (WQI): A case study of Bhaktapur Municipality. *Bulletin of Nepal Hydrogeological Association*. 6, 43-62 Retrieved from https://www.researchgate.net/publication/354904339_Assessment_of_groundwater_quality_by_using_Water_Quality_Index_WQI_A_case_study_of_Bhaktapur_Municipality

Singh, S., & Hussian, A. (2016). Water quality index development for groundwater quality assessment of Greater Noida sub-basin, Uttar Pradesh, India. *Civil and Environmental Engineering*

Thakur, J.K., Diwakar, J., & Singh, S.K., (2015). Hydrogeochemical evaluation of groundwater of Bhaktapur Municipality, Nepal. *Environmental Earth Sciences*, 74(6), pp.4973-4988.

Wekesa. A.M., & Ontieo. C, (2022). Assessment of Groundwater Quality Using Water Quality Index from Selected Springs in Manga Subcounty, Nyamira County, Kenya. *The Scientific World Journal*, Retrieved from https://downloads.hindawi.com/journals/tswj/2022/3498394.pdf