GROUNDWATER QUALITY ASSESSMENT OF BHAKTAPUR MUNICIPALITY BY USING DRINKING WATER QUALITY INDEX

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Abstract— Groundwater is an important source of drinking water in the Kathmandu Valley as it contributes nearly 50-70% of the total water supply. Groundwater quality is mainly affected by the untreated/partially treated wastewater and excessive use of pesticides and fertilizers in agricultural areas. Therefore, monitoring of groundwater quality should be done regularly so that the associated risks from the pollutants can be identified and hence reduced. Water quality index (WQI) is one of the most effective ways for determining groundwater quality as it is a representative value reflecting the combined influence of various water quality parameters. The present study aims to develop WQI for assessing the groundwater quality of the Bhaktapur municipality. In order to achieve the aims, samples were collected from 25 wells of the Bhaktapur municipality during pre-monsoon, monsoon and post-monsoon period in 2018. The groundwater samples were subjected to a comprehensive analysis of 11 physico-chemical parameters including pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), total hardness, total alkalinity, chloride, phosphate, ammonia, iron, and nitrate. WQI was calculated by following the weighted arithmetic index method from the values obtained from the analysis of physico-chemical parameters. Furthermore, correlation matrix was formulated to determine the relationship between physico-chemical parameters. The WQI values ranged from 23.03 to 943.15 and the overall groundwater quality status of Bhaktapur municipality was found to be poor. The reasons for the poor quality of wells of Bhaktapur municipality may be due to septic contamination, agricultural percolation, construction and demolition activities and direct influx of rainwater in open wells.

Keywords: groundwater quality, Water Quality Index (WQI), physico-chemical parameters, correlation matrix, Bhaktapur municipality

I. INTRODUCTION

A. Background

Rapid population growth, urban sprawl, and increasing developmental activities are leading to increment in freshwater demand in the Kathmandu valley. The limited availability of surface water has increased the dependency of people towards groundwater resources [1]. Groundwater serves as the most important source of water in the Kathmandu Valley as it contributes around 50-70% of total water supply and satisfies the optimum requirements for drinking water [2] [17]. Unfortunately, the massive extraction of groundwater has led to an abrupt decline in groundwater level and deterioration of its quality [3]. The quality of groundwater is equally as significant as its quantity. The quality of groundwater depends on several factors including surface water, precipitation, geochemical processes, the composition of recharged water and seasonal variation [4] [15].The variations in water quality are indicated by its physical, chemical and biological conditions which are directly influenced by anthropogenic activities including untreated/partially treated wastewater, excessive use of pesticides and chemical fertilizers [5]. Deterioration of groundwater quality poses a significant threat to human health and other living organisms, economic development and social affluence. Therefore, monitoring of groundwater quality should be done regularly so that the associated risks from the pollutants can be identified and hence reduced.

Various studies regarding the assessment of groundwater quality have failed to deliver their results in an understandable way to the general public [6] [7]. Assessment of groundwater quality considering multiple physico-chemical and biological parameters would benefit from a single metric used to present the information in simple terms. Water quality index (WQI) provides a representative value reflecting the combined influence of various water quality parameters [8]. WQI aims to reduce the complexity of water quality data and present the information in a simple and understandable manner to the policymakers and concerned citizens. WQI also has some limitations as many basic microbiological parameters are usually not considered in this index [9] [16]. Few studies have, however, included E. coli and some faecal organisms in the WQI, but this condition is very rare [7] [10]. Despite its limitations, it is still regarded as an essential tool for determining the status of water quality in terms of physico-chemical parameters.

Likewise, in the Bhaktapur municipality, where most people depend on groundwater for domestic purposes, the extensive extraction of groundwater has put the sustainability of groundwater resources under severe threat. Also, there is a wide gap in understanding its overall quality. Therefore, the present study aims to develop WQI for assessing the groundwater quality and determine the suitability of water for drinking purpose in the Bhaktapur municipality.

B. Objectives

1. To determine a set of 11 different physico-chemical parameters (pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), total hardness, total alkalinity, chloride, phosphate, ammonia, iron and nitrate) and compare the parametric values with national standards/WHO guidelines.
2. To determine the correlation between those physico-chemical parameters.
3. To find the suitability of groundwater for drinking purpose in terms of Water Quality Index (WQI)

C. Limitations

1. Only 11 water quality parameters were considered.
2. None of the biological parameter could be included.
3. The results are site specific and hence can't be generalized.

II. MATERIALS AND METHODS

A. Study Area

Bhaktapur Municipality lies at 27°36'N to 27°40'N latitude, 85°21'E to 85°31'E longitude and 1401 meters above sea level. Administratively, it used to be there in Bhaktapur district in Bagmati zone in central development region of Nepal. And at present, it lies in Province number 3, is one of the four municipalities of Bhaktapur district (Figure 1). According to 2011 census, the population of 81,748 resides in 17,639 households in this municipality. The city is divided into ten wards and spreads over an area of 6.88 square kilometers. The mean daily temperature over this area ranges from 2°C to 15°C in winter and from 19°C to 27°C in summer. People of the municipality depends on wells, stone spouts, tube wells, and KUKL (Kathmandu Upatyaka Khanepani Limited) supply to fulfill their water needs. As per Diwakar et. al., (2008) there are 87 stone spouts, 220 wells, and 7207 piped lines servicing 185 public taps in the municipality.

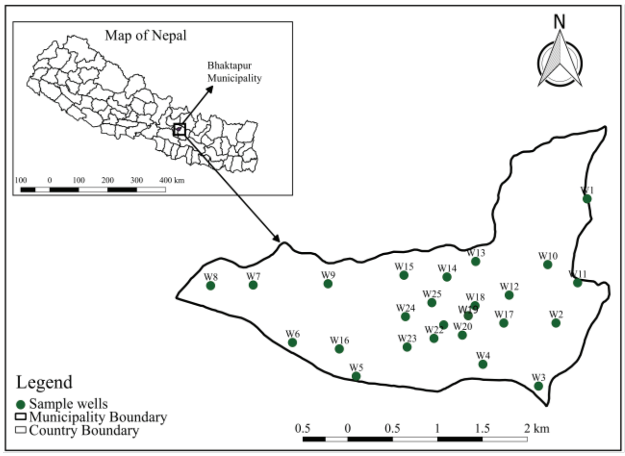

Fig. 1. Map of Study area with the locations of sample wells

B. Data Collection

To represent the entire municipality, 25 sample wells (both public and private) were selected considering the spatial coverage and the human settlements. The study was carried out in pre-monsoon (May), monsoon (July), and post-monsoon (November) of 2018. The physical parameters (pH, EC, TDS and Turbidity) were measured in the site itself with the help of respective meters as presented below in Table 1. And, for the chemical parameters (total hardness, total alkalinity, chloride, phosphate, ammonia, iron and nitrate), water samples were collected in plastic bottles of 1 liter. The samples were taken to the laboratory and chemical analyses were done within 24 hours. The concentrations of different chemical parameters were determined with the help of the drinking water quality kit of Environment and Public Health Organization (ENPHO). All the data were recorded in an android application called Open Data Kit (ODK) Collect and transferred to S4W-Nepal's server. For this, we used a customized ODK form that records date and time, Global Positioning System (GPS)location, value of each water quality parameter and respective images.

C. Data analysis

1. Comparison with the Standards

After measuring all the physico-chemical parameters, the obtained values were compared with National Drinking Water Quality Standard (NDWQS), 2005 and World Health Organization (WHO) standards. The standards for different water quality parameters and the recommending agencies are given below in Table 1.

2. Correlation Matrix

A correlation matrix was formulated by calculating the correlation coefficients of different pairs of parameters to determine the relationship between physico-chemical parameters i.e. whether the concentration of a parameter increases or decreases with the increase and decrease of another parameters.

3. Water Quality Index

The drinking water quality index (WQI) was also calculated. A water quality index, like other indices systems, relates a group of water quality parameters to a common scale and combines them into a single number in accordance with a chosen method of computation. The desired use of WQI is to assess water quality trends for management purpose even though it is not meant for an absolute measure of the degree of pollution or the actual water quality [11]. Application of WQI is a useful method in assessing the water quality. WQI was calculated considering all those eleven physico-chemical parameters using NDWQS-2005 and WHO standards by following the formula given by Brown et. al. (1972) [12] as follows and the status of water quality was classified as per Chatterjee & Raziuddin (2002), (Table 2).

$$WQI = \sum_{n=1}^{n} \mathrm{Wi} \times \mathrm{qi}$$

Where,
The unit weight factor (Wi) is calculated as
Wi = 1/11 = 0.0909
The quality rating qi is determined as follows:

$$qi = \frac{100\ (Vo - Vi)}{(\mathrm{Si} - \mathrm{Vi})}$$

Where,
Vo = Observed value of the nth parameters at a given sampling station
Si = Standard permissible value of nth parameter
Vi= Ideal value of the nth parameter in pure water
All the ideal values (Vi) are taken as zero for the drinking water except for pH = 7.0. The unit weights (Wi) for all the 11 chosen parameters are given in Table 1 below.

Table 1: Drinking water standards, recommending agencies and unit weights

S.N.	Parameter (unit)	Method of determination	Standard Value(Si)	Recommending Agency	Unit Weightage (Wi)
1	EC(µS/cm)	Honeforest TDS, EC & Temp meter	1500	NDWQS	0.0909
2	TDS (mg/L)		1000	NDWQS	0.0909
3	Alkalinity (mg/L)	Titration with 0.1N HCl	500	NDWQS	0.0909
4	Hardness (mg/L)	Environment and Public Health Organization's (ENPHO) Drinking Water Test Kit	500	WHO	0.0909
5	Chloride (mg/L)		250	NDWQS	0.0909
6	Nitrate (mg/L)		50	NDWQS	0.0909
7	Turbidity (NTU)		5 (10	NDWQS	0.0909
8	Phosphate (mg/L)		5	WHO	0.0909
9	Ammonia (mg/L)		1.5	NDWQS	0.0909
10	Iron (mg/L)		0.3 (3)	NDWQS	0.0909
11	pH	pH meter	6.5 - 8.5*	NDWQS	0.0909
				Total Weightage	1.0000

* These values show lower and upper limits.
( ) Values in parenthesis refers to the acceptable values only when alternative is not available.

NTU = Nephelometric Turbidity Unit
µS/cm = Microsiemens per centimeters
mg/L = Milligrams per Liter

NDWQS = Nepal's National Drinking Water Quality Standards 2005
WHO = World Health Organization's Drinking Water Quality Standards

Table 2: Water quality status based on WQI values (Chatterjee & Raziuddin, 2002)

S.N.	*WQI range*	*Water Quality Status*
1	0-25	Excellent
2	26-50	Good
3	51-75	Poor
4	76-100	Very poor
5	100 and above	Unsuitable for drinking

III. Results and Discussions

A. Comparision with the Standards

pH: The pH values for the collected samples ranged from 6.69 to 11.6 and values of seven and nine samples exceeded the NDWQS in pre-monsoon and monsoon respectively. The variation in pH of water does not cause severe health hazards, however, low pH induces the formation of toxic trihalomethanes, which are harmful [11]. It also plays an important role in the clarification process and disinfection of drinking water. For effective disinfection with chlorine, the pH should preferably be less than eight, however, lower-pH water (<7) is more likely to be corrosive. Failure to minimize corrosion can result in the contamination of drinking water and adverse effect on its taste and appearance [8].

Total dissolved solids: In the present study, the values of TDS ranged from 116 mg/L to 874 mg/L. TDS values of the samples were within the National standard. The presence of dissolved solids in water may affect its taste [8].

Electrical conductivity: Electrical conductivity is a parameter in water affected by the presence of dissolved ions. Significant changes in conductivity could then be an indicator that a discharge or some other source of pollution has entered in a stream [8]. In our study the values of EC ranged from 246 to 1863 µs/cm. The National standard being 1500 µs/cm, only one sample in pre-monsoon and four samples in monsoon exceeded the limit.

Turbidity: The values of turbidity ranged from 1 to 412 NTU. The permissible turbidity prescribed as a standard for drinking water is between 5 (10) NTU. The high value of turbidity in the samples may be due to septic contamination. Recent research establishes a correlation between gastro-intestinal infections with high turbidity [8].

Total hardness: In fresh water sources, hardness is mainly due to the presence of calcium and magnesium salts. Hardness values were recorded between 64 and 440 mg/L where all samples were within the limit. Temporary hardness more than 200 mg/L as CaCO3 may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings. Water with hardness less than 100 mg/l may, in contrast, have a low buffering capacity and will be more corrosive for water pipes [8].

Total alkalinity: Alkalinity in the groundwater may be present due to hydroxides, carbonates and bicarbonates and bicarbonate ions [8]. Total alkalinity values are within 20 to 1590 mg/L. Seven samples in pre-monsoon and eighteen samples in post-monsoon have exceeded the WHO standard. High values of total alkalinity in the samples might be due to septic contamination [8]. Alkalinity in itself is not harmful to human beings.

Chloride: The concentrations of chloride were found to vary within 0 to 196 mg/L. Though chloride concentration is high in groundwater, but it is within the permissible limit. Taste thresholds for the chloride anion depend on the associated cations and the concentration ranges from 200 to 300 mg/L for sodium, potassium and calcium chloride [8].

Ammonia: Ammonia of mineral origin is rare in natural water, but its presence is quite generally a result of natural degradation processes most inevitably ammonification of organic matter. According to Tamrakar and Shakya, (2013), sewage has large quantities of nitrogenous matter, thus its disposal tends to increase the ammonia content of the waters. The concentration of ammonia varied from 0 to 3 mg/L. The standard being 1.5 mg/L, two samples in monsoon and nine samples each in per-monsoon and post monsoon exceeded the limit.

Nitrate: Nitrate is found naturally in the environment and is an important plant nutrient. Some groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation. The values of nitrate in the samples ranged from 0 to 100 mg/L. Six samples in monsoon and three samples each in pre and post monsoon exceeded the standard limit of 50 mg/L. The presence of nitrate in drinking water is a potential health hazard when present in large quantities. The combination of nitrates with amines, amides, or other nitrogenous compounds through the action of bacteria in the digestive tract results in the formation of nitrosamines, which are potentially carcinogenic [8].

Phosphate: The phosphate is one of the limiting nutrients for plants whether free-floating algae or more substantial rooted weeds, but excess phosphate concentration causes eutrophication. The concentration of phosphate in the samples ranged from 0 to 1 mg/L. All the samples were within the limit of 5 mg/L. According to Rajbhandari (2005), the source of phosphate may be fertilizers, detergents, and other phosphorus compounds.

Iron: Iron is one of the most abundant elements of the rocks and soil, ranking fourth by weight. All kinds of water including groundwater have appreciable quantities of iron. The amount of iron present in the samples varied from 0 to 5 mg/L. 3 mg/L being the National permissible standard, only one sample was out of this limit in post monsoon. As per Tamrakar and Shakya, (2013), though this metal has got little concern as a health hazard but is still considered as a nuisance in exceeding quantities for domestic as well as industrial uses.

B. Correlation matrix

Table 3 shows the correlation between physico-chemical parameters of the groundwater samples. Among 11 different physico-chemical parameters, EC showed a perfect strong correlation with TDS as the value of correlation coefficient (r) was 1. This is because EC, the capacity of liquid to conduct electric charge directly depends on the concentration of dissolved ions, measured as TDS [13] [14]. Table 3 also explicit that there was no relation between Ammonia and Chloride (r=0) whereas there was a high negative correlation between chloride and pH (r= -0.36).

Table 3: Correlation matrix of the Physico-chemical parameters

Parameters	*pH*	*EC*	*Chloride*	*Iron*	*Turbidity*	*Nitrate*	*Phosphate*	*TDS*	*Ammonia*	*Hardness*	*Alkalinity*
pH	1										
EC	0.32	1									
Chloride	-0.36	-0.09	1								
Iron	-0.03	0.09	0.14	1							
Turbidity	-0.26	-0.08	0.32	0.52	1						
Nitrate	0.41	0.16	-0.11	-0.15	-0.21	1					
Phosphate	0.43	0.38	-0.28	-0.07	-0.22	0.40	1				
TDS	0.33	1	-0.09	0.09	-0.08	0.15	0.38	1			
Ammonia	-0.22	-0.12	0	0.03	0.28	-0.29	0.10	-0.12	1		
Hardness	-0.30	0.24	0.04	0.02	0.28	-0.19	-0.11	0.24	0.25	1	
Alkalinity	-0.27	-0.15	0.06	0.01	0.28	-0.32	-0.05	-0.15	0.41	0.45	1

C. *Water Quality Index*

In the present study, application of WQI gives a comparative evaluation of water quality at different sampling locations in different seasons of 2018. The water quality status of all the samples in different seasons of 2018 is presented below in Table 4. As per WQI results, 20 percent of the groundwater samples in pre-monsoon have good quality, 48 percent have poor quality and remaining 32 percent are unsuitable for drinking. Similarly, in monsoon 52 percent groundwater samples have good quality water, 36 percent have poor quality and remaining 12 percent wells have water which is unsuitable for drinking. And for post monsoon water samples from 48 percent wells are of good quality, 44 percent wells have poor quality water and the water of remaining 8 percent well is unsuitable for drinking. The WQI distribution of sampling wells in pre-monsoon, monsoon and post-monsoon of 2018 is presented below in figure 2.

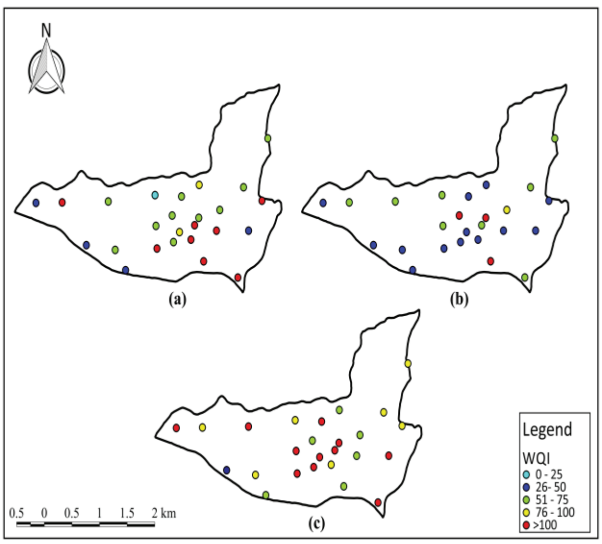

Fig. 2. WQI distribution of sampling wells in a) pre-monsoon, b) monsoon and c) post-monsoon of 2018

Table 4: Water quality status of the samples in different seasons of 2018

Season	Water Quality Status				
	Excellent	Good	Poor	Very Poor	Unsuitable for Drinking
Pre-monsoon	1	4	10	2	8
Monsoon	0	13	8	1	3
Post-monsoon	0	12	8	3	2

The different water quality status of the sampling wells can be attributed to the factors like septic contamination, agricultural percolation, construction and demolition activities and direct influx of rainwater in the open wells. And, seasonal fluctuation in water quality might be because the monsoonal water influx and the dilution effect.

IV. Conclusion

The drinking water quality index was calculated for the 25 wells from the Bhaktapur municipality for pre-monsoon, monsoon and post-monsoon period in 2018 considering a set of 11 physico-chemical parameters including pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), total hardness, total alkalinity, chloride, phosphate, ammonia, iron and nitrate. The parametric values were compared with NDWQS 2005 and WHO standards. All the samples (n=75) were found to be within standards for total dissolved solids, hardness and phosphate. The standards of pH, electrical conductivity, total alkalinity, ammonia, nitrate and iron were crossed by 16, 5, 25, 11, 9 and 1 samples, respectively. The overall groundwater quality status of Bhaktapur municipality was found to be poor. 1.33 percent of water samples have excellent water quality status, 38.67 percent have good quality, 34.67 percent have poor quality, 8 percent have very poor quality and remaining 17.33 percent water samples were unsuitable for drinking. Out of eleven parameters considered, electrical conductivity shows a perfect correlation (r=1) with total dissolved solids. The reasons for the poor quality of wells of Bhaktapur municipality may be due to septic contamination, agricultural percolation, construction and demolition activities and direct influx of rainwater in open wells. So cover systems and regular cleaning of the wells is recommended. The findings from our study may serve as an important frame of reference for future studies on the groundwater quality assessment of the study area.

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