Assessment of traditional dug well water of Lalitpur metropolitan city in pre-monsoon season

Sony Bajracharya*, Pawan Raj Shakya, Raihan Shrestha*, Nishana Shrestha*, Hrejon Tiwari*, Ajay Jha*, Achut Ram Pradhananga ** and Prem Kumar Shrestha ****

*Department of Zoology, Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

**Department of Chemistry, Padmakanya Multiple Campus, Tribhuvan University, Kathmandu, Nepal.

Abstract: Total 79 water samples were collected from dug wells located in five different municipal wards of Lalitpur Metropolitan City for assessment of water quality during pre-monsoon season. Physico-chemical parameters (temperature, turbidity, electrical conductivity (EC), pH, total hardness (TH), total alkalinity (TA), chloride, nitrate, ammonia and iron) and microbiological parameters (total coliform and protozoan parasites) were determined using standard protocols. The range and mean concentrations of the selected parameters in the water samples were found to vary among the selected wards under investigation. The physico-chemical parameters were compared with National Drinking Water Quality Standard (NDWQS) of Nepal and WHO standards. Parameters like pH, chloride, nitrate and iron were found within the permissible limits of NDWQS and WHO guidelines whereas parameter such as ammonia exceeded the maximum permissible limits. Turbidity, EC and TH however showed variable levels within NDWQS and WHO standards. Total coliform count showed only 4 (5.1%) of the total water samples were risk free whereas 43 (54.4%) samples demonstrated maximum microbial contamination and high risk level. Three types of protozoan parasites viz., Cyclospora, Cryptosporidium and Giardia were detected in the water samples. Among the five municipal wards, W. No. 16 has the highest percentage (66.7%) of total coliform contamination in dug wells. Pearson's correlation analysis was also performed to understand the relationships among the selected water quality parameters. Presence of total coliform and protozoan parasites and exceeding the maximum permissible limits by some physicochemical parameters shows the water quality of dug wells of Lalitpur Metropolitan City is not satisfactory. But, the quality can be improved by effective treatment technologies, planning and policies, strategies and management practices.

Keywords: Dug well water; Physico-chemical parameters; Total coliform; Protozoan parasites; Lalitpur metropolitan city.

Introduction

Well water comes from sources beneath the Earth's surface known as groundwater which covers 98% of the earth's available fresh water. Globally, people use about 321 billion gallons of surface water and about 77 billion gallons of ground water per day for human consumption[1]. Water supply from holy rivers, stone spouts and ancient wells also hold important cultural and spiritual meaning. Although many wells and stone spouts remain dried for several months in a year, many are still viable water sources, especially during the monsoon when water tables have risen. However, rapid urban development and an increasing reliance on groundwater are diminishing public water supplies like wells and spouts. This causes over-exploitation of groundwater storage, resulting in draw-down of the groundwater level and drying of water

Author for correspondence: Sony Bajracharya, Department of Zoology, Amrit Campus, Tribhuvan University, Kathmandu, Nepal.
Email: miss.sony.bajracharya@gmail.com

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resources[2]. Contamination of ground water supplies, on the other hand, is a concern that further restricts supply of water.

Well water is one of the most common routes for germs like coliform to enter the human body. Some of the pathogenic protozoan parasites such as *Giardia*, *Entamoeba histolytica*, *Cryptosporidium*, etc. may be present in well water due to contamination through improper management of solid wastes as well as domestic waste waters. It has been reported that the contaminated water is responsible for about 80% of all the diseases in human beings[3]. Since many people rely on groundwater, the traditional water supply system through dug wells, stone spouts and other sources needs to be preserved. Kathmandu Valley is reported to have the worst water supply system in Nepal.

The daily demand for water in the Valley is around 360 MLD but the supply is less than half, approximately 76 MLD in the dry season and 123 MLD in the rainy season. Consequently, groundwater has become a major natural resource contributing the water supply system in Lalitpur Metropolitan City (LMC). There are a number of dug wells in this metropolis which have gone dry or whose water levels have declined considerably in the alluvial and hard rock areas. The average lifespan of a well is 30-50 years, although they can last longer or shorter depending on different circumstances. Several studies have revealed both chemical and bacterial contaminations in groundwater in many areas of the Kathmandu Valley[4-7].

Particularly, the level of contamination in water increases during monsoon season. Under the given situation, standards and safety of drinking water have always become major concerns. Study on water quality assessment concerning the environmental and public health issues in Lalitpur Metropolitan City is scanty. This study therefore aimed to assess water quality status of dug wells located at different wards of LMC in pre-monsoon season and evaluate its suitability for drinking by comparing parameters with the standard value provided by National Drinking Water Quality Standard (NDWQS) and WHO guidelines.

Materials and methods

Study area and selection of sampling sites

Lalitpur Metropolitan City, historically well known as Patan, is the third largest city of Nepal after Kathmandu and Pokhara. It is located in the south-central part of Kathmandu valley which is a new metropolitan city of Nepal. The city has an area of 37.4 sq. km., 27° 40′ 0″ N latitude, 85° 19′ 0″ E longitude and 1325 m above the sea level. Climate is characterized by relatively high temperatures and evenly distributed precipitation throughout the year. The population density of the valley is only 97 per sq. km. and LMC has a population of 226,728 as of 2011 national census. It is best known for its rich cultural heritage, particularly its tradition of arts and crafts and is divided into 29 municipal wards. For the study purpose, preliminary information was gathered from Lalitpur Municipality regarding number of traditional dug wells distributed throughout the municipal wards of LMC. Among 29 municipal wards of LMC, 13 wards lie within the core area, i.e., ward; 6, 7, 8, 9, 11, 12, 16, 17, 18, 19, 20, 21 and 22. The LMC has a record of 346 traditional dug wells and a total of 270 within the core area alone[8,9]. Our field survey as well as interview with local respondents revealed that only five municipal wards *viz.*, 6, 7, 12, 16 and 19 (Figure 1) from the core area of LMC have an access to dug well water throughout the year. Hence, our study was confined to the above five municipal wards only. The number of traditional dug wells representing 6, 7, 12, 16 and 19 municipal wards were 11, 19, 17, 15 and 17 respectively. For the present study, a total of 79 dug well water samples from the above wards were, therefore collected during pre-monsoon season (March-April, 2020).

Sample collection and analysis

For analysis of physico-chemical parameters, water samples were collected from dug wells in well cleaned and washed PET bottles using buckets during early morning hours to avoid any kind of human disturbance. For microbiological parameters, 100 mL sterile bottles were used for sample collection. The aseptically collected water samples were well labeled and delivered immediately to the laboratories.

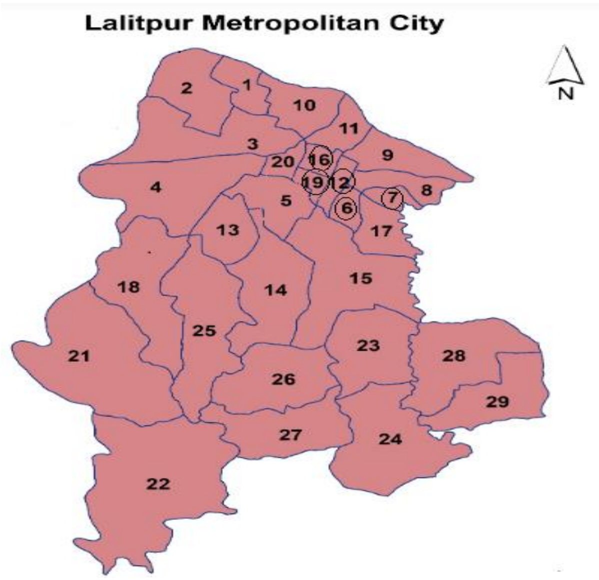

Figure 1: Location map of Lalitpur Metropolitan City showing sampling wards

The samples were quickly then analyzed for physio-chemical and total coliform count test and observations for protozoan parasites on the arrival to the laboratory. Some parameters such as pH, electrical conductivity (EC) and temperature were recorded in situ during sampling period. Similarly, parameters such as total hardness, chloride and total alkalinity were determined at Environmental Science lab, Padmakanya Campus, Bagbazar; while tests for turbidity, nitrate, ammonia and iron were performed at Aastha Scientific Research Services Pvt. Ltd., Dillibazar, Kathmandu as per the availability of lab instruments and facilities. Microbiological parameters such as total coliform and protozoan parasites were analyzed at Microbiology laboratory, Amrit Science Campus. The samples were preserved at 4^0C in a refrigerator when immediate analyses were not possible. All the collected samples were analyzed in triplicate. Precautions, preservation of water samples and standard methods for analyses of physico-chemical and microbial parameters were adopted following the protocols as described by Trivedy and Goel[10], APHA[11] and [c]Lopez, *et. al.*[12] as summarized in Table 1. Temperature and pH were analyzed by a mercuric thermometer and pH meter (Lutron pH-220) respectively.

Table 1. Materials/ Methods used for analyzing water quality parameters.

Parameter (unit)	Materials/ Methods
Physical	
pH	[a] pH meter
Temperature (^{0}C)	[a] Mercuric thermometer
Turbidity (NTU)	[b] Nephelometric method
Conductivity (µS/cm)	[a] Digital Conductivity meter
Chemical	
Total hardness (mg/L)	[b] EDTA titration
Total alkalinity (mg/L)	[b] Acid-base titration
Chloride (mg/L)	[b] Argentometric titration
Nitrate (mg/L)	[b] Brucine method
Ammonia (mg/L)	[b] Nesslerization method
Iron (mg/L)	[b] 1,10 phenanthroline method
Microbiological	
Total coliform (cfu/100mL)	[b] Membrane filtration technique
Protozoan parasites	[c] Routine parasitology method using light microscopy

[a] Trivedy and Goel[10]; [b] APHA[11]; [c]Lopez, *et. al.*[12]

Statistical analysis

Descriptive statistics such as frequency, percentage, range, mean and standard deviation were used wherever applicable. The correlations among the water quality parameters were also tested using Pearson's Correlation coefficient at significance level of $p<0.05$.

Results and discussion

Physico-chemical characteristics of dug well water

Table 2 shows the mean and range of all tested water samples and the values compared against NDWQS[13] and WHO[14] guidelines for evaluating drinking water quality.

Table 2. Physico-chemical characteristics of dug well water samples from five different wards of LMC (Mean ± SD).

Parameters (Unit)		Sampling sites					NDWQS	WHO
		W. No. 6 (n=11)	W. No. 7 (n=19)	W. No. 12 (n=17)	W. No. 16 (n=15)	W. No. 19 (n=17)		
Temp. (˚C)	Range	16.0 – 17.3	16.4 – 18.5	17.0 – 18.3	18.0 – 19.1	14.9 – 17.5	–	–
	Mean	16.9 ± 0.6	17.3 ± 0.8	17.5 ± 0.6	18.7 ± 0.5	15.7 ± 1.5		
Turbidity (NTU)	Range	4.8 – 5.9	1.5 – 5.0	1.2 – 5.5	0.8 – 1.2	1.3 – 5.8	5 (10)	5
	Mean	5.3 ± 0.5	3.18 ± 1.8	3.0 ± 1.8	1.0 ± 0.2	2.6 ± 2.1		
EC (µS/cm)	Range	689 – 891	826 – 2010	328 – 984	656 – 737	638 – 830	1500	800–1000
	Mean	777 ± 98	1477 ± 501	726 ± 293	695 ± 34	725 ± 79		
pH	Range	6.6 – 7.3	6.4 – 7.0	6.3 – 6.7	6.3 – 6.5	6.7 – 7.0	6.5 – 8.5	6.5– 8.5
	Mean	6.9 ± 0.3	6.7 ± 0.3	6.4 ± 0.2	6.4 ± 0.1	6.9 ± 0.1		
T. Hardness (mg/L)	Range	112 – 180	128 – 198	80 – 230	114 – 128	130 – 178	500	80–120
	Mean	160 ± 33	173 ± 31	147 ± 63	121 ± 6	148 ± 21		
T. Alkalinity (mg/L)	Range	20.0 – 24.4	18.0 – 40.0	12.2 – 14.9	24.0 – 27.8	24.0 – 28.0	–	–
	Mean	23.2 ± 2.1	25.6 ± 10.3	13.7 ± 1.1	25.4 ± 1.8	29.4 ± 6.0		
Chloride (mg/L)	Range	56.8 – 78.1	28.4 – 99.4	49.7 – 78.1	42.6 – 78.1	63.9 – 71.0	250	250
	Mean	65.7 ± 10.7	69.2 ± 33.0	63.9 ± 13.0	62.1 ± 15.7	67.5 ± 4.1		
Nitrate (mg/L)	Range	20.2 – 28.7	22.0 – 27.5	26.2 – 36.3	26.4 – 42.9	27.4 – 34.1	50	50
	Mean	23.2 ± 3.8	24.6 ± 2.4	30.0 ± 4.4	36.7 ± 7.2	30.0 ± 3.0		
Ammonia (mg/L)	Range	1.48 – 1.67	1.89 – 4.45	0.08 – 8.38	1.59 – 1.78	1.45 – 10.47	1.5	1.5
	Mean	1.58 ± 0.08	2.97 ± 1.10	2.24 ± 4.07	1.66 ± 0.08	4.52 ± 4.11		
Iron (mg/L)	Range	0.05 – 0.19	0.10 – 0.24	0.04 – 0.27	0.04 – 0.07	0.09 – 0.28	0.3	0.3
	Mean	0.10 ± 0.06	0.20 ± 0.06	0.11 ± 0.11	0.06 ± 0.01	0.19 ± 0.08		

Temperature: In the present study, mean temperature of water samples in situ was recorded maximum (18.7 ˚C) at W. No. 16 and minimum (15.7 ˚C) at W. No. 19. The pleasant taste of water may be affected by temperature parameter as well as dissolution of CO_2 and other gases[15]. Although there is no NDWQS and WHO guideline values available for temperature, a range of 7 – 11 ˚C has pleasant taste and more palatable than warm water[16].

Turbidity: The water samples from 7, 12, 16 and 19 W. Nos. showed the turbidity levels within the acceptable limits as per NDWQS and WHO guidelines. Water samples from W. No. 6 however showed a turbidity range of 4.8 – 5.9 NTU and its mean value (5.3 NTU) slightly crossed WHO standard. High turbidity was also reported in studies conducted earlier drinking water quality of Kathmandu Metropolitan City[17-19]. Turbidity is an important indication of particulate matters present either in suspended or dissolved form. The particles may include sediments particularly algae, microorganisms, slit and clay, and other inorganic as well as organic matter[10]. Several disease-causing agents such as parasites, bacteria and viruses may provide indication for turbidity in water.

Electrical conductivity (EC): EC values in dug well water samples from W. Nos. 6, 12, 16 and 19 were found within NDWQS and WHO guidelines but W. No. 7 exceeded WHO guideline with its mean level of 1477 µS/cm in the water samples. In this ward, the EC range was found between 826 – 2010 µS/cm as maximum in consistent with the findings of Bajracharya *et al*.[17], Tamrakar and Shakya[18] and Shakya *et al*.[19] who also reported higher EC values in their studies. The EC value measures ionic mobility in water. Inorganic materials and other salts in dissolved state are responsible for electrical conductivity of water.

pH: Results revealed that the mean pH values of dug well water from all the five wards were found to be slightly acidic but within NDWQS and WHO standards. This means that the water samples showed the acceptable level of pH in consistent with the findings of Tamrakar and Shakya[18] and Tamrakar[20]. The acidity of water is more commonly due to CO_2. This increases carbonic acid and decreases water pH. Besides, a large variety of domestic and industrial discharges that contain considerable amount of acids, alkalis, bleaching materials, heavy metals, detergents etc., also alter the pH of receiving water[10]. Besides, the fluctuation in pH levels may be attributed to respiration and photosynthetic activities in water body.

Total hardness: All the five wards showed total hardness of dug well water samples within the maximum permissible level of NDWQS but crossed WHO standard range. The mean level of hardness (173 mg/L) and range (128 – 198 mg/L) were recorded high in W. No. 7. Similar findings were also reported in well water samples from Kathmandu[19]. Hardness of water is caused due to calcium and magnesium ions. Human diets also need the same elements which may be fulfilled to extent by drinking hard water, but no health effect has been reported so far due to hardness of water. However, very hard water creates problem in human health as its presence helps organisms to live comfortably in water.

Total alkalinity: Alkalinity of water is mainly due to hydroxide, carbonates and bicarbonates[21]. Among the tested water samples, the total alkalinity of dugwell water was found high in W. No. 19 and low in W. No. 12. Although NDQWS and WHO standards for this parameter are not available, the amount of alkalinity for typical drinking water should be in the range of 20-200 mg/L. So far there is no health concerns related to alkalinity; however, water less than 150 mg/L alkalinity is more likely to be corrosive and greater than 150 mg/L may contribute to scaling.

Chloride: The concentrations of chloride in dug well water from all the five wards under investigation were found well below the maximum permissible limits as per NDWQS and WHO standards. Chlorides occur in all-natural water system as NaCl, KCl and $CaCl_2$ in varying concentrations. They can be an indicator of pollution and are important in detecting the contamination of groundwater by sewage. Agricultural runoff containing inorganic fertilizers, animal feeds, septic tank effluents, domestic wastewater etc., are some of the notable sources of chloride contamination in ground water[22]. Human excretes chloride in the form of urine in an average of 6 g per person per day and increases the amount of chloride in municipal wastewater and the receiving groundwater[15].

Nitrate: The nitrate content in the tested dug well water from all the five wards was found below the maximum permissible limits of NDWQS and WHO standards in consistent with the findings of Shakya *et al.*[19] and Diwakar *et al.*[23]. Sources of nitrate may include sewage disposal system, septic tanks, industrial and municipal wastewater, refuse dumps, animal feeds, decaying plant debris and urban drainage. They can also be contaminated into surface or groundwater directly from agriculture runoff containing nitrate in fertilizer[24]. Nitrate is often considered as a contaminant in drinking water (primarily from groundwater and wells) since it brings about harmful biological effects. The oxygen carrying capacity of blood in human may be reduced by high nitrate concentration in water, causing methemoglobinemia. Gastric and intestinal cancer has been reported due to nitrate[25].

Ammonia: Among the tested dug well water samples, W. No. 19 recorded high (4.52 mg/L) and W. No. 6 low (1.58 mg/L) ammonia content. However, this parameter exceeded both NDWQS and WHO guidelines in all the five wards under study. High concentration of ammonia was also reported in the previous studies conducted in Kathmandu valley[17, 26, 27].

Ammonia in higher concentration is often harmful to aquatic animals, biota as well as human health. Water contaminated with ammonia only indicates the recent pollution due to sewage. While the nitrite with ammonia indicates the lapse of sometime for the occurrence of pollution, only nitrate form indicates that all nitrogenous matter has been oxidized. Bacteria can oxidize ammonia to nitrite (NO_2^-) and nitrate (NO_3), and finally used by plants. This gaseous compound in nitrite (NO_2^-) form is more toxic than nitrate (NO_3^-) [25].

Iron: Results revealed that iron content in dug well water from all the five wards did not cross the acceptable limits of NDWQS and WHO standards in contradiction with the findings of Bajracharya *et al.*[17], Tamrakar and Shakya[18] and Pant[28] who reported high iron content in groundwater samples of Kathmandu Valley. Iron is present in nature such as in rivers, lakes and groundwater, soil, sediments and rocks. Iron can promote undesirable bacterial growth in water containing dissolved CO_2[22]. It can develop slimy coating on pipes and screen and clog them. In addition, it can leave water with an unpleasant taste and odor and can even leave brownish stains on laundry, and fixtures with reddish-brown particles. Although iron has got little concern as a health hazard but still considered as a nuisance in excessive quantities.

Table 3 shows microbiological characteristics of dug well water and their contamination ranges and risk levels ward-wise.

Microbiological characteristics of dug well water

Total coliform: As for the microbial contamination range and risk level based on total coliform count, only 4 (5.1%) of the total tested samples were found risk free as per NDWQS and WHO standards of which 1 (5.3%), 1 (5.9%) and 2 (11.8%) were contributed by W. Nos. 7, 12 and 19 respectively. This means that only 4 (5.1%) of the total water samples was found total coliform count negative and safe as per NDWQS and WHO standards for microbial contamination. Of the total water samples, 43 (54.4%) samples demonstrated high risk levels, the highest percentage (66.7%) being contributed by W. No. 16 followed by W. Nos. 7 (57.9%), 6 (54.5%), 12 (52.9%) and 19 (41.2%) respectively. Results revealed the risk levels by number and percentage of the tested water samples in the order of high risk > intermediate risk > very high risk > low risk > risk free. The results are in agreement with Diwakar *et al.*[23], Pant[28], Prasai *et al.*[29] and Koju *et al.*[30] who also reported microbial contamination in water from different sources such as tap water, stone spout, well, tube well water exceeding both National and WHO standards. Bacteria belonging to coliform group are often used as indicator of fecal contamination in water quality assessment. Fecal matter is the potential source of microbial contamination in surface and groundwater. Fecal matter in water can seep into water sources like spring, dug well, tube well, stone

Table 3. Number and percentage (in parenthesis) of dug well water samples ward-wise showing microbial contamination range and risk levels based on total coliform count (cfu/100ml)

*Microbial contamination ranges /Risk level	W. No. 6 n=11	W. No. 7 n=19	W. No. 12 n=17	W. No. 16 n=15	W. No. 19 n=17	Total n=79
0/ risk free	0	1 (5.3)	1 (5.9)	0	2 (11.8)	4 (5.1)
1-10/Low risk	1 (9.1)	2 (10.5)	1 (5.9)	0	2 (11.8)	6 (7.5)
10-100/Intermediate risk	3 (27.3)	3 (15.8)	6 (35.3)	3 (20)	4 (23.4)	19 (24.1)
100-1000/High risk	6 (54.5)	11 (57.9)	9 (52.9)	10 (66.7)	7 (41.2)	43 (54.4)
> 1000/ Very high risk	1 (9.1)	2 (10.5)	0	2 (13.3)	2 (11.8)	7 (8.9)
Total	11 (100)	19 (100)	17 (100)	15 (100)	17 (100)	79 (100)

*Diwakar, *et.al.*[23]

spout etc., which may pollute not only aquatic environment but also affect human health by water borne diseases like cholera, hepatitis, typhoid fever, dysentery, gastroenteritis etc[31]. Besides, the unrepaired old pipeline systems, irregular supply of drinking water in the pipeline, improper drainage system, pipeline leakage and untreated water sources are some of the principal reason of microbial contamination in water sources affecting drinking water quality[10] of the study area as well.

Protozoan parasites: Table 4 shows protozoan parasites in dug well water samples from all the five municipal wards of Lalitpur Metropolitan City. In the present study, altogether three types of protozoan parasites *viz.*, *Cyclospora*, *Cryptosporidium* and *Giardia* were detected, and their images are presented in Figure 2. Among the wards, only W. No. 19 showed all the three parasitic species in its water samples. Haramoto[32] also detected *Giardia* and *Cryptosporidium* parasites in groundwater of Kathmandu Valley while Lopez *et al.*[12] found *Cyclospora* in community consuming groundwater in Haiti. Higher percentage of positive cases of parasitic infections was found in children who used well water, mixed sources, municipal water and hand pump water. Comparison of infection rate between protozoa and helminth showed protozoan parasites infecting more children[33]. Protozoan parasites are the causative agents for suffering various diseases in the host body. The presence of protozoan parasites may be due to contamination through improper management of solid wastes, sewage disposal as well as domestic waste waters.

Table 4. Protozoan parasites observed in some representative water samples ward-wise.

Protozoan parasites	W. No. 6	W. No. 7	W. No. 12	W. No. 16	W. No. 19
Cyclospora sp.	(+)	(+)	(-)	(-)	(+)
Cryptosporidium sp.	(-)	(+)	(-)	(-)	(+)
Giardia sp.	(+)	(-)	(+)	(+)	(+)
(+): Presence; (-): Absence					

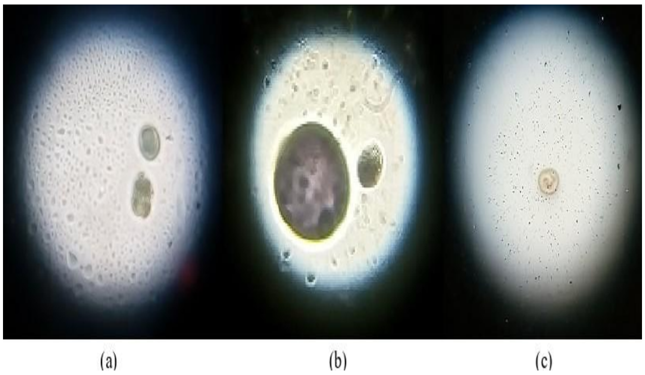

Figure 2: Images showing protozoan parasites a)Oocyst of Cyclospora sp. (b) Oocyst of Cryptosporidium sp. and (c) Cyst of Giardia sp. in dug well water

Correlations among water quality parameters

The inter-relationship among the water quality parameters is often expressed by Pearson's correlation coefficient that indicates their potential sources. The obtained correlation matrix is presented in Table 5. The positive correlation among the parameters may be attributed to common anthropogenic and/or natural sources.

On the contrary, temperature parameter showed a significant negative correlation with pH ($r= -0.625, p<0.05$) and ammonia ($r= -0.436, p<0.05$); pH with total coliform ($r= -0.45, p<0.05$) and chloride with total coliform ($r= -0.9, p<0.05$). Besides, results also revealed weak positive as well as negative correlations among the water quality parameters (Table 5). The present correlation study is in agreement with several previous analyses on correlation between physico-chemical and microbiological characteristics[34, 35, 36].

The correlation measures the strength of a linear relationship between any two variables. Results revealed a significant positive correlation of turbidity with ammonia ($r=0.455, p<0.05$) and iron ($r=0.414, p<0.05$).

Similarly, EC showed a significant correlation with TH ($r=0.637, p<0.05$); pH with TH ($r=0.538, p<0.05$) and TA ($r=0.358, p<0.05$); TA with ammonia ($r=0.438, p<0.05$) and iron ($r=0.0.402, p<0.05$) and ammonia with iron ($r=0.776, p<0.05$).

Table 5. Relationships among physio-chemical and microbiological parameters based on Pearson's correlation test.											
Constant Variables	Temp.	Turbidity	EC	pH	TH	Nitrate	Chloride	TA	Ammonia	Iron	Total Coliform
Temp.	1.000	-0.357	0.036	-0.625*	-0.261	0.340	-0.029	-0.173	-0.436*	-0.373	0.18
Turbidity	-0.357	1.000	0.183	0.378	0.238	-0.351	0.023	0.223	0.455*	0.414*	-0.03
EC	0.036	0.183	1.000	0.220	0.637*	-0.377	0.215	0.374	-0.041	0.221	-0.09
pH	-0.625*	0.378	0.220	1.000	0.538*	-0.350	0.418	0.358*	0.201	0.148	-0.45*
TH	-0.261	0.238	0.637*	0.538*	1.000	-0.354	0.183	0.108	-0.118	0.044	-0.13
Nitrate	0.340	-0.351	-0.377	-0.350	-0.354	1.000	0.037	0.090	0.282	0.022	-0.01
Chloride	-0.029	0.023	0.215	0.418	0.183	0.037	1.000	0.142	0.165	0.035	-0.9*
TA	-0.173	0.223	0.374	0.358*	0.108	0.090	0.142	1.000	0.438*	0.402*	-0.13
Ammonia	-0.436*	0.455*	-0.041	0.201	-0.118	0.282	0.165	0.438*	1.000	0.776*	-0.19
Iron	-0.373	0.414*	0.221	0.148	0.044	0.022	0.035	0.402*	0.776*	1.000	-0.06
Total Coliform	0.18	-0.03	-0.09	-0.45*	-0.13	-0.01	-0.9*	-0.13	-0.19	-0.06	1.000
Temp.: Temperature; EC: Electrical conductivity; TH: Total hardness; TA: Total alkalinity * Correlation is significant at the 0.05 level p-value											

Conclusion

In the present study, dug well water samples were tested in order to assess their water quality status in Lalitpur Metropolitan City. The study included a total of 79 water samples from five different municipal wards of the metropolis based on the operational conditions of dug wells during pre-monsoon season. Among the water quality parameters, pH, chloride, nitrate and iron levels of all the tested water samples were found within the acceptable range of NDWQS and WHO guidelines while ammonia content from W. No. 19 recorded from high (4.52 mg/L) to W. No. 6 low (1.58 mg/L) crossed their maximum permissible limits. Turbidity range of 4.8 – 5.9 NTU with its mean value (5.3 NTU) from W. No. 6 slightly crossed WHO standard.. EC and TH of W. No. 7 both exceeded WHO guideline with their range and mean value of 826 – 2010 µS/cm (1477 µS/cm) and 128 – 198 mg/L (173 mg/L) in the water samples respectively. Total coliform count revealed that only 4 (5.1%) samples of the total tested water samples were found risk free whereas 43 (54.4%) samples demonstrated maximum microbial contamination range and high-risk level. It was found that W. No. 16 contributed the highest percentage (66.7%) of total coliform contamination in dug well water. Besides, three types of protozoan parasites viz., *Cyclospora*, *Cryptosporidium* and *Giardia* were also detected in the water samples. Pearson's correlation analysis showed both positive as well as negative relationships among the selected water quality parameters. Temperature parameter showed a significant negative correlation with pH ($r= -0.625$, $p<0.05$) and ammonia ($r= -0.436$, $p<0.05$); pH with total coliform ($r= -0.45$, $p<0.05$) and chloride with total coliform ($r= -0.9$, $p<0.05$) and a significant positive correlation of turbidity with ammonia ($r=0.455$, $p<0.05$) and iron ($r=0.414$, $p<0.05$).

Based on the above findings, we conclude that the water quality status of dug wells in Lalitpur Metropolitan City is not satisfactory. The conservation of traditional dug wells as well as stone spouts in the city is equally important along with their water quality status. The periodic examinations of water quality of the dug wells are therefore, very much crucial for maintaining the identity of this ancient city in compliance with the obligations of the cultural heritage site. Besides, appropriate efforts and effective measures must be undertaken in order to improve the present water quality status of the dug wells in this historic city.

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