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POST-EARTHQUAKE WATER QUALITY IN BHAKTAPUR DISTRICT, NEPAL

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Abstract. Drinking water quality of Bhaktapur district was analyzed after massive earthquake of 2015. Water samples were randomly collected from the groundwater and surface water sources across the study area. Samples were analyzed for physical (temperature, pH, electrical conductivity and turbidity), chemical (hardness, chloride, ammonia, and nitrate), and microbiological (*E. coli* and total coliform bacteria) parameters using standard methods. The results demonstrated that the water samples were contaminated mostly with *E. coli* and total coliform (TC) bacteria. The bacterial population enumerated for *E. coli* (100 CFU/100 ml) and TC (300 CFU/100 ml) exceeded the National Drinking Water Quality Standard (NDWQS). Physical and chemical parameters analyzed for temperature, pH, conductivity, hardness, chloride, ammonia, and nitrate were within the acceptable limit of the NDWQS. However, the turbidity and ammonia was 34.6 NTU and 3.6 mg/l, were within the maximum values recommended by the NDWQS. This study exhibits that the groundwater and surface water quality of Bhaktapur district is contaminated with *E. coli* and TC bacteria hence, is vulnerable to drink. The water contaminated with bacteria (*E. coli* and TC), presence of ammonia and turbidity more than the limit of NDWQS may pose health risks and cannot be accepted for drinking purpose without purification following appropriate scientific methods.

Keywords: *drinking water; earthquake victim, water quality, water sample.*

Introduction

Water quality of surface and groundwater may alter after massive earthquakes. This change in water quality can occur due to the intermixing of water among aquifers, influx of water from different areas to water sources, change in concentration of dissolved gases, and dissolution of precipitated minerals or infiltration of pollutants from soil to groundwater table. Similarly, ground layer movement influences the quality and quantity of water (Wang *et al.*, 2004). Massive earthquakes may cause crack in the rocksand facilitate in leaching of metallic ions to groundwater aquifer. This can change physical characteristics and chemical composition of water (Esposito *et al.*, 2001; Hsu, Tung, 2004; Yang *et al.*, 2007; Sato *et al.*, 2014; Banjara, Paudel, 2017). Similarly, groundwater level also alters with equal possibility of formation and disappearance of new springs depending on the strength of quake and geological formation of earthquake affected area (Chia *et al.*, 2001; Matsumoto *et al.*, 2003).

Safe drinking water is essential for healthy human life. The water to be used for human consumption should be safe and free from contaminants. Nepal experienced massive earthquake of 7.8 magnitudes in the Richter scale on 25 April 2015. The quake damaged structures and cut-off supply systems including water. Interruption of water supply compelled the people to depend on the sources available around the area. Use of contaminated water for drinking purpose can cause waterborne epidemics such as diarrhoea, dysentery, hepatitis and sometimes cholera in acute cases. To minimize the threat of waterborne epidemics and reduce the risk monitoring of drinking water quality prior to the supply is necessary. Therefore, in the present work we analyzed drinking water quality of groundwater and surface water in Bhaktapur district following the massive earthquake of 2015 from the major drinking water sources.

The major objective of this study was to monitor the post-earthquake groundwater and surface water quality of Bhaktapur district.

Materials and Methods

Study area

The epicentre of massive earthquake of 2015 was in the Barpak of Gorkha district which is about 175 km northwest to Kathmandu valley. Following Gorkha earthquake, thousands of aftershocks were recorded in the seismometer at the department of mines and geology and the frequency of aftershocks are still in progress. The Gorkha earthquake damaged infrastructures very badly and lost more than 9,000 lives. The damage was localized not only in the Barpak area, but also affected 14 districts (providences) around Barpak including Kathmandu, Lalitpur, and Bhaktapur districts in the Kathmandu valley.

Among the areas, Bhaktapur a historical place and one of the world heritage sites was affected very much, where the quake damaged monuments, temples, public, and private structures. Structural damage affected the drinking water supply system in most of the places of Bhaktapur district and compelled the people to use contaminated water supplied by the private water suppliers. Use of contaminated water for drinking and other purpose can cause waterborne diseases such as dysentery, diarrhea, abdominal pain, and cholera in acute conditions. Due to collapse of public and private buildings more than 300 people died alone in Bhaktapur district (NRCS, 2015).

The study was carried out in the urban and semi-urban areas of Bhaktapur district (Fig. 1). The Bhaktapur district is located in the Midland of the Himalayas, lies in between 27°36′to 27°44′ North and 85°21′ and 85°32′ East is oval in shape with length approximately 21.6 km E-W and breadth 11.2 km N-S (DPHO, 2016).The district has a central flat part at an elevation of 1,331-2,191m above mean sea level and covers an area of 119 km² (DDC, 2016).

The population of Bhaktapur district is 0.3 million with an average population density of 2,560 person per km^2 (CBS, 2012).

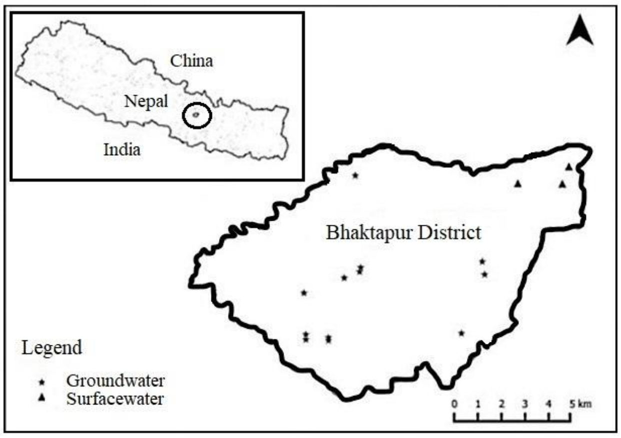

Fig.1. Map of Nepal showing sampling sites in Bhaktapur district

Drinking water supplied from the municipality is not sufficient in Bhaktapur district. Most of the people across this area either depend on groundwater or the surface water sources to fulfil their daily water demand. Water supplied by the municipality is also not pure hence, practice of household treatment systems exists where people use treatment systems made from locally available materials. Out of total water demand of Bhaktapur, 74.2% water is supplied from the groundwater and surface water sources, and 25.8% water is supplied from the municipality supply system (DWSS, 2011). Due to this water scarcity the processed water which is popular as mineral waterhas now become one of the major sources of drinking water. The processed water has now gained commercial status and available in the market in 0.5 – 20 l polyethylene terephthalate (PET) bottle and jars.

Materials

Ammonium chloride, liquid ammonia, silver nitrate, erichrome black-T, (Fisher scientific), ethylene diamine-tetraacetic acid (Qualigens fine chemicals), magnesium sulfate, and sodium chloride (Merck), were the AR grade chemicalspurchased from local suppliers in Kathmandu. Membrane filter paper of 0.45 μm pore size and M-endo agar Hi-media were used in the estimation of total coliform.

Sample collection

Altogether 15 water samples were collected from groundwater (deep boring of depth >200 m – 12) and surface water sources (stream – 03) from different places in the Bhaktapur district within a week of the earthquake at the same time. The water sources, their location, and the number of consumers are presented in table 1.

Table 1. Water sources in the Bhaktapur district

Water source	Location	Consumer (person)
KatunjeDW	Katunje	12000
JhaukhelDW	Duwakot	7000
Sudal deep boring	Sudal	3130
ShyantangDW	Shyantang	3000
SimkholaDW	Simkhola	3000
Dug-well, Byasi	Byasi	2400
Jhaukhel deepboring	Jhaukhel	1700
UttishghariDW	Gundu	1300
GunduDW	Gundu	500
TathaliDW	Tathali	300
Siddhapokhari deep boring	Siddhapokhari	240
Gundu community DW	Gundu	100

DW – drinking water.

Surface water was collected from Nagarkot, which is about 10 km north-east from Bhaktapur city centre. The Nagarkot is semi-urban region and is the highest elevated area (2,195 m) of Bhaktapur district. Water samples were collected from the main bus stop, Nayagaun, and Lamatol sites of Nagarkot. Most of the people in Nagarkot area depend on surface water sources for drinking water and other applications. Interview with the local people revealed that about 1000 people reside around Nagarkot bus station, Nayagaun, and Lamatol of Nagarkot area. Municipality water supply system is not available in Nagarkot and people fulfil their daily drinking water requirement either from surface water sources or purchase groundwater supplied by private water suppliers (tanker water).

Water samples were collected according to standard method (APHA, 2000). The water samples were randomly collected from groundwater (deep boring) and surface water sources in polyethylene bottles (~250 ml). Samples for the analysis of total coliform were collected in sterilized polyethylene bottles. Bottles were autoclaved in an autoclave at 121°C for 15 m and 172368.925 Pa

(Pascal) pressure for sterilization. Similarly, samples for the analysis of chemical parameters (hardness, chloride, ammonia, and nitrate) were collected in polyethylene bottles cleaned by distilled water for several times. Before sample collection, sample bottles were purged at least three times by the water to be collected from respective sources. The samples were stored in a portable icebox and transported to the laboratory within 6 h and stored at ~4^{o} C in a refrigerator until analysis.

Sample analysis

The samples were analyzed for physical (temperature, pH, electrical conductivity, and turbidity), chemical (hardness, chloride, ammonia, and nitrate), and microbiological (*E. coli* and coliform) parameters. The temperature, pH and EC were measured *in-situ* using thermometer (LINE SEIKI TC-1100), pH meter (TOA HM-10P), conductivity meter (WTW LF 91), respectively. Turbidity was measured using nephelometer (ELICO, CL 52). The hardness and chloride were measured volumetrically. Standard test kits were used to estimate ammonia (HACH, NI-8) and nitrate (Machery-Nagel, Ref 935065). Measuring efficiency of test kits was 0–3 mg/l and 2–50 mg/l for ammonia and nitrate, respectively. For measurement of ammonia, two standard glass tubes were filled to the mark with the water to be tested. Three drops of nessler reagent was added to one of the tubes by swirling and placed aside for 1–5 min for colour development (yellow colour develops if ammonia is present in water). The tubes were inserted into colour comparator by following instructions mentioned in the sample analysis manual and observed the colour. Nitrate was determined as per the guidelines described in the sample analysis manual. In this method, test vessel was rinsed for several times with the water to be tested and filled the sample to the mark by adding 5 ml water. Five drops of test reagent-1 (NO_3-1) was added in the test vessel and mixed by swirling. One level measuring spoon of test reagent-2 (NO_3-2) was further added in the solution, swirled for another 30 second and placed the vessel with content aside for colour development. After 5 min, colour was assigned in the sample by comparing the colour in the standard colour chart.

Microbiological parameters analyzed for the estimation of *E. coli* and TC bacteria were quantified by Membrane Filtration (MF) Method (APHA, 2000). The samples (100 ml for each) were filtered using sterile filter paper with pore size of 0.45 µm by applying vacuum suction and incubated in an incubator at 37°C for 24-48 h in M-endo agar media. After incubation, *E. coli* and total coliform bacteria were enumerated by counting the colonies.

Results and Discussion

People in Bhaktapur area depend on groundwater and surface water sources to fulfil their daily water requirements. Following the disaster, earthquake victims staying in the temporary camps at different places of Bhaktapur were also supplied drinking water from these sources.

It is difficult to compare post earthquake water quality data of Bhaktapur district because of unavailability of the prior earthquake data. However, findings of the work of Pant (2010) carried out for water quality analysis from Kathmandu, Lalitpur, and Bhaktapur district of Kathmandu valley is considered as a reference.

Physical and chemical analysis

The samples were analysed for physical, chemical, and microbiological parameters and presented in Table 2, 3 and 4.

Table 2. Physical parameter

Source	Temperature, ^{o}C				pH				EC,µS/cm				Turbidity, NTU			
	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.
GW	25.3	26.2	25.9	± 0.21	6.5	8.2	7.5	± 0.49	4.5	379.0	183.2	±92.32	0.9	34.6	6.9	±9.67
SW	25.7	25.9	25.8	± 0.10	7.1	7.4	7.2	± 0.15	49.0	182.0	101.3	±70.88	0.8	3.6	1.8	±1.56
NDWQS		*NA*				6.5-8.5				1500				5		

GW–groundwater, SW – surface water, NDWQS – National Drinking Water Quality Standards, NA – not available, Min – minimum, Max – maximum, Std. dev. – standard deviation

The result shows that the maximum value of turbidity was 34.6 NTU and 3.6 NTU for ground and surface water, respectively. For 31.5% of groundwater samples turbidly exceeded the NDWQS (5 NTU). Turbidity in water is due to presence of foreign materials. Such materials remain in water either in dissolved condition or in suspended form making the water turbid. Additionally, soil particles from the soil erosion around the sources due to the earthquake can also make water turbid. Study shows that groundwater microbial genera of Kathmandu increased after the earthquake (Uprety *et al.* 2017). Such microbial organisms like coliform and algae along with metallic ions in dissolved condition contribute turbidity in water (Pant, 2010). Although, turbid water is considered less hazardous for health, however, such water is aesthetically unacceptable for drinking purpose but can be removed implementing simple filtration techniques.

The EC in water is due to the presence of dissolved ionic substances and EC increases with increase in the concentration of ionic materials. Maximum EC estimated in groundwater and surface water was 379µS/cm and 182 µS/cm. Maximum level of EC present in shallow water is due to easy availability of ionic substances like metallic ions, organic matters containing ionic charges, ammonium and nitrate ions. However, in deep aquifer, the possibility of groundwater contamination is less than that of shallow water because of the increased depth and safely covered top (Sawyer *et al.* 2003, Dzwairo *et al.* 2006, Pant, 2010). The results shows that water sources in the Bhaktapur district are not rich in ionic substancesand are within guidelines of NDWQS (1500 μS/cm).

The range of pH was 6.5-8.2 and 7.1-7.4, respectively for groundwater and surface water and within the drinking water quality guidelines. The pH in water is due to bed rock/soil composition of water body, presence of organic matter in waters, dumping of chemicals into water, and amount of acid precipitation. The pH values are measured from pH 2 to pH 14 and the pH value at 7 is considered neutral pH, where both the characteristics of acid and base are dominant. The pH <7 is acidic and the acidity increases as pH value decreases from pH 7. Similarly, the alkalinity of water increases with increase in the pH of water from pH 7 to higher pH value. There are no evidences of association between drinking water pH and impact on public health. Nevertheless, extreme pH (both acidic and basic pHs) may cause skin and eyes irritation (WHO, 2007). Likewise, metallic ions leached from water supply system and water disinfection by-products formed as a result of water treatment processes may increase pH that may have impact on public health. However, for this study drinking water pH in the study area is within the drinking water quality guidelines.

The maximum temperature of groundwater and surface water was 26.2°C and 25.9°C. Water temperature parameter is considered non crucial for the drinking purpose and the reason can be the nonhazardous property of temperature on public health. Therefore, NDWQS has not included the value of temperature parameter as drinking water quality guideline. Nevertheless, the European Economic Community (EEC) and Canadian drinking-water guidelines have recommended maximum drinking-water temperatures of 25°C and 15°C, respectively (National Water Quality..., 1996).

Chemical parameters analyzed for the hardness, chloride, ammonia, and nitrate are within the NDWQS (Table 3). Hardness in water is due to the presence of metal carbonate and bicarbonates, particularly the calcium and magnesium carbonate. The carbonate containing metal compounds remains in water in the dissolved state and contribute in water hardness. However, hardness in water do not pose health impacts, nevertheless the negative effect of hard water can be observed in laundry industries as excess soap is consumed during laundering. Additionally, water hardness can also cause blockage in water supply system by forming excess clogged materials in the pipes.

Table 3. Concentration of chemical parameter (mg/l)

Source	Hardness				Chloride				Ammonia				Nitrate			
	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.
GW	6.0	186.0	78.5	±45.73	15.6	59.6	28.9	-10.94	0.24	3.6	1.3	±1.23	0.0	15.0	2.2	±3.59
SW	14.0	48.0	29.3	±17.24	8.5	34.0	19.3	-13.16	0.12	0.24	0.16	±0.06	0.0	8.0	2.6	±4.62
NDWQS		500				250				1.5				50		

Maximum concentration of chloride in ground and surface water was 59.6 mg/l and 34.0 mg/l. Chloride is present in water mainly due to agricultural activities and street runoff. Chemical fertilizers like potassium used in the field is rich in chloride and if the fertilizer is used more than the recommended dosage, the excess chloride content of potassium fertilizer can get accessed to water resources through street runoff or by leaching to groundwater table via soil pores. Other sources of chloride in waters may be dissolution of salts resulting from irrigation in the deep groundwater sources. Chloride concentration in the water collected from different sources in Bhaktapur district is in accordance with the NDWQS (2005).

The maximum level of ammonia estimated in groundwater and surface water was 3.6 mg/l and 0.24 mg/l. The value of ammonia estimated in groundwater exceeds drinking water quality guideline of 1.5 mg/l. However, for surface water, ammonia level was within the standard limit. The reason of increased ammonia in groundwater may be due to unhealthy agricultural practices, where chemical fertilizer is used haphazardly in the fields to increase crop production. The increasing trend of fertilizer usage in the fields led to increase the amount of ammonia in groundwater. Similarly, industrial and sewage treatment discharge disposed in open field can also contribute in the increment of ammonia concentration in groundwater table. Presence of ammonia in water system causes oxygen depletion and eutrophication (Vayenas *et al.*, 1997). Public health impact associated with ammonia is negligible at the level recommended in drinking water quality standards (MoPPW, 2005). However, ingestion of concentrated ammonia causes mouth, throat and gastrointestinal tracts irritation in human. These effects may likely occur if the concentration of ammonia in drinking water is beyond the recommended guidelines.

Maximum concentration of nitrate in groundwater was 15.0 mg/l. In surface water, it was estimated only in the sample collected from Lamatol site with maximum value of 8.0 mg/l. These values are within the limits of NDWQS (50 mg/l). Nitrate occurs naturally in surface and groundwater at a concentration that does not generally cause health problems. High concentration of nitrate in groundwater often result due to inappropriate construction of groundwater source, location of the source, overuse of chemical fertilizers in the field, and improper disposal of human and animal wastes. Sources of nitrate that can access to groundwater may be chemical fertilizers, septic systems, animal feedlots, and industrial and food processing wastes. Health effect of nitrate in drinking water is most significantly linked to methemoglobinemia, also known as “blue-baby syndrome”. Nitrate concentration in water samples collected from groundwater and surface water sources in the present work are in accordance with the drinking water quality standards.

Microbiological analysis

The bacterial population enumerated for *E. coli* and TC in groundwater and surface water extremely exceeded the NDWQ standards (Table 4). Previous studies also demonstrated that there is wider microbiological contamination of groundwater of Kathmandu valley including Bhaktapur (Pant, 2010; Pant *et al.* 2016; Uprety *et al.* 2017). The *E. coli* in groundwater was enumerated from 0 to >100 CFU/100 ml of water and for TC it was 0 to >300 CFU/100 ml of water. In surface water *E. coli* was estimated from 30 to >100 CFU/100 ml of water. These are the minimum and maximum number of *E. coli* enumerated in surface water samples. The TC bacteria were enumerated >100 CFU/100 ml of water and estimated only in the sample collected from Lamatol site of Nagarkot area. Presence of *E. coli* in water is an indication of faecal contamination, whereas coliform are general microbiological contaminants.

Table 4. Microbiological analysis

Source	*E. coli*		Total Coliform (TC)	
	Min	Max	Min	Max
GW	0.0	100	0.0	300
SW	30	100	100	100
NDWQS		0		0

Maximum *E. coli* and TC enumerated in groundwater and surface water is probably due to poor drainage facility and improper construction pattern of septic reservoirs in the area. Construction of septic tank close to the groundwater sources may be one of the reasons of microbial contamination to groundwater, which was common almost in all the places of the study site. Consequently, effluent from septic tank can easily percolate down to the groundwater table which can lead to high microbial contamination. Similarly, disposal of garbage and household wastes near the water sources also contribute in the increment of bacterial population in ground and surface waters. Domestic wastewaters including septic effluent discharge practice in surface water without pre-treatment is common in most of the places of Bhaktapur district. Such practices deteriorate water quality of surface water by contaminating with microbiological contaminants.

Primary cause of faecal contamination in water can be the damage of sewage infrastructures following massive earthquakes. In urban areas of Kathmandu valley sewage system and drinking water distribution channels are very old and constructed side by side. During the earthquake shaking of the grounds may collapsedthe systems and increased the risk of water contamination by mixing the sewage in drinking water. Groundwater aquifer, particularly the shallow water sources are prone to contamination with biological contaminants (Environment Canterbury, 2011). The reason of high possibility of contamination may be due to insufficient depth of shallow waters, open top of the sources, haphazard disposal of garbage and household wastes around the sources, percolation of sewage from septic tank to groundwater table, and street runoffs. Similarly, inadequate cleaning of these water sources may be another reason of biological contamination of groundwater.

Microbiological contaminants are the causal agent of waterborne diseases such as diarrhoea, nausea, gastroenteritis, typhoid, dysentery, cholera and other health related problems (Shar *et al.*, 2007). Globally, diarrheal diseases alone are responsible for nearly two million deaths in a year which can be attributed to unsafe drinking water as well as inadequate sanitation and personal hygiene (WHO, 2004). A total of 58 countries from all over the world have reported 589,854 cholera cases in 2011 (WHO, 2012). In Nepal, annually about 10,500 people particularly the children under five years die each year due to diarrheal diseases (MoPPW, 2011).

Changes in post-earthquake water quality parameters have widely been studied and changes in chemical and microbial parameters have been reported (Banjara, Paudel, 2017; Uprety *et al.*, 2017). However, in case of Kathmandu valley previous studies and this study demonstrated the microbial contamination of water is quite common before and after the earthquake (Pant, 2010; Pant *et al.* 2016; Uprety *et al.*, 2017). In a country like ours where the use of ground water is prevalent for domestic and drinking purpose microbial contamination of water may have severe effect on human health (Banjara, Paudel, 2017). Physical and chemical alteration of ground water may occur after earthquake however this study exhibits that physical and chemical parameters generally are within the NDWQS (1996) guidelines while the microbial contamination of water could pose risk to the public health.

Conclusions

Post-earthquake water quality analysis was carried out in the Bhaktapur district for drinking water. A total of 15 water samples were randomly collected from groundwater (deep boring >200 m depth – 12), and surface water sources (river and stream – 3). These are the major drinking water sources, where most of the people depend to fulfil their daily water demand. The samples were analyzed for physical (temperature, pH, conductivity, and turbidity), chemical (hardness, chloride, ammonia, and nitrate), and microbiological (*E. coli* and coliform) parameters. The maximum *E. coli* and total coliform bacteria enumerated in the samples were >100 CFU and >300 CFU per one hundred ml of water in groundwater and surface waters, respectively. Physical and chemical parameters were within the NDWQS except ammonia in groundwater samples. Ammonia was estimated beyond the recommended values of drinking water guideline (6.3 mg/l). The water quality in Bhaktapur district is poor due to the presence of *E. coli* and coliform and the amount of ammonia more than the standard limit. The *E. coli* and coliform containing water as such cannot be used for drinking purpose, unless treated using suitable treatment method.

Recommendations

Findings of this study suggest that after the massive earthquake the bacterial contamination of groundwater and surface water in the Bhaktapur district is vulnerable to use for drinking purpose. Therefore, we suggest decontaminating the water using suitable treatment method. Currently, different water decontaminants are available in the market. Nevertheless, boiling is appropriate and reliable means of water purification. Hence, we suggest using only boiled water for drinking purpose and strictly follow personal hygienic practices. Such practices can minimize the risk of waterborne diseases, which are mainly due to poor water quality, lapses in sanitation and personal hygiene.

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References

APHA. 2000. *Standard Methods for the Examination of Water and Wastewater.* Washington DC.

Banjara, S.; Paudel, S. R. 2017. Earthquake-Science in Himalayas: Ground water quality change and its implications. *Journal of the Institute of Engineering,* 13(1), 201-205. https://doi.org/10.3126/jie.v13i1.20367

Environment Canterbury. 2011. *Earthquake impacts on groundwater* [online], [cited 28May 2019]. Available at: http://ecan.govt.nz/publications/General/earthquake-impacts-groundwater-update-3-130511.pdf

CBS. 2012. *National Population and Housing Census 2011,* Central Bureau of Statistics, GoN, 2012.

Chia, Y.; Wang, Y.-S.; Chiu, J. J.; Liu, C.-W. 2001. Changes of groundwater level due to the 1999 Chi-Chi Earthquake in the Choshui River Alluvial Fan in Taiwan. *Bulletin of the Seismological Society of America*, 91(5), 1062-1068. https://doi.org/10.1785/0120000726

DDC. 2016. *Brief Introduction: Bhaktapur at a Glance* [online], [cited 28 May 2019]. Available at: http://ddcbhaktapur.gov.np/en/brief-introduction.

DPHO. 2016. *General Information of Bhaktapur* [online], [cited 28 May 2019]. Available at: http://www.dphobhaktapur.gov.np/m/cms/about-us.html.

DWSS. *National Coverage and Functionality Status of Water Supply and Sanitation in Nepal*. Department of Water Supply and Sanitatioin, Panipokhari, Kathmandu, 2011.

Dzwairo, B.; Hoko, Z.; Love, D.; Guzha, E. 2006. Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. *Physics and Chemistry of the Earth*, 31(15–16), 779–788, https://doi.org/10.1016/j.pce.2006.08.031.

Esposito, E.; Pece, R.; Porfido, S.; Tranfaglia, G. 2001. Hydrological anomalies connected to earthquakes in Southern Apennines. *Natural Hazards and Earth System Sciences*, 1, 137-144. https://doi.org/10.5194/nhess-1-137-2001.

Hsu, K.-C.; Tung, C.-C. 2004. On estimating the earthquake-induced changes in hydrogeological properties of the Choshuishi Alluvial Fan, Taiwan. *Hydrogeology Journal*, 13(3), 467-480. https://doi.org/10.1007/s10040-004-0335-3

Matsumoto, N.; Kitagawa, G.; Roeloffs, E. A. 2003.Hydrological response to earthquakes in the Haibara well, central Japan-I. Groundwater level changes revealed using state space decomposition of atmospheric pressure, rainfall and tidal responses. *Geophysical Journal International*, 155(3), 885-898. https://doi.org/10.1111/j.1365-246X.2003.02103.x

MoPPW. *Nepal Drinking Water Quality Standards. 2005 Implementation Directives for National Drinking Water Quality Standards*. Ministry of Urban Development, GoN, 2005.

MoPPW. *Water Supply, Sanitation and Hygiene (WASH) Sector Status Report 2011*. Ministry of Physical Planning and Work, GoN, 2011.

NDWQS. *National Drinking Water Quality Standard 2005.* Ministry of Physical Planning and Work, GoN.

NRCS. *Details on Damage and Relief Material of Massive Earthquake on April 25, 26 and May 12 2015*. Nepal Red Cross Society, Bhaktapur, Nepal, 2015.

National Water Quality Management Strategy. Australian Drinking Water Guidelines. National Health and Medical Research Council, Agriculture and resource management council of Australia and New Zealand, 1996.

Pant, B. R. 2010. Ground water quality in the Kathmandu valley of Nepal. *Environmental Monitoring and Assessment*, 178(1), 477-485. https://doi.org/10.1007/s10661-010-1706-y

Pant, B. R.;Thapa, K.; Koju, R. 2016. Post-earthquake drinking water quality in the Kathmandu valley: A pilot study. *Al Ameen Journal of Medical Science*, 9(2), 130-133.

Sato, T.; Matsumoto, N.; Kitagawa, Y.; Koizumi, N.; Takahashi, M.; Kuwahara, Y. 2014. Changes in groundwater level associated with the 2003 Tokachi-oki earthquake. *Earth, Planets and Space,* 56(3), 395-400. https://doi.org/10.1186/BF03353071

Sawyer, C. N.; McCarty, P. L.; Parkin, G. F. 2003.*Chemistry for environmental engineering and science*. New York: McGraw–Hill.

Shar, A. H.; Kazi, Y. F.; Zardari, M.; Soomro, I. H. 2007. Enumeration of total and faecal coliform bacteria in drinking water of Khairpur City, Sindh, Pakistan. *Bangladesh Journal of Microbiology*, 24(2). https://doi.org/10.3329/bjm.v24i2.1266

Uprety, S.; Hong, P-Y.; Sadik, N.; Dangol, B.; Adhikari, R.;Jutla, A.; Shisler, J.L.; Degnan, P.; Nguyen, T.H. 2017. The effect of the 2015 earthquake on the bacterial community compositions in water in Nepal. *Frontiers in Microbiology*, 8, 2380. https://doi.org/10.3389/fmicb.2017.02380

Vayenas, D. V.; Pavlou, S.; Lyberatos, G. 1997. Development of a dynamic model describing nitrification and nitratification in trickilng filters. *Water Research*, 31(5), 1135-1147, https://doi.org/10.1016/S0043-1354(96)00355-7

Wang, C.-y.; Wang, C.-H.; Manga, M. 2004.Coseismic release of water from mountains: Evidence from the 1999 (Mw = 7.5) Chi-Chi, Taiwan, earthquake. *Geology*, 32(9), 769-772. https://doi.org/10.1130/G20753.1

WHO. 2004. *Water sanitation and hygiene links to health.* World Health Organization [online], [cited 25 May 2019]. Available at: https://www.who.int/water_sanitation_health/publications/facts2004/en.

WHO. 2007. *pH in drinking-water. Revised background document for development of WHO Guidelines for Drinking-water Quality*. World Health Organization,Geneva, Switzerland [online], [cited 10 April 2019]. Available at: citedhttp://www.who.int/water_sanitation_health/dwq/chemicals/en/ph.pdf.

WHO. 2012. *The Weekly Epidemiological Record*. World Health Organization, Geneva, Switzerland.

Yang, Z.; Deng, Z.; Tao, J.; Gu, Y.; Wang, Z.; Liu, C. 2007. Coseismic effects of water temperature based on digital observation from Tayuan well, Beijing. *Acta Seismologica Sinica*, 20(2), 212-223. https://doi.org/10.1007/s11589-007-0212-y