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Tap Water Quality Degradation in an Intermittent Water Supply Area

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Abstract Decentralized tap water systems are an important drinking water source worldwide. A good quality, high-pressure continuous water supply (CWS) is always the target of any urban settlement. However, tap water in some areas are reported with deteriorated water quality even though treated well before supplying. Such deterioration of tap water quality is reported widely from areas with low water availability and in economically poor countries where water are supplied intermittently (IWS). This study focuses in identifying tap water quality in IWS and causes of water quality degradation using nitrate-nitrogen (NO_3-N) as an indicator and stable isotopes of hydrogen (δD) as tracer. Nine water reservoirs and ninety municipal tap water (ten per reservoir) samples were collected during the wet (June–September) and dry (November–February) seasons in the Kathmandu Valley (KV), Nepal. Ten percent of the tap water samples exhibited higher NO_3-N than those of their respective reservoirs during the wet season, while 16% exhibited higher concentrations during the dry season. Similarly, the isotopic signatures of tap water exhibited 3% and 23% higher concentrations than those of their respective reservoirs during the wet and dry seasons, respectively. Coupling analysis between NO_3-N and δD demonstrates close connection of groundwater and tap water. The results indicate groundwater intrusion as the primary component in controlling tap water quality variations within the same distribution networks during IWS. Meanwhile, the obtained results also indicate probable areas of intrusion in the KV as well as usefulness of δD as a tool in the assessment of tap water systems.

Keywords Tap water contamination · Intermittent water supply · Low pressurized tap · Groundwater intrusion · Developing country · Kathmandu Valley

1 Introduction

Maintaining safe drinking water for growing populations is a major global issue. In addition, anthropogenic impacts on water sources and climate change have raised serious concerns regarding drinking water resources (IPCC, 2008). The construction of continuously available and easily accessible water sources,

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their maintenance, and sustainability are continually being developed to cope with drinking water scarcity. Therefore, decentralized municipal tap water systems have served as a critical component of safe and convenient drinkable water (Howard & Bartram, 2003).

Although municipal tap water networks are safe, they are vulnerable to artificial (pressure loads, management, and replacement) and natural changes (underground stresses, earthquakes, disasters) that can cause dislocations and ruptures (Chandra et al., 2016; Wols et al., 2014). Losses of 5–35% of water (Lambert et al., 2014) through ruptures in municipal tap water networks are inevitable which can reach up to 50% in low-income countries (Dudley & Stolton, 2003). These ruptures and losses have a significant effect of water leakage faced by areas with continuous water supply (CWS) (24 h) wherein the water supply is steadily under high pressure. On the other hand, intermittent water supply (IWS) strategy with limited supply per day (<24 h) to per week (1–3 h in a week) has been adopted as a counter measure to cope with water shortages and losses in economically poor countries (van den Berg & Danilenko, 2011; WHO & UNICEF, 2000). However, chemical and microbiological contamination has been found to be significantly higher during IWS than during CWS (Erickson et al., 2017; Kumpel & Nelson, 2014).

Previous studies have reported that contamination of the tap water distribution network-harbored material (DNHM) is caused by chemical disintegration and microbiological re-growth (Liu et al., 2017). Disintegration and re-growth are even higher in IWS settings during periods of no supply (Coelho et al., 2003). In addition, the occurrence of transient low or negative pressure mechanisms in the distribution pipes during IWS is ubiquitous during transport (Fontanazza et al., 2015; Kumpel & Nelson, 2014; van den Berg & Danilenko, 2011). Presence of any ruptures in the distribution network thus acts as a major gateway for subsurface backflow and foreign water intrusions. These intrusions ultimately contribute to the degradation and contamination of drinking water quality, which is also related to the surrounding groundwater conditions (Grimmeisen et al., 2016). Groundwater, which is in close contact with municipal drinking water pipes, is reported to be contaminated with both chemical and microbiological contaminants, especially in developing countries (Nakamura et al., 2012; Shakya et al., 2019b; Shrestha et al., 2014; Umezawa et al., 2009), resulting in a higher likelihood of the deterioration of tap water quality caused by backflow into pipe network. Any changes in the tap water quality compared with reservoirs and nearby contaminated groundwater might indicate the tap water quality variations within the same network. Since NO_3-N in groundwater is considered an indicator of contaminations, studies focusing on determination of the tap water quality especially from NO_3-N create a concept on the drinking water situation and its possible risk (Schullehner et al., 2018). However, chemical and microbial tracers alone may not be reliable for defining tap water degradation, whether it is from the DNHM or intrusions. Meanwhile, the use of oxygen ($\delta^{18}O$-H_2O) and hydrogen (δD) isotopes in water has been advantageous for identifying various types of mixing in diverse hydrological studies (Craig, 1961; Gonfiantini et al., 1998). The fractionation of the isotopic signatures (δD and $\delta^{18}O$-H_2O) of water caused by natural processes (evaporation or condensation) is identical and can be identified. The distinct isotopic values of various water sources, as well as the properties of the isotopic tracers, have aided a wide variety of mixing studies and have been used advantageously for hydrological studies (Nakamura et al., 2016; Yang et al., 2012). Additionally, stable isotopes especially δD is unaffected by the pre-treatment processes. With all the advantages, stable isotopes have been used to determine the water dynamics in urban areas with CWS (Bowen et al., 2007; de Wet et al., 2020; Ehleringer et al., 2016; Jameel et al., 2018; Tipple et al., 2017; Zhao et al., 2017). As CWS does not experience foreign intrusions (Erickson et al., 2017), the dependency on isotopic signatures for tap water conditions and dynamics in an IWS setting presents challenges. Thus, the isotopic signatures coupled with chemical parameters among the water sources might be beneficial for understanding and investigating municipal tap water chemical contamination in urban areas facing IWS.

In this study, we investigated the municipal drinking water system of the Kathmandu Valley (KV) in Nepal. Similar to other cities in South Asia facing IWS (including Delhi, Dhaka, and Karachi), the KV faces higher intermittent supplies of all drinking water systems (McIntosh, 2003). Most of the residents in the KV experience an IWS for 2–4 h/week (Shrestha et al., 2017). More specifically, they experience intermittent supplies three or fewer times per week for two or fewer hour each time (Guragai et al., 2017). Despite better access to drinking water than in rural areas of Nepal, people in the KV experience safe drinking water problems in terms of both quality and quantity (Koju et al., 2015; Thapa et al., 2017, 2019; Udmale et al., 2016; Warner et al., 2008). Furthermore, the study area is often reported with the aging distribution network pipes and management (KUKL, 2019). The coupled use of NO_3-N as an indicator of contamination and isotopic signatures in areas severely affected by water shortages and intermittent distribution presents a new perspective on the diversity of tap water chemical contamination status in urban areas. Therefore, we highlighted the seasonal tap water NO_3-N contamination, its possible causes in the KV IWS, and the use of isotopic signatures as a tool in tracking the area of contamination from the distribution reservoir to the end users in the urban area.

2 Materials and Methods

2.1 Study Area

The KV is located in the foothills of the Himalayas and is an isolated closed intermountain basin. The basin extends from 27°32′34″ to 27°49′11″ N and from 85°11′10″ to 85°31′10″ E (Fig. 1). The valley covers an area of 664 km^2, with elevations ranging from 1212 to 2722 m above sea level. The water resources in the valley are rainfall-dependent. The

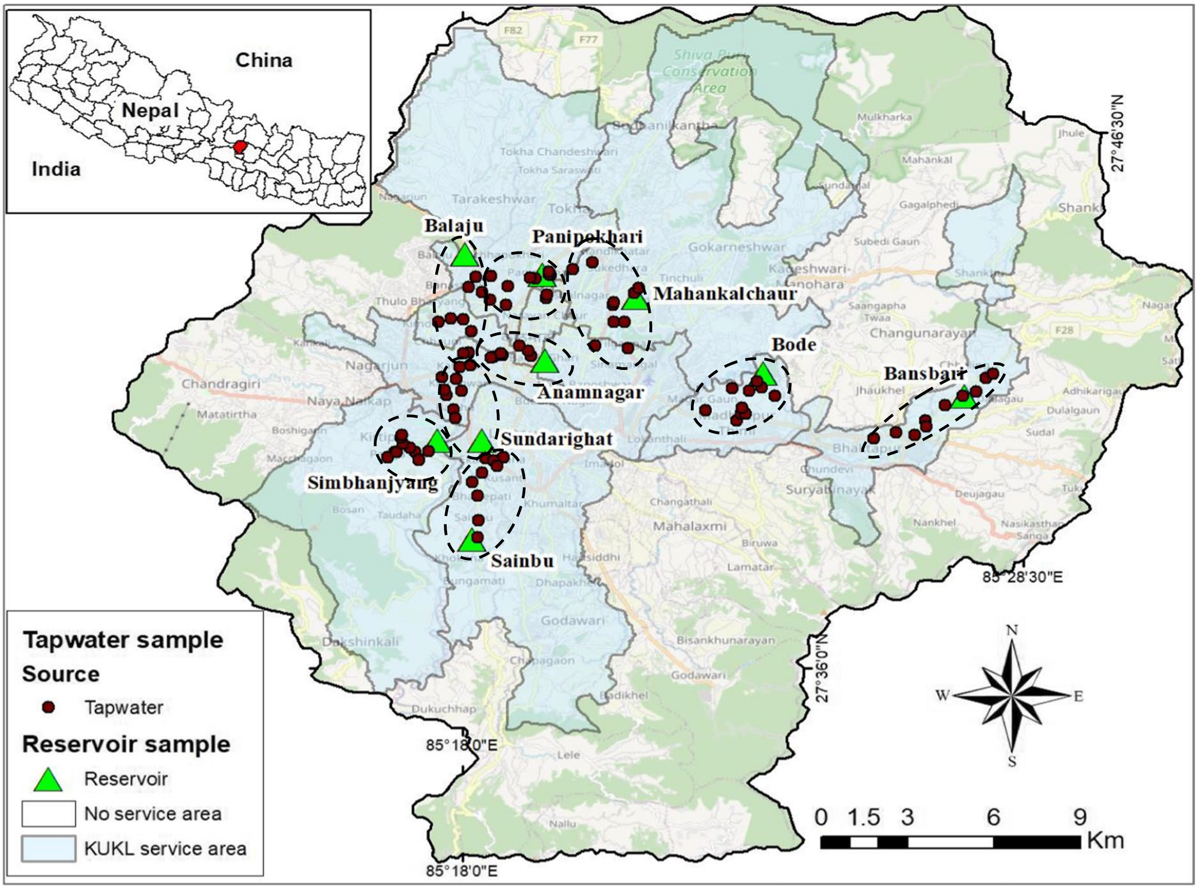

Fig. 1 Geographical boundary of the Kathmandu (KTM) Valley, with KUKL service areas shown in blue. Areas outside of the blue highlighted regions are not serviced by KUKL. The dashed line represents tap water from their respective reservoirs

KV receives 80% of its annual rainfall during the monsoon (wet) season (June–September), 14% during the pre-monsoon season (March–May), and 6% during the dry season (November–February) (Prajapati et al., 2021).

The sole water supply utility, *Kathmandu Upatyaka Khanepani Limited* (KUKL), has difficulties covering the annual drinking water demand for a population of 2.5 million people. According to KUKL (2021), the total demand for drinking water in 2019 reached 470 million liters per day (MLD); however, the provider was only able to provide 120 MLD during the wet season and 108 MLD during the dry season. The water supply demand is managed by a long intermittent supply, while the deficits are covered by groundwater supplies and other water vendors. Deep groundwater extracted from spatially distributed aquifers reaching the depths of 75–300 m is used for the drinking water supply by KUKL, while shallow groundwater at depths of up to 50 m is commonly used for local water use.

2.2 Tap Water and Reservoir Sample Collection

In this study, 198 samples were collected from around the KV during 2018–2019 (Fig. 1). Spatially distributed treated drinking water reservoirs in nine service areas, as well as 10 successive municipal taps (at the consumer end) within 3–5 km of the reservoir, were sampled during two consecutive seasons, i.e., wet (June–September 2018) and dry (November 2018–February 2019). Ninety-nine samples were collected per season. Tap water samples were collected 5–10 min after the supply started during the intermittent cycle. In case of reservoirs, samples were collected from the storage tanks. The samples were collected in 120 ml airtight high-density polyvinyl chloride (PVC) bottles. The samples were transferred from the collection area stored in a cooler bag with no preservatives added, then stored at − 4 °C. The samples were then transferred to the Interdisciplinary Centre for River Basin Environment at the University of Yamanashi (ICRE-UY) in Japan for further analysis.

The groundwater data used for comparison with the tap water data were adopted from the data previously reported by Shakya et al., (2019a, b).

2.3 Laboratory Analyses

The hydrogen (H) and oxygen (O) stable isotopic compositions and the chemical parameters of the samples were analyzed in the laboratory at ICRE-UY. The dual isotopic signatures were analyzed using cavity ring-down spectroscopy (L1102-i, Picarro, Santa Clara, CA, USA). The abbreviations δD and $\delta^{18}O\text{-}H_2O$ relative to Vienna Standard Mean Ocean Water (V-SMOW) are used to represent the stable isotopes of hydrogen and oxygen in water, respectively. All isotopic ratios are expressed in per mil format (‰), as shown in Eq. 1:

$$\delta^{N}E = \left(\frac{R_{sample} - R_{V-SMOV}}{R_{V-SMOV}}\right) x\ 1000\ (‰) \qquad (1)$$

where N is the atomic mass of the heavy isotope of the element, and E and R are the ratios of the heavy to light isotopes ($^{2}H/^{1}H$ or $^{18}O/^{16}O$). The measured analytical error of the equipment was 0.5‰ for δD and 0.1‰ for $\delta^{18}O\text{-}H_2O$.

The elemental concentrations of the samples (NO_3-N) were measured using ion chromatography (ICS-1100, Dionex, USA), with an analytical error of 5%.

2.4 Statistical Analyses

Mapping of the analyzed isotopic signatures and chemical parameters was performed using ArcMap version 10.3.1 (Esri Inc., USA). A paired *t*-test was performed to identify the temporal variations among the samples—based on *p*-value of 0.05—using the Statistical Package for Social Studies version 20 (SPSS Inc., Chicago, IL, USA).

3 Results and Discussion

Tables 1 and 2 list the statistics of the NO_3-N concentrations and stable isotopic signatures of the water samples (δD and $\delta^{18}O\text{-}H_2O$) obtained from the drinking water reservoirs and tap water in the KV, respectively.

Table 1 Isotopic signatures and hydrochemical data for the tap water samples (isotopic values in ‰ and NO_3-N in mg N/L)

ID	Associated supply reservoir	Northing	Easting	Wet			Dry		
				$\delta^{18}O-H_2O$	δD	NO_3-N	$\delta^{18}O-H_2O$	δD	NO_3-N
KIA 1	Anamnagar	27.70295	85.302	−8.71	−58.00	0.20	−8.12	−53.80	0.11
KIA 2		27.70139	85.30897	−8.74	−57.33	0.14	−8.24	−55.70	0.20
KIA 3		27.70216	85.31252	−8.54	−56.02	0.17	−7.91	−51.10	0.13
KIA 4		27.70168	85.30985	−8.60	−57.21	0.19	−8.06	−52.80	0.04
KIA 5		27.70278	85.31195	−8.65	−56.58	0.21	−8.37	−55.80	0.01
KIA 6		27.70121	85.30886	−8.75	−57.35	0.22	−8.55	−57.50	n.d
KIA 7		27.70355	85.32065	−8.73	−57.61	0.17	−7.92	−51.10	0.60
KIA 8		27.70189	85.32143	−8.63	−56.45	0.16	−7.49	−47.90	0.44
KIA 10		27.70523	85.31795	−8.63	−56.77	0.09	−8.06	−53.50	0.03
KIA 11	Sainbu	27.64276	85.30469	−8.95	−59.12	0.43	−8.84	−61.00	0.38
KIA 12		27.64812	85.30511	−8.87	−59.13	0.06	−8.96	−61.10	0.36
KIA 13		27.65639	85.30482	−8.95	−59.30	0.31	−8.24	−56.90	0.92
KIA 14		27.66383	85.30613	−8.96	−59.34	0.41	−9.10	−62.80	0.09
KIA 15		27.66894	85.31294	−8.92	−59.60	0.42	−9.20	−62.50	0.32
KIA 16		27.66839	85.30719	−8.81	−58.88	0.57	−8.77	−58.50	0.25
KIA 17		27.6676	85.30968	−8.90	−59.28	0.45	−9.07	−61.20	0.24
KIA 18		27.66608	85.31083	−8.96	−59.72	0.46	−8.23	−56.80	1.25
KIA 19		27.66082	85.30314	−8.98	−59.46	0.45	−8.29	−57.50	1.88
KIA 20		27.66823	85.30356	−9.01	−59.14	0.45	−9.09	−62.30	0.13
KIA 21	Mahankalchaur (Mhchaur.)	27.7225	85.35361	−8.59	−55.33	0.17	−8.36	−55.50	0.11
KIA 22		27.72417	85.355	−8.71	−56.41	0.17	−8.11	−52.90	0.12
KIA 23		27.71861	85.34694	−8.73	−56.25	0.13	−8.43	−57.70	0.06
KIA 24		27.71306	85.35056	−8.68	−56.44	0.19	−8.42	−55.70	0.06
KIA 25		27.71944	85.34722	−8.73	−56.09	0.17	−7.97	−50.90	0.12
KIA 26		27.70528	85.34139	−8.79	−56.79	0.15	−8.34	−56.10	0.11
KIA 27		27.70444	85.35167	−8.79	−56.59	0.18	−8.41	−55.90	0.04
KIA 28		27.71306	85.34722	−8.66	−56.06	0.18	−8.12	−54.30	n.d
KIA 29		27.7325	85.34056	−8.82	−56.81	0.22	−8.58	−58.90	0.17
KIA 30		27.73011	85.33452	−8.78	−56.49	0.14	−8.34	−56.20	n.d
KIA 32	Bode	27.69167	85.39333	−9.23	−64.05	0.33	−9.26	−67.30	0.13
KIA 33		27.69361	85.39194	−9.45	−66.23	0.24	−9.33	−67.30	n.d
KIA 34		27.68417	85.37583	−9.38	−65.47	0.49	−9.13	−67.00	0.29
KIA 35		27.69056	85.38944	−9.28	−64.54	0.24	−9.30	−66.70	0.24
KIA 36		27.69139	85.38417	−9.36	−65.38	2.15	−9.21	−67.00	1.25
KIA 37		27.68306	85.38694	−9.42	−65.69	0.18	−9.38	−66.40	0.17
KIA 38		27.68306	85.38833	−9.47	−66.26	0.39	−9.25	−67.20	0.66
KIA 39		27.68889	85.3975	−9.19	−64.53	0.05	−9.13	−66.50	n.d

Table 1 (continued)

ID	Associated supply reservoir	Northing	Easting	Wet			Dry		
				δ^{18}O-H$_2$O	δD	NO$_3$-N	δ^{18}O-H$_2$O	δD	NO$_3$-N
KIA 41	Sundarighat (Sdghat.)	27.68444	85.29722	−8.92	−59.84	0.55	−8.92	−63.90	0.27
KIA 42		27.68167	85.29778	−8.76	−58.00	0.54	−8.65	−60.10	0.21
KIA 43		27.69056	85.29972	−8.77	−58.47	1.12	−8.90	−63.00	0.33
KIA 44		27.68917	85.295	−8.16	−55.34	4.20	−8.63	−61.10	0.81
KIA 45		27.69444	85.29806	−8.88	−59.45	0.49	−8.90	−62.00	0.31
KIA 46		27.69833	85.29917	−8.93	−60.60	0.72	−9.03	−64.00	0.29
KIA 47		27.695	85.29361	−8.80	−59.45	0.36	−8.69	−61.60	0.49
KIA 49		27.69889	85.3025	−8.69	−58.75	0.54	−8.76	−61.50	0.46
KIA 50		27.70278	85.30028	−8.76	−58.70	0.43	−8.98	−63.80	0.22
KIA 51	Balaju	27.71306	85.2925	−8.91	−59.61	0.40	−8.87	−62.20	0.61
KIA 52		27.71417	85.29639	−8.74	−56.60	0.11	−8.47	−57.10	0.16
KIA 53		27.71389	85.30028	−8.78	−56.24	0.14	−8.47	−56.80	0.24
KIA 54		27.71	85.30278	−8.90	−58.81	0.14	−7.34	−51.00	1.07
KIA 55		27.72444	85.30194	−8.86	−57.44	0.14	−8.54	−57.50	n.d
KIA 56		27.72	85.,2975	−8.83	−57.52	0.15	−8.03	−53.40	0.28
KIA 57		27.72806	85.30889	−8.81	−57.24	0.13	−8.11	−52.80	0.23
KIA 58		27.72778	85.30417	−8.96	−57.48	0.14	−8.31	−56.60	0.04
KIA 59		27.72028	85.30861	−8.84	−57.24	0.13	−8.36	−56.70	0.18
KIA 60		27.72278	85.30611	−8.79	−57.03	n.d	−8.42	−56.30	0.17
KIA 61	Panipokhari (Panipok.)	27.72893	85.32725	−8.99	−60.18	2.28	−8.22	−53.20	1.07
KIA 62		27.72814	85.32767	−8.33	−59.23	8.11	−8.75	−59.80	0.74
KIA 63		27.7284	85.327	−8.66	−60.18	2.88	−8.70	−59.40	0.27
KIA 64		27.72923	85.32703	−9.05	−59.93	0.18	−8.61	−59.80	0.67
KIA 65		27.7207	85.32623	−8.86	−59.35	0.25	−8.69	−59.90	0.25
KIA 66		27.72179	85.32652	−8.92	−59.55	0.61	−8.70	−59.80	1.03
KIA 67		27.72462	85.3143	−8.82	−59.46	0.86	−8.55	−59.10	0.52
KIA 68		27.72704	85.32294	−8.77	−59.07	0.92	−8.60	−59.20	0.47
KIA 69		27.72745	85.32117	−8.93	−60.14	0.67	−8.92	−60.20	0.33
KIA 71	Simbhanjyang (Sim.)	27.67052	85.28526	−8.95	−63.00	3.32	−8.62	−59.20	1.24
KIA 72		27.67086	85.28954	−8.31	−55.18	0.22	−7.88	−52.20	0.16
KIA 73		27.66802	85.28635	−7.95	−52.91	0.08	−7.88	−51.70	0.16
KIA 74		27.6705	85.27896	−7.81	−52.14	0.24	−7.33	−46.10	0.05
KIA 75		27.66883	85.27677	−7.92	−52.47	0.14	−7.81	−51.90	0.14
KIA 76		27.67042	85.27964	−8.02	−52.52	0.21	−7.71	−52.00	0.15
KIA 77		27.6718	85.28361	−8.04	−52.09	0.20	−7.37	−47.10	0.28
KIA 78		27.67322	85.28158	−8.02	−52.66	0.22	−7.69	−52.20	0.07
KIA 79		27.67528	85.28098	−7.94	−52.98	0.03	−7.70	−52.70	0.14
KIA 80		27.67595	85.28131	−8.06	−52.52	0.18	−7.44	−48.50	0.04

Table 1 (continued)

ID	Associated supply reservoir	Northing	Easting	Wet			Dry		
				δ^{18}O-H_2O	δD	NO_3-N	δ^{18}O-H_2O	δD	NO_3-N
KIA 81	Bansbari	27.675	85.42833	−8.00	−52.91	0.22	−7.59	−51.40	0.02
KIA 82		27.67694	85.43528	−8.92	−59.84	0.55	−8.92	−63.90	0.27
KIA 83		27.68083	85.44444	−8.76	−58.00	0.54	−8.65	−60.10	0.21
KIA 84		27.68583	85.45056	−8.77	−58.47	1.12	−8.90	−63.00	0.33
KIA 85		27.67615	85.4411	−8.16	−55.34	4.20	−8.63	−61.10	0.81
KIA 86		27.67889	85.44472	−8.88	−59.45	0.49	−8.90	−62.00	0.31
KIA 87		27.68889	85.45611	−8.93	−60.60	0.72	−9.03	−64.00	0.29
KIA 88		27.69028	85.46028	−8.80	−59.45	0.36	−8.69	−61.60	0.49
KIA 89		27.69472	85.46333	−8.69	−58.75	0.54	−8.76	−61.50	0.46
KIA 90		27.69611	85.46566	−8.76	−58.70	0.43	−8.98	−63.80	0.22

n.d. not detected

Table 2 Isotopic signatures and NO_3-N data for the reservoirs (isotopic values in ‰ and NO_3-N in mg N/L)

ID	Reservoir	Northing	Easting	Wet			Dry		
				δ^{18}O-H_2O	δD	NO_3-N	δ^{18}O-H_2O	δD	NO_3-N
KIA 91	PID	27.72861	85.325	−8.40	−54.67	0.22	−8.43	−56.70	0.20
KIA 92	Anamnagar	27.70033	85.32589	−8.83	−57.44	0.23	−8.30	−55.60	0.16
KIA 93	Bode	27.69628	85.39402	−9.08	−64.09	0.21	−9.33	−68.00	0.32
KIA 94	Sim	27.67444	85.29222	−8.77	−58.57	0.27	−8.85	−60.50	0.27
KIA 95	Bansbari	27.68889	85.45667	−7.76	−51.37	0.18	−7.56	−51.20	0.08
KIA 96	Sundarighat	27.67444	85.30611	−8.80	−59.99	0.84	−8.14	−56.60	0.57
KIA 97	Chabahil	27.77111	85.35417	−8.82	−58.76	0.19	−8.17	−56.10	0.05
KIA 98	Sainbu	27.64214	85.30314	−8.81	−58.71	0.41	−8.70	−61.10	0.31
KIA 99	Balaju	27.73531	85.30086	−8.47	−56.61	0.86	−8.09	−54.80	0.51

3.1 Nitrate Concentrations of the Reservoir and Tap Water

The NO_3-N concentrations varied spatially and temporally (wet and dry seasons) (Fig. 2). NO_3-N ranged from 0.03 to 8.11 mg N/L during the wet season and from 0.01 to 1.88 mg N/L during the dry season. The average NO_3-N concentration during the wet season was higher (0.54 mg N/L) than during the dry season (0.37 mg N/L). Statistically, the values were found to differ significantly ($p < 0.05$) between the two seasons (Table 3), even though the NO_3-N concentrations in some locations were similar. Similarly, the NO_3-N concentrations of the reservoirs ranged from 0.18 to 0.84 mg N/L during the wet season and from 0.05 to 0.57 mg N/L during the dry season (Table 2). The concentrations of NO_3-N in both the reservoir and tap water samples were below the permissible limit of 10 mg N/L specified by both the World Health Organization (WHO) and the Nepal Drinking Water Quality Standard (NDWQS). However, Schullehner et al. (2018) suggests that when conforming with the permissible limit, the higher concentration of NO_3-N during the dry season possesses risk to the water users.

In general, the water quality of the distribution tank and tap water must be identical. Although chloride (Cl^-) is considered to be a major conservative tracer, Cl^- was not considered in this study, as no free chlorine was measured from the samples. However, the NO_3-N concentrations of the tap water and reservoir samples exhibited differences (Fig. 2). Compared with their respective reservoirs, 10% of the tap

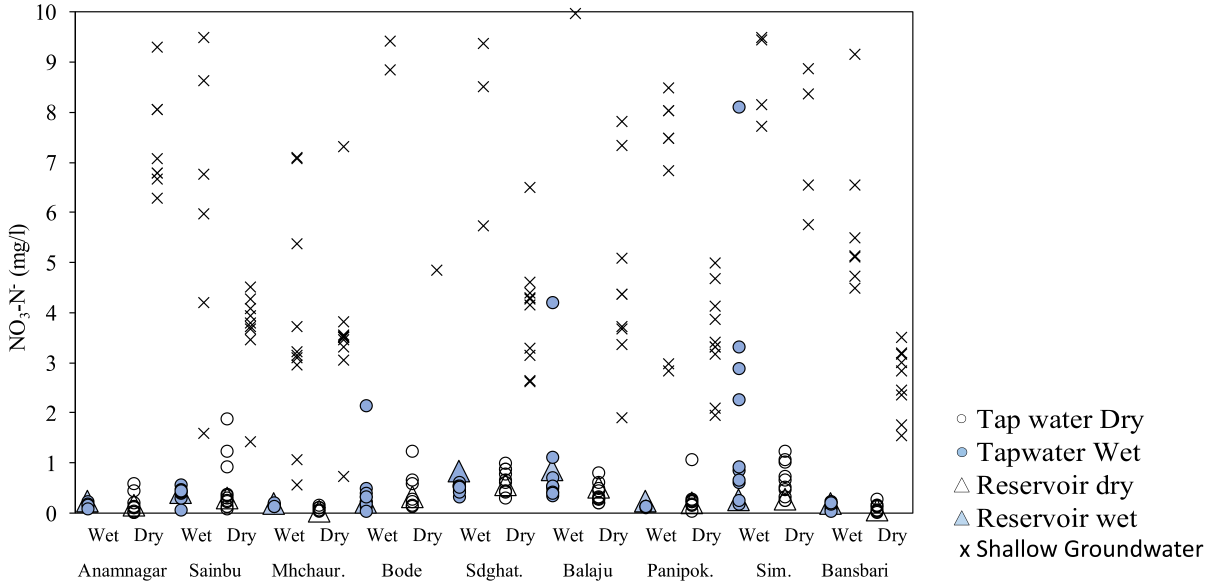

Fig. 2 Reservoir, tap water, and groundwater NO_3-N concentrations. Cross mark plotted at the right of each season represents groundwater NO_3-N (mg/l) concentrations from the nearby tap water location during each consecutive season. Groundwater data are acquired from Shakya et al. (2019b)

Table 3 Correlation matrix between NO_3-N and δD, and seasonal $\delta^{18}O$ of tap water samples

	$NO_3\text{-}N_{wet}$	δD_{dry}	$\delta^{18}O_{dry}$
$NO_3\text{-}N_{wet}$	-	-	-
$NO_3\text{-}N_{dry}$	<0.05*	>0.05	-
δD_{wet}	<0.05*	>0.05	-
$\delta^{18}O_{wet}$	-	-	<0.05*

*Significantly difference

water samples had higher NO_3-N concentrations than the reservoirs during the wet and dry seasons, while 16% of the tap water samples had higher NO_3-N concentrations during the dry season. Anamnagar (dry 2), Sainbu (dry 3), Bode (wet 1, dry 3), Sundarighat (dry 2), Balaju (wet 2, dry 1), Panipokhari (wet 1), and Simbhanjyang (wet 6, dry 5) exhibited local contamination. Such areas of contamination are generally observed due to DNHM in IWS, while little or no contamination is observed in areas with CWS (Erickson et al., 2017, Kumpel and Nelson, 2014). In addition to DNHM, backflow and/or re-suspension of particulate matter induced by low and transient negative pressure during transfer is the governing contamination mechanism (Erickson et al., 2017; Kumpel and Nelson, 2014; van den Berg & Danilenko, 2011). Similarly, in previous studies (Nakamura et al., 2014; Shakya et al., 2019b; Warner et al., 2008), groundwater in the KV was determined to be contaminated by chemical and microbiological components due to the leaky septic systems. Although a time series analysis was not performed, the shifts in NO_3-N concentrations away from the reservoir and close to the groundwater indicate occurrence of various degrees of NO_3-N contaminations from groundwater which is spatially varied by heterogenous anthropogenic nitrogen loading in the subsurface (Nakamura et al., 2014; Shakya et al., 2019b). As shown in Fig. 2, the deflections of tap water concentrations from those of the reservoirs were higher during the dry season, and higher NO_3-N concentrations were observed during the wet season. Similar results regarding the contamination of stored piped water have been reported in the KV during the dry season with a larger supply gap (Shrestha et al., 2013). Although precise conclusions could not be drawn from the NO_3-N concentrations alone, assumptions can be made where the increment in groundwater level and heterogeneously distributed NO_3-N concentration during the wet season might have created such variations. The assumptions follow a study of India and Panama (Erickson et al., 2017), where the degree of intrusion was higher in areas with a lower supply, which can be used to explain the higher NO_3-N deflection during the dry season in the KV. Additionally, high demand and extraction during periods of low-pressure tap water play a vital role in the intrusion (Fontanazza et al., 2015). Compared with the wet season, drinking water demand and extraction in the KV are higher during the dry season (KUKL, 2021), causing contamination backflow in numerous locations. However, 2% of the samples during the dry season and 7% during the wet season had NO_3-N concentrations lower than those of the Sundarighat and Balaju reservoirs (Fig. 2). Such conditions wherein the tap water has lower concentrations of NO_3-N than the reservoirs and lower occurrences of contamination are presumed to be caused by mixing with rainwater having lower NO_3-N concentration.

3.2 Stable Isotopes of Reservoir and Tap Water

The δD and $\delta^{18}O$-H_2O of the tap water ranged from − 66.23 to − 52.1‰ and from − 9.48 to − 7.81‰, respectively, during the wet season, and ranged from − 67.3 to − 46.1‰ and from − 9.38 to − 7.33‰, respectively, during the dry season. Seasonally, δD exhibited no significant changes (> 0.05), while $\delta^{18}O$-H_2O had significant variations (< 0.05). Similarly, the reservoir samples ranged from − 64.09 to − 51.37‰ and from − 9.08 to − 7.76‰, respectively, during the wet season, and ranged from − 51.2 to − 68.0‰ and from − 9.33 to − 7.56‰, respectively, during the dry season (Tables 1 and 2). The isotopic ranges were considerably higher during the dry season than during the wet season (Fig. 2). Among the service areas, Bode had the lightest isotopic values, while Bansbari had the heaviest water isotopic values during both the dry and the wet seasons. A graph of δD vs. $\delta^{18}O$-H_2O (Fig. 3) shows the spatial and temporal variations in the isotopic signatures. As reported by Wet et al. (2020), the degree of evapoconcentration or groundwater intrusion that is recharged under different climatic condition can cause variations in the tap water composition. Compared with the global (GMWL) and local (LMWL) meteoric water lines, which are defined as $\delta D = 8 * \delta^{18}O\text{-}H_2O + 10$ (Craig, 1961) and $\delta D = 8.1 * \delta^{18}O\text{-}H_2O + 12.3$ (Gajurel et al., 2006), respectively, no evidence of evaporation was observed. As the isotopic signatures of deep

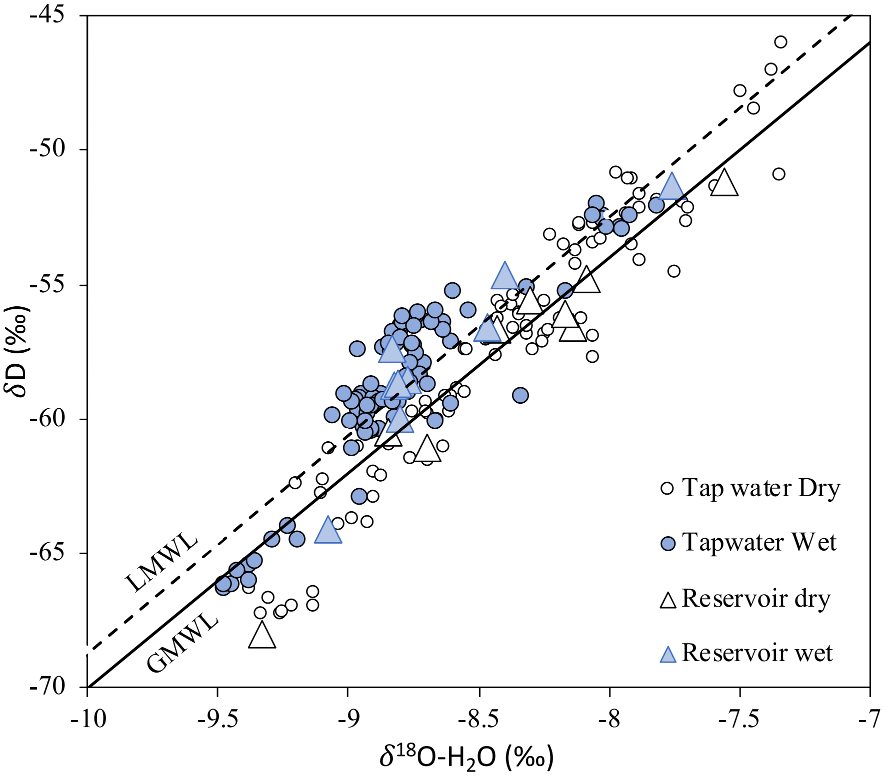

Fig. 3 Plot of δD vs. $\delta^{18}O$-H_2O of the tap water and reservoir samples compared with the global meteoric water line (GMWL) (Craig, 1961) and local meteoric water line (LMWL) (Gajurel et al., 2006)

groundwater are constant throughout the entire year (Chapagain et al., 2009), cluster of the isotopic signatures from reservoirs during the wet season shows the influence of local precipitation during the pre-treatment. However, the contribution of rainfall during pre-treatment is less likely to occur. Additionally, the valley is a closed basin and no intra-basin water transport for tap water network occurred until the study was performed; the variations in the seasonal isotopic signatures are affected by spatially distributed aquifer affected by the local rainfall during the wet season. The isotopic signatures of the tap water sources varied spatially, as their sources are recharged at various altitudes (West et al., 2014; Wet et al., 2020; Zhao et al., 2017). The spatiotemporal variations therefore represent the use of isotopically distinguishable local water sources (Shakya et al., 2019a).

We also compared the δD composition of the tap water samples with that of the reservoirs and the groundwater (Fig. 4). For a threshold of 3‰, 28% of the isotopic values of the tap water samples were displaced away from the values of the reservoirs during the dry season, while 5% were displaced during the wet season. Because evapoconcentration does not cause isotope fractionation, the tap water variations were likely due to groundwater contamination during the drinking water transfer. As with NO_3-N, the spatial isotopic distributions of the tap water sample varied with those of the on-site groundwater (Fig. 4). In addition, the tap water anomalies varied from the respective reservoirs but were similar to the respective on-site shallow groundwater isotopic signatures. Temporally, the δD values were more clustered during the wet season than the dry season The monsoon rainfall accounts for a large part of the groundwater in the KV (Prajapati et al., 2021), and the δD values indicate the rainfall control on the tap water network in the KV.

3.3 Comparison of δD and NO_3-N

The similarities and anomalies observed in the tap water samples provide information on intrusion contamination within the tap water network. Coupled techniques have helped to determine the source and mechanism of various hydrological and hydrogeochemical processes (Umezawa et al., 2009). No significant correlations in spatial variations were observed between NO_3-N and δD in the samples, a phenomenon that might be attributed to changes in the rate of transfer and nearby groundwater condition. In addition, a Pearson correlation

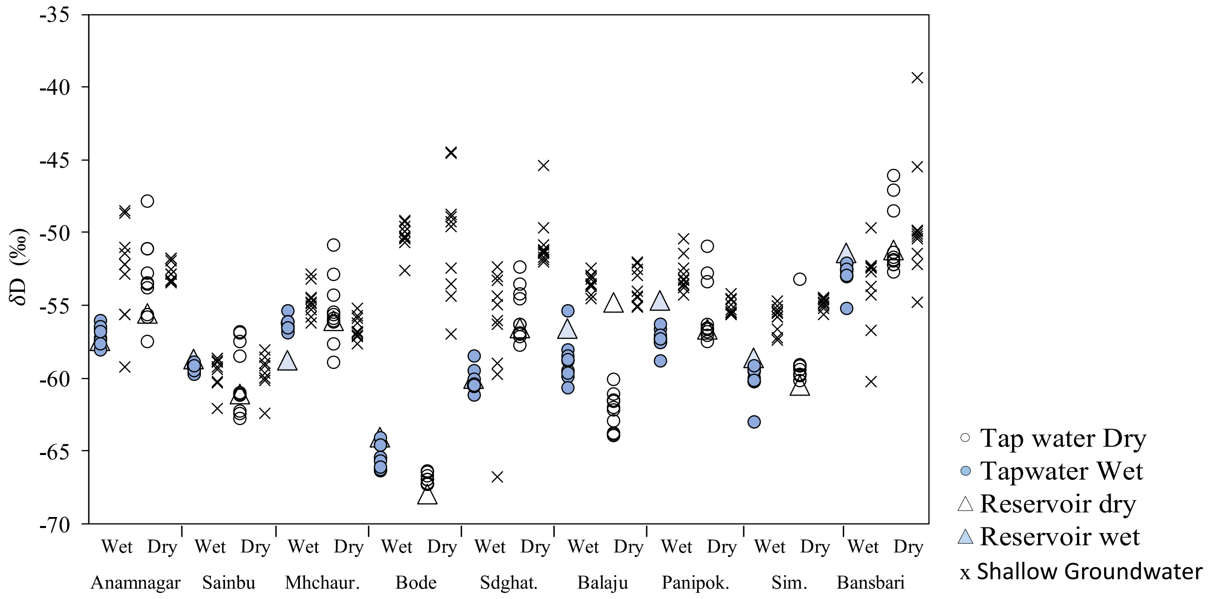

Fig. 4 Isotopic signatures of the tap water samples and those of their respective reservoirs and on-site groundwater. Cross mark plotted at the right of each season represents groundwater δD (‰) concentrations from the nearby tap water location during each consecutive season. Groundwater data are acquired from Shakya et al. (2019a)

indicates similarities between the deflected NO_3-N and δD values. Although only 16% of the samples had higher NO_3-N values than those of the reservoirs during the dry season, similar behaviors were observed for the variations between NO_3-N versus δD and were significantly related (p-value > 0.05). This statistical similarity between higher NO_3-N and δD values reflects intrusions from nearby groundwater sources. Comparisons of the groundwater isotopic values and those of the tap water (Fig. 4) suggest advantages in identifying possible intrusion areas. In contrast, the coherence of the NO_3-N and δD values decreased to < 10% during the wet season, with no significant correlation (p-value < 0.05). This implies the possibilities of rainfall dominated groundwater intrusions creating difficulties in disparity between groundwater and tap water from reservoirs. Uncertainty remains regarding those tap water samples with lower NO_3-N values and similar δD as of the groundwater. This uncertainty may be due to the amount of rainfall infiltration and anthropogenic nitrate loading to the groundwater; however, further mixing analyses are required to confirm this. Although few of the anomalies coincided (i.e., 20 samples for both NO_3-N and δD), the obtained results indicate that δD can be used as a potential indicator in identifying the tap water leakage and groundwater intrusions.

Despite the tap water dynamics caused by the use of various water sources (Bowen et al., 2007; de Wet et al., 2020; Tipple et al., 2017; Zhao et al., 2017), the contamination from the groundwater intrusion was responsible for the variations in the isotopic signatures of the reservoirs and tap water samples. The use of coupled indicators NO_3-N and δD provided a clear picture of nearby groundwater intrusions. Furthermore, comparisons of NO_3-N and δD made between tap water and groundwater signal the locations of groundwater intrusions and backflow whether nearby or far from the end users within tap water network. This also helps the management to identify the areas for immediate maintenance of tap water network. Although the paper lacks information on pressure control during the water supply and water demands, due to constraints in continuous data measurement, this study presents baseline data that can be used to widen the study of tap water using stable isotopes, particularly in developing nations facing IWS.

4 Conclusions

Losses of the municipal supplied water through ruptures and breakages in the tap network during the high pressurized CWS is the major urban water supply issue. However, negative pressure developed during the IWS not only creates water losses but also results in contaminations due to intrusions of the groundwater through the ruptures during water transport from the reservoir to the tap. This study showcased the contamination status especially NO_3-N contamination in the municipal distributed tap water and the cause of contaminations in an area facing IWS. Even when the NO_3-N concentrations were within established drinking water quality standards, a comparative analysis of the tap water, reservoirs, and the surrounding groundwater indicates that up to 10% of NO_3-N from tap water samples were not similar to the reservoirs during the wet season, while the same increased to 16% during the dry season. Those tap water with difference NO_3-N values were found to be close to the groundwater, indicating the possibilities of intrusions. Similarly, the stable isotopic signatures of the tap water samples also varied compared with their respective reservoirs, irrespective of any fractionation caused by evaporation showing 5% variation during the wet and 28% during the dry season. The differences between wet and dry season indicates the control of the rainwater even in the tap water networks of the area with IWS. The positive correlation between NO_3-N and δD indicates groundwater intrusion as one of the prime causes of water quality deterioration within the same distribution area (caused by the low or negative pressure either nearby or far from the end users). Furthermore, this study also depicts the use of δD as a possible tracer for evaluating the tap water conditions when locating the intrusions in the area with IWS.

Despite the fact that pressure control and the water supply vary depending on the distribution network and water demands, we were unable to associate pressure control information with continuous monitoring. Additionally, other conservative hydrochemical and microbiological tracers and pressure information, which can serve as strong supporting information in IWS studies, are not included due to the lack of data availability and will be including as the future task. Nevertheless, this study provided insights into the seasonal variations in NO_3-N concentrations in the area with IWS (KV as an example) and causes of NO_3-N contaminations using δD as a tracer. The tap water variations due to possible foreign water interactions and differences of δD from reservoir to the tap mentioned in this study are expected to establish the baseline in creating precise tap water studies, particularly in low-income countries.

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Data Availability The excel file of analyzed tap water data and reservoir water that supports the findings of this study are all available in repository "figshare" and cited as Shakya et al. (2021).

Data are presented in "Tap water contamination status of an intermittent water supply_.xlsx." The tap water data are presented in Table 1 while the reservoir water sample data are presented in Table 2.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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