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RESEARCH ARTICLE

Stone Spout Water Quality for Drinking Purposes in Kathmandu Metropolitan: An Assessment Using Water Quality Index

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Abstract

Stone spouts, emblematic of the Kathmandu Valley culture, represent traditional water supply systems with religious, cultural, spiritual, and economic importance. The water sources in the valley partially meet the drinking water requirements of the residents. The study aims to assess the water quality of the traditional stone spouts located in Kathmandu Metropolitan City by using the water quality index (WQI). Water samples were collected from twenty stone spouts within the metropolitan area during the pre-monsoon period (May 2024). Ten selected physicochemical parameters *viz.*, electrical conductivity, total dissolved solids, pH, total hardness, ammonia, fluoride, chloride, nitrate, sulfate, and total iron were examined, and the water quality was assessed using the WQI. Ammonia, fluoride, nitrate, and iron were identified as the main issues in many sampled stone spouts exceeding the permissible limits of NDWQS (2022). The results indicated that the WQI values varied between 19 and 330, with the majority of samples collected from the stone spouts classified as grade E, suggesting that they are unsuitable for drinking. Out of the stone spouts examined, only Gyan dhara and Pepsicola dhungedhara fall under grade A according to the WQI. Linear regression analysis indicated that as TDS and iron levels increase, the WQI also increases. Results suggested that prompt measures are needed to properly treat spout water to reduce contaminants. The study's results are expected to provide the concerned authorities with essential information about the water quality of the Kathmandu metropolitan stone spouts for the continued sustainability of the traditional water supply systems.

Keywords: Linear regression; NDWQS; Physicochemical; Water quality; Water quality testing

Introduction

Stone spouts, locally known as Dhungedhara in Nepali and Hiti in Newari, have been the traditional water supply systems in Kathmandu Valley for centuries. These spouts, primarily in Kathmandu Valley, were the initial hydraulic structures employed in Nepal for collecting and distributing drinking water [1]. The primary water sources for stone spouts were ancient canals (Rajkulos), shallow aquifers, and springs [2]. The water spouts, a symbol of the Kathmandu Valley civilization, continue to provide drinking water for many urban dwellers. The construction of these stone spouts in the

Valley, which hold historical and cultural importance, is associated with the Kirats' early settlements, followed by the Lichchhavi era, and later expanded during the Malla rule [3]. During the 17th century, the Malla rulers of the Valley began a significant water supply project. King Pratap Malla of Kathmandu (1641–74) and King Jitamitra Malla of Bhaktapur (1673–96) built extensive canals known as Rajkulo for religious reasons and to supply water to conduits and farmlands [4]. During the time of the Lichchhavi rulers, these stone spouts were called *Kirti*, which means 'merit', and later on during the Malla dynasty they became popularly known as *Hiti*, meaning 'tap'. Various monuments and scriptures provide evidence of stone spouts dating back to the Lichchhavi period in Nepalese history. During the Shah era (1768–2008 CE), the construction of stone spouts slowly declined, with only a few spouts built during the Rana regime (1846-1951 AD). When private taps were expanded in the 1950s by the last Rana rulers and other elected rulers, spout water was gradually abandoned and even considered unhealthy and polluted. At the same time, new development projects and other construction activities on the land limited the recharging capacity of traditional spouts leading to a very vulnerable and impoverished condition [2, 5].

Pradhan [6] estimated that more than 95% of the stone spouts are located in Kathmandu Valley and play a crucial role in providing drinking water to the local communities. Amatya [7] revealed that there were a large number of traditional stone water spouts in the Valley: 237 in Kathmandu, 77 in Lalitpur, and 53 in Bhaktapur. Similarly, Upadhya et al. [8] found a total of 287 stone spouts in the Valley, with 128 in Kathmandu, 101 in Lalitpur, and 58 in Bhaktapur. During their surveys, they noted a total of 146 flowing stone spouts in September 2018 (post-monsoon) and 112 in March 2019 (pre-monsoon). Additionally, 69 stone spouts were reported flowing, and 59 dried in Kathmandu alone. In 2019, the Kathmandu Valley Water Supply Management Board (KVWSMB) reported 573 spouts in the Valley, with 94 of them being lost [9]. Among the 479 available spouts, 224 were found flowing at the time of the survey. These functional spouts were the primary source of drinking water for low-income households and had a total discharge of 2.43 MLD (million liters per day). In Kathmandu Metropolitan, there were a total of 179 stone spouts, with 52 of them being lost completely. Out of the 127 stone spouts surveyed, 79 were dry, 8 had water droplets, and 40 had flowing water, with a combined discharge of 0.38 MLD [9].

The rapid population growth and unplanned urbanization in the Kathmandu Valley are increasing water demand. Besides, the Valley is also characterized by its deteriorated water quality and water shortage, particularly in the dry season [10]. In 2021, the Valley's water demand was 470 MLD, and the supply was 106 MLD during the wet season and 80 MLD during the dry season [11]. The average daily production was 126.55 MLD (inclusive of 84.93 MLD surface water and 41.63 MLD groundwater). Still, the Valley faces a significant gap between supply and demand. The usage of shallow and deep groundwater resources is expanding to address the supply-demand gap. Even though KUKL has begun dispensing the highly anticipated Melamchi water on a test run after the Melamchi Water Supply Project (MWSP)'s completion in 2021, there will remain a notable disparity between the supply and demand in the Valley because of the fast urban growth and daily water consumption behaviors [12]. In such limited circumstances, traditional stone spouts can meet the water needs of certain communities. Nonetheless, these spouts are deteriorating because of excessive groundwater extraction, relentless development, and pollution from sewage, septic tanks, and industrial waste [12]. Despite being dry for several months almost every year, many traditional wells and stone spouts are still in operation, particularly during the monsoon season when water levels rise.

Residents of the Kathmandu Valley use groundwater sources such as stone spouts, dug wells, and tube wells for their daily needs. Shallow groundwater quality, such as stone spout water, easily changes with the presence of contaminants [13]. The unpredictable nature of shallow groundwater is a public health concern because it is closely connected to human well-being. People generally perceive spout water to have better quality and consider it fit for drinking. Nonetheless, several research studies have indicated the existence of pollutants in spout water. Pathak and Hiratsuka [14] as well as Karkey et al. [15] found elevated levels of nitrate in shallow groundwater (including stone spout water) in Kathmandu Valley, exceeding WHO recommendations. A study by Shakya et al. [16] found increased levels of total hardness and nitrate in water samples collected from the stone spouts within Kathmandu municipality. Likewise, research carried out by Bajracharya et al. [17], Karki et al. [18], Gaire et al. [19], Paudel and Basi-Chipalu [20] and Shrestha et al. [21] indicated the existence of different chemical and microbial pollutants in the Valley's groundwater including spout water. An in-depth analysis of the existing literature reveals that only limited research studies have focused on the water quality of stone spouts in Kathmandu Metropolitan. Furthermore, there is a lack of assessment regarding the water quality status using an appropriate water quality index in the individual stone spout in the metropolitan city. Integrating a water quality index (WQI) would combine all water quality parameters and assist in assessing the status of drinkability. As shallow groundwater quality is influenced by groundwater extraction, population increase, changes in land use, and urban development, it is essential to monitor the quality of spout water regularly. Therefore, this study aims to evaluate the water quality of stone spouts located in the Kathmandu metropolitan for drinking purposes in compliance with NDWQS [22] guidelines using a water quality index (WQI).

Materials and Methods

Study Area

In this study, required information regarding the status of local traditional stone spouts was first collected through field surveys, relevant municipal wards of Kathmandu Metropolitan City, and discussions with local key informants.

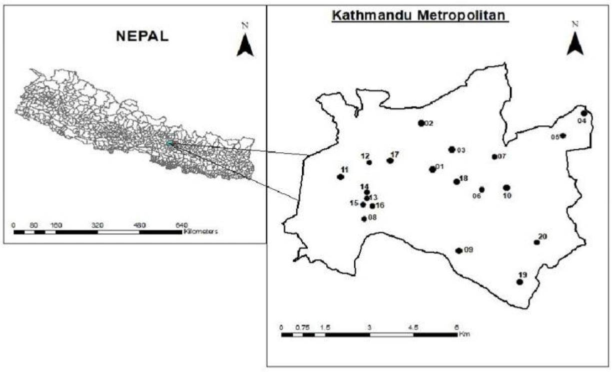

Fig. 1: Map of the study area and sampling locations indicating stone spouts within the Kathmandu Metropolitan.

Our field survey, carried out in the pre-monsoon period (May 2024), identified 40 flowing spouts, consistent with the earlier report [9]. From 40 flowing spouts, we selected only 20 spouts on a lottery basis for the study. Accordingly, the study area and sampling locations were designated using the global positioning system (GPS), illustrated in **Fig. 1**, and details are given in **Table 1**.

Table 1: Name and location of stone spouts in Kathmandu Metropolitan

Sample code	Name of stone spouts	Location	Latitude	Longitude
SS01	Naxal Dhara	Naxal	27.7134° N	85.3253° E
SS02	Ranibari Dhungedhara	Ranibari	27.7290° N	85.3229° E
SS03	Bhatbhateni Dhara	Bhatbhateni	27.7202° N	85.3313° E
SS04	Aru Bari Dhara	Aru Bari Similtar	27.7321° N	85.3723° E
SS05	Tinchuli Dhara	Baudha	27.7260° N	85.3660° E
SS06	Darshan Dhara	Ram Mandir Tole	27.7079° N	85.3410° E
SS07	Balganesh Dhara	Pashupati, Bankali	27.7181° N	85.3449° E
SS08	Pakku Dhara	Teku	27.6977° N	85.3050° E
SS09	Sajha Dhara	Buddhanagar	27.6877° N	85.3339° E
SS10	Kriyaputri Dhara	Pashupati	27.7081° N	85.3480° E
SS11	Bhut Hiti	Banasthali	27.7124° N	85.2979° E
SS12	Kal Dhara	Paknajol	27.7164° N	85.3068° E
SS13	Maru Hiti	Maru Tole	27.7045° N	85.3054° E
SS14	Banja Hiti	Banju Tole	27.7055° N	85.3055° E
SS15	Bhindhyo Hiti	Bhimsensthan	27.7026° N	85.3043° E
SS16	Ko Hiti	Kohiti Marga	27.6672° N	85.3045° E
SS17	Gaa Hiti	Thamel	27.7174° N	85.3128° E
SS18	Gyan Dhara	Bhairab Galli	27.7099° N	85.3336° E
SS19	Jadibuti Dhara	Swora Galli	27.6768° N	85.3523° E
SS20	Dungedhara	Pepsicola	27.6892° N	85.3578° E

Sample Collection and Analyses

Water samples were collected from the sampling locations following standard procedures of the American Public Health Association (APHA) [23]. The collecting 1 L capacity PET bottles were thoroughly acid-washed and distilled water rinsed to prevent any potential contamination. All samples were collected early in the morning to reduce the effects of temperature on other measurements and to prevent human interference. Three replicates of water samples from each stone spout were taken at different time intervals throughout the study period, all within the same morning hours to measure possible variations in the studied parameters. Each water sample was clearly labeled, stored in ice boxes, and immediately brought to the chemistry laboratory of Padmakanya Campus, Bagbazar and Aastha Scientific Research Service Pvt. Ltd., Dillibazar, Kathmandu as per the instrumental facilities and to ensure testing on the same day. When immediate analysis was not possible, the samples were kept in a refrigerator at 4 °C for preservation. To analyze total iron, 2 ml of nitric acid (analytical grade) was added to each sample to ensure a pH range of 2–3 after the acidification. The samples were pre-filtered in the laboratory before conducting the analysis. In this study, a total of 10 water quality parameters were analyzed according to standard testing methods [23] in the laboratory, except pH, electrical conductivity (EC), and total dissolved solids (TDS). The three physical parameters were recorded on-site with portable instruments (pH, EC, and TDS meters), while the other chemical parameters were analyzed in the laboratories as mentioned earlier. The test parameters, analytical methods, and instruments used for the analyses are presented in **Table 2**.

Table 2: Test parameters, analytical methods, and instruments used for water quality analyses

S.N.	Physicochemical parameters	Unit	Methods of analyses	Instruments
1.	Electrical conductivity (EC)	µS/cm	Conductivity meter	Hanna DiST3 Tester (HI98303)
2.	Total dissolved solids (TDS)	mg/L	TDS meter	EI Electronics-651
3.	pH	-	pH meter	Hanna HI98100
4.	Total hardness (TH) as $CaCO_3$	mg/L	EDTA titrimetric method	-
5.	Ammonia (NH_3)	mg/L	Colorimetric method using Nessler's reagent	Shimadzu 1800 spectrophotometer
6.	Fluoride (F^-)	mg/L	Colorimetric method using alizarin red S	”
7.	Chloride (Cl^-)	mg/L	Argentometric method	-
8.	Nitrate (NO_3^-)	mg/L	Colorimetric method using brucine sulphate heptahydrate	Shimadzu 1800 spectrophotometer
9.	Sulphate (SO_4^{2-})	mg/L	Colorimetric method using methylene blue	”
10.	Total iron (Fe)	mg/L	Colorimetric method using 1,10-phenanthroline	”

Water Quality Index (WQI)

The water quality index (WQI) was assessed using the recommended drinking water quality standards set by the National Drinking Water Quality Standard (NDWQS) [22]. Among numerous water quality indices, the weighted arithmetic method was employed to calculate the WQI for each water sample. The index was initially proposed by Horton [24] and later developed by Brown et al. [25]. The WQI is a mathematical tool that condenses large amounts of data into one integer. It represents the degree of water quality while reducing potential biases and subjective assessments from water quality experts. The weighted arithmetic water quality index (WQI) is calculated in the following way:

$$WQI = \sum_{i=1}^{n} WiQi \Big/ \sum_{i=1}^{n} Wi \qquad (1)$$

where, n = number of variables or parameters, Wi = unit weight for the *i*th parameter, Qi = quality rating (sub-index) of the *i*th water quality parameter. The unit weight (Wi) for each water quality parameter is calculated by using Eq. (2):

$$Wi = K/Si \qquad (2)$$

where, Wi = unit weight for the *i*th parameter, Si = recommended standard value for *i*th parameters, K = proportionality constant. The following equation can be used to compute the value of K:

$$K = 1/\sum\left(1/Si\right) \qquad (3)$$

According to Brown et al. [25], the quality rating or sub-index (Qi) is calculated using the equation below:

$$Qi = 100\left[\left(Vo - Vi\right)/\left(Si - Vi\right)\right] \qquad (4)$$

where Vo = measured concentration of *i*th parameter in the analyzed water, Vi = ideal value of *i*th parameter in pure water. All the ideal values (Vi) are considered zero for pure water, except pH [26]. For pH, the ideal value remains 7.0 (for natural/pure water) while the permissible limit is 8.5. Subsequently, the quality of water was classified as excellent, good, poor, very poor, or unsuitable based on WQI values as depicted in **Table 3** [25, 27].

Table 3: Water quality rating according to WQI.

WQI value	Water quality rating	Grading
0 – 25	Excellent water quality	A
26 – 50	Good water quality	B
51 – 75	Poor water quality	C
76 – 100	Very poor water quality	D
>100	Unsuitable for drinking purposes	E

The Statistics

Data processing and analysis were performed using Excel spreadsheets on an IBM PC. Descriptive statistical metrics like mean, range and standard deviation were employed to present the data as needed. Where relevant, linear regression analysis was also performed.

Results and Discussion

Physicochemical Characteristics of Spout Water

Table 4: Physicochemical characteristics of spout water of Kathmandu Metropolitan (n=3).

Sample code	EC (µS/cm)	TDS (mg/L)	pH	TH (mg/L)	NH_3 (mg/L)	F^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	SO_4^{2-} (mg/L)	Fe (mg/L)
SS01	920	435	7.6	205	1.58	1.87	108.3	64.6	15.3	0.19
SS02	568	274	7.1	144	0.52	0.80	57.5	22.1	6.5	0.07
SS03	611	330	6.5	159	1.04	0.47	69.5	41.7	6.0	0.19
SS04	394	205	6.8	115	0.10	0.85	46.3	12.1	9.4	0.18
SS05	467	252	8.0	131	0.24	0.62	59.2	22.8	7.1	0.42
SS06	455	235	6.7	130	0.22	0.76	52.8	36.5	6.9	0.20
SS07	440	210	6.6	125	0.20	0.78	50.9	20.5	7.0	0.36
SS08	1640	852	7.7	381	4.60	3.50	219.3	135.8	51.2	0.92
SS09	838	390	6.9	187	1.58	1.98	107.9	58.2	12.7	0.30
SS10	445	236	6.9	129	0.22	0.72	55.4	28.3	5.1	0.24
SS11	760	358	6.5	179	1.48	0.85	99.6	44.3	7.7	0.22
SS12	527	260	7.2	137	0.42	0.62	61.8	120.8	3.8	0.45
SS13	1105	547	6.8	231	1.72	1.95	138.6	109.3	29.2	0.22
SS14	1215	635	6.7	279	2.70	2.52	168.2	128.2	36.7	0.57
SS15	1158	561	6.9	255	1.86	3.02	146.7	124.8	26.9	0.24
SS16	1100	535	6.7	223	1.65	2.05	127.2	94.0	18.5	0.20
SS17	615	320	7.1	161	0.65	0.97	98.5	48.0	5.9	0.30
SS18	594	308	6.6	154	0.62	0.39	65.8	30.6	7.8	0.02
SS19	342	192	6.7	108	0.02	0.09	38.2	18.9	3.9	0.12
SS20	254	135	6.5	80	0.02	0.11	34.4	13.5	2.7	0.09
Overall mean	722	364	6.9	176	1.07	1.25	90.3	58.8	13.3	0.28
Min.	254	135	6.5	80	0.02	0.09	34.4	12.1	2.7	0.02
Max.	1640	852	8.0	381	4.60	3.50	219.3	135.8	51.2	0.92
SD	362	181	0.4	71	1.13	0.97	49.3	43.3	12.9	0.20
NDWQS [22]	1500	1000	6.5-8.5	500	1.5	0.5-1.5	250	50	250	0.3

Table 4 presents the mean values of the ten selected physicochemical parameters from the sampled spout water.Results indicate that the physicochemical characteristics of the spout water exhibited significant variability, likely due to variations in soil type, geological conditions, and pollution levels across different locations [28]. Dissolved solids, including various inorganic materials and ions such as chlorides, sulfides, and carbonates, conduct electrical currents in water [16]. Consequently, electrical conductivity (EC) serves as an indicator of the water's ion content or salinity. This study's EC values range from 254 µS/cm (SS20; Pepsicola dhungedhara) to 1640 µS/cm (SS08; Pakku dhara), averaging 722 µS/cm. Results reveal that the EC levels of water samples from all stone spouts, except SS08, are within the acceptable limit set by NDWQS [22]. When EC exceeds the permissible limit, it may induce corrosive properties in water and negatively affect its aesthetic quality [29]. Total dissolved

solids (TDS) are an important measurement for water quality that can indicate pollution or the presence of contaminants, and impact the water's suitability for drinking and other uses. In this study, it is very strongly and linearly correlated with EC (**Fig. 2**).

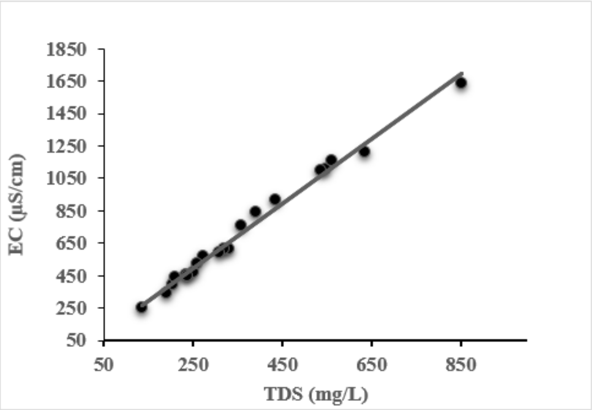

Fig. 2: Linear correlation between EC and TDS.

The TDS parameter varies from 135 mg/L at SS20 (Pepsicola dhungedhara) to 852 mg/L at SS08 (Pakku dhara), and an overall mean of 364 mg/L, which remains within the acceptable limit (**Table 4**). If the levels of TDS exceed the threshold, it may restrict the utility of water for drinking, irrigation, and industrial applications [29]. TDS encompasses calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, iron, lead, and copper, as well as humic substances and various other organic compounds. The main sources of TDS include agricultural practices, runoff from residential areas, soil leaching leading to contamination, and point source pollution from industrial or sewage treatment facilities [30]. pH is an important water quality parameter and is a crucial indicator for evaluating the quality and contamination of any aquifer system, as it is closely linked to other chemical components in water [31]. It is not static as it fluctuates over time and can change throughout the day. The leaching of soils, organic matter, and rocks is affected by pH. As per NDWQS [22], the acceptable pH range for drinking water is 6.5 to 8.5. In this study, the pH range in all tested water samples varies between 6.5 and 8.0 (overall mean 6.9), which is within the permissible range. This study's results align with those of Shakya et al. [16] and Bajracharya et al. [17], who also reported that the pH values of various water sources remained within the acceptable range. When the permissible limit of pH is crossed, it can harm aquatic organisms, by affecting different chemical components in water, including ammonia, hydrogen sulfide, and heavy metals [32].

In this study, the hardness of water ranges from 80 mg/L at SS20 (Pepsicola dhungedhara) to 381 mg/L at SS08 (Pakku dhara), with an average of 176 mg/L overall. All total hardness values from the analyzed water samples comply with the acceptable limits set by the NDWQS guidelines. Hardness in water results from the presence of dissolved calcium, and to a lesser extent, magnesium. Most natural waters contain bicarbonates as the prevalent ions, primarily associated with calcium rather than magnesium [33]. Major contributors of calcium and magnesium include sewage and industrial waste. While water hardness is not known to have negative health effects, some studies suggest it may be linked to health concerns such as cardiovascular issues, kidney stones, growth delays, and reproductive problems in people [34, 35]. Additionally, the primary effects of hardness involve scale buildup, scum formation, and an increased need for soap to create lather. Ammonia present in water serves as an indicator of potential contamination from bacteria, sewage, and animal waste. It is typically introduced through organic waste disposal, runoff from fertilizers, and sewage systems [36]. In this study, SS08 (Pakku dhara) exhibits notably elevated ammonia levels (4.6

mg/L) compared to other surveyed stone spouts, exceeding the permissible limit (1.5 mg/L). Additionally, the ammonia concentrations in SS01 (Naxal dhara), SS09 (Sajha dhara), SS13 (Maru Hiti), SS14 (Banja Hiti), SS15 (Bhindhyo Hiti), and SS16 (Ko Hiti) also cross the maximum allowed levels according to the NDWQS standard, in line with the findings by Bajracharya et al. [17] concerning traditional dug well water in Lalitpur metropolitan. The presence of ammonia in water can pose health risks as it has the potential to convert into nitrate [37]. Elevated ammonia levels in drinking water may result in symptoms such as tremors in the arms or hands, drowsiness, agitation, lethargic movements, and personality changes [36]. Iron is found in various natural sources such as lakes, rivers, and groundwater, including soil, sediments, and rocks. The most prevalent source of iron in groundwater is the weathering of iron-containing minerals and rocks [31]. In aquifers, iron naturally exists in the reduced Fe^{2+} state, but its dissolution elevates its concentration in groundwater. The oxidized form of iron (Fe^{3+}), is insoluble in water and tends to form a brown-red precipitate. In this study, total iron levels range from 0.02 mg/L (Gyan dhara) to 0.92 mg/L (SS08; Pakku dhara) with an overall mean of 0.28 mg/L. Among the studied stone spouts, SS05 (Tinchuli dhara), SS07 (Balganesh dhara), SS08 (Pakku dhara), SS12 (Kal dhara), and SS14 (Banja dhara) exhibit iron concentrations that exceed the permissible limit of 0.3 mg/L (**Table 4**). While iron generally poses little health risk, higher concentrations can still be considered a nuisance.

Fluoride can be released from fluoride-rich minerals found in the surrounding rocks and soil, particularly in regions with high geological fluoride levels [38]. Pesticides or fertilizers containing fluoride can raise fluoride concentrations in adjacent water sources [39]. Furthermore, urban development and construction can disrupt soil and rock layers, which may release fluoride [40]. In this study, fluoride concentrations vary from 0.09 to 3.91 mg/L, with an average of 1.25 mg/L overall. SS08 (Pakku dhara) records the highest fluoride concentration, while SS19 (Jadibuti dhara) indicates the lowest. The fluoride levels cross the permissible limit (1.5 mg/L) in SS01 (Naxal dhara), SS08 (Pakku dhara), SS09 (Sajha dhara), SS13 (Maru Hiti), SS14 (Banja Hiti), SS15 (Bhindhyo Hiti), and SS16 (Ko Hiti). Depending on the fluoride concentration and duration of exposure, water containing fluoride can lead to various health issues in humans, including dental and skeletal fluorosis, thyroid problems, and potential neurological effects [41]. Chloride is naturally present in all forms of freshwater and groundwater at different concentration levels. The ions are highly mobile and can infiltrate groundwater from natural sources, sewage, industrial discharges, urban runoff that contains de-ionizing salts, landfill leachates, and drainage from irrigation [42]. Elevated chloride levels can impart a salty flavor to water. In this study, the chloride concentration in stone spout water ranges from 34.4 mg/L (SS20; Pepsicola dhungedhara) to 219.3 mg/L (SS08; Pakku dhara) with an average of 90.3 mg/L overall, with all tested samples remaining below the permissible limit (250 mg/L) established by NDWQS [22]. These results are consistent with findings from Karki et al. [18], and Paudel and Basi-Chipalu [20], who also indicated a safe chloride threshold in water samples from various sources in Kathmandu. While low chloride levels in drinking water do not generally pose health risks, excessive chloride intake can lead to hyperchloremia, which is characterized by elevated chloride levels in the blood [43].

Nitrate found in groundwater originates from various sources, including soil organic matter, urban runoff, landfills, septic tanks, municipal sewage, and animal waste [44]. Concentrations greater than 3.0 mg/L frequently indicate human influence [45]. In the study area, nitrate levels vary, with SS04 (Arubari dhara) measuring 12.1 mg/L and SS08 (Pakku dhara) reaching 135.8 mg/L (overall mean 58.8 mg/L). The nitrate concentrations at SS01 (Naxal dhara), SS08 (Pakku dhara), SS09 (Sajha dhara), SS12 (Kal dhara), SS13 (Maru Hiti), SS14 (Banja Hiti), SS15 (Bhindhyo Hiti), and SS16 (Ko Hiti) exceed the acceptable limit of 50 mg/L set by NDWQS [22]. Elevated nitrate levels in drinking water increase the risk of gastric ulcers/cancer and pose other health risks to infants and pregnant women (Rao 2006), as well as potential birth defects and hypertension [46]. Moreover, infants exposed to nitrate concentrations above 10 mg/L may develop blue baby syndrome, or methemoglobinemia [47]. Potential contaminations of sulfate in groundwater or stone spout water in urban areas may involve industrial processes, wastewater releases, landfills, sulfate-containing fertilizers, the dissolution of sulfate minerals such as gypsum, construction and demolition activities, and the use of road salts [48]. Urban regions can experience high levels of acid rain, which may elevate sulfate levels in groundwater. This study's results indicate that sulfate concentrations range from 2.7 mg/L (SS20; Pepsicola dhungedhara) to 51.2 mg/L (SS08; Pakku dhara) and an average of 13.3 mg/L overall. All analyzed water samples remain within the acceptable limit of 250 mg/L set by NDWQS [22]. Excessive sulfate concentrations in water can pose various health risks to humans, including diarrhea, gastrointestinal issues, and dehydration [49]. Elevated sulfate concentrations may give water a bitter taste, reducing its palatability. Moreover, sulfates can accelerate the corrosion of plumbing systems, which may cause the leaching of heavy metals such as lead or copper into drinking water, potentially resulting in serious health issues [50].

Water Quality Index (WQI)

The water quality index (WQI), determined using ten physicochemical parameters, has been computed following the drinking water quality standards set by NDWQS [22] guidelines. The WQI serves as an effective means of assessing the general quality of water. **Table 5** presents the prescribed standards and calculated values for water quality used in the computation of the WQI.

Table 5: Water quality standards, proportionality constant (K), and calculated unit weight (Wi) for each parameter

Parameters	Si	1/Si	K	Wi
EC	1500	6.67×10^{-4}	0.208	1.38×10^{-4}
TDS	1000	1.00×10^{-3}		2.08×10^{-4}
pH	8.5	1.18×10^{-1}		2.44×10^{-4}
TH	500	2.00×10^{-3}		4.15×10^{-4}
NH_3	1.5	6.67×10^{-1}		1.38×10^{-1}
F^-	1.5	6.67×10^{-1}		1.38×10^{-1}
Cl^-	250	4.00×10^{-3}		8.31×10^{-4}
NO_3^-	50	2.00×10^{-2}		4.15×10^{-3}
SO_4^{2-}	250	4.00×10^{-3}		8.31×10^{-4}
Fe	0.3	3.33		6.92×10^{-1}
-	-	$\sum 1/Si = 4.816$		$\sum Wi = 1.00$

The WQI for stone water spouts in the Kathmandu metropolitan area is shown in **Table 6**. Results reveal that most of the water samples collected from the stone spouts are unsuitable for drinking. The WQI values for all sampled water range from 19 to 330, classifying the water quality from grade A to E. Of the 20 stone spouts examined, water samples from 9 (SS05, SS07-SS09, and SS12-SS16) fall under grade E, indicating they are unsuitable for drinking. In contrast, only 2 stone spouts (SS18 and SS20) received a grade A rating, reflecting excellent water quality and confirming that these sources are safe for drinking and other uses.

Table 6: Water quality index (WQI) of the spout water, Kathmandu metropolitan

S.	Qi										∑Qi	**WQI**	WQR	GRD
code	EC	TDS	pH	TH	NH_3	F^-	Cl-	NO_3^-	SO_4^{2-}	Fe				
SS01	61.3	43.5	40.0	41.0	105.3	280.5	43.3	129.2	6.1	63.3	813.6	99	VP	D
SS02	37.9	27.4	6.7	28.8	34.7	120.0	23.0	44.2	2.6	23.3	348.5	38	GD	B
SS03	40.7	33.0	-33.3	31.8	69.3	70.5	27.8	83.4	2.4	63.3	455.6	64	PR	C
SS04	26.3	20.5	-13.3	23.0	6.7	127.5	18.5	24.2	3.8	60.0	323.6	61	PR	C
SS05	31.1	25.2	66.7	26.2	16.0	93.0	23.7	45.6	2.8	140.0	470.3	114	UFD	E
SS06	30.3	23.5	-20.0	26.0	14.7	114	21.1	73.0	2.8	66.7	392.1	65	PR	C
SS07	29.3	21.0	-26.7	25.0	13.3	117	20.4	41.0	2.8	120.0	416.5	102	UFD	E
SS08	109.3	85.2	46.7	76.2	306.7	525.0	87.7	271.6	20.5	306.7	1835.5	330	UFD	E
SS09	55.9	39.0	-6.7	37.4	105.3	297.0	43.2	116.4	5.1	100.0	805.9	126	UFD	E
SS10	29.7	23.6	-6.7	25.8	14.7	108.0	22.2	56.6	2.0	80.0	369.2	73	PR	C
SS11	50.7	35.8	-33.3	35.8	98.7	127.5	39.8	88.6	3.1	73.3	586.6	83	VP	D
SS12	35.1	26.0	13.3	27.4	28.0	93.0	24.7	241.6	1.5	150.0	640.7	122	UFD	E
SS13	73.7	54.7	-13.3	46.2	114.7	292.5	55.4	218.6	11.7	73.3	954.1	108	UFD	E
SS14	81.0	63.5	-20.0	55.8	180.0	378.0	67.3	256.4	14.7	190.0	1306.7	210	UFD	E
SS15	77.2	56.1	-6.7	51.0	124.0	453.0	58.7	249.6	10.8	80.0	1167.0	137	UFD	E
SS16	73.3	53.5	-20.0	44.6	110.0	307.5	50.9	188.0	7.4	66.7	921.9	105	UFD	E
SS17	41.0	32.0	6.7	32.2	43.3	145.5	39.4	96.0	2.4	100.0	538.5	96	VP	D
SS18	39.6	30.8	-26.7	30.8	41.3	58.5	26.3	61.2	3.1	6.7	325.0	19	EXC	A
SS19	22.8	19.2	-20.0	21.6	13	13.5	15.3	37.8	1.6	40.0	193.1	30	GD	B
SS20	16.9	13.5	-33.3	16.0	13	16.5	13.8	27.0	1.1	30.0	169.4	24	EXC	A

WQR: Water quality rating; GRD: Grading; EXC: Excellent; GD: Good; PR: Poor; VP: Very poor; UFD: Unsuitable for drinking

The findings suggest that human activities, such as extensive use of fertilizers, septic tank leaks, and the discharge of organic materials, significantly affect the water quality in the study area [28]. Similarly, only 2 stone spouts (SS02 and SS19) fall under grade B, which signifies they provide good water quality. This water is appropriate for domestic, agricultural, and commercial use [21]. Four stone spouts (SS03, SS04, SS06, and SS10) are classified as grade C, providing low water quality that can solely be utilized for irrigation and industrial applications. Three stone spouts (SS01, SS11, and SS17) are classified as grade D, supplying very poor-quality water. Shrestha et al. [21] also indicated that most groundwater from different sources in the Kathmandu Valley is unfit for drinking. Similar conclusions were drawn by Gaihre et al. [19] and Maharjan et al. [51]. However, Adhikari et al. [28] found good water quality in stone spouts when evaluating drinking water quality from various sources in the squatter settlements along the Bagmati River corridors in Kathmandu. In this study, we analyzed linear regression to evaluate the relationship between the water quality index (response variable) and the selected physicochemical parameters (explanatory variables). Subsequently, only the regression analysis of parameters (TDS and total iron) based on R^2 (coefficient of determination) values that could significantly impact the WQI of spout water is discussed here. Accordingly, the linear regression between WQI and TDS demonstrates that an increase in the WQI ($y = 0.3277x - 18.801$, $R^2 = 0.7105$) is correlated with an increase in TDS (**Fig. 3a**). Similarly, a linear regression between WQI and iron also reveals that the WQI increases ($y = 330.03x + 9.5672$, $R^2 = 0.896$) as the iron level does (**Fig. 3b**), similar to the study by Shrestha et al. [21]. The TDS may impact clarity and water quality. The presence of different dissolved substances, such as salts, minerals, and organic materials, is indicated by high TDS levels. Without producing any coloration or turbidity, iron (II) concentrations in anaerobic groundwater can reach several parts per million [52]. An increase in both parameters increases the WQI value and hence decreases water quality.

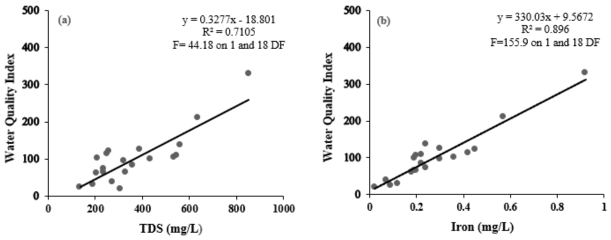

Fig. 3: Linear regression between water quality index and (a) TDS and (b) iron of water at 1 and 18 DF

Conclusions

This study evaluates the water quality in the twenty traditional stone spouts in the Kathmandu Metropolitan area using the water quality index (WQI). Of the ten examined physiochemical parameters, only the concentrations of TDS, pH, TH, Cl^-, and SO_4^{2-} are within permissible limits and in compliance with NDWQS guidelines in all tested water samples. Ammonia, fluoride, nitrate, and total iron levels exceeded allowable limits in many stone water spouts, posing significant issues. Based on WQI, it can be concluded that most stone water spouts fall under grade E indicating that they are unfit for human consumption. Only two stone water spouts, Gyan Dhara and Pepsicola Dhungedhara, are considered safe for drinking based on the WQI. However, it is crucial to perform microbial testing and assess the influence of seasonal fluctuations on water quality. Linear regression also indicates that as the TDS and iron levels increase, the WQI also increases. Hence, utilizing untreated stone water spouts can greatly affect human health. Recognizing the significance of the water sources for Kathmandu's residents, it is crucial to prioritize monitoring and water quality treatment to mitigate health risks. Overall, this study could benefit government officials and policymakers in developing sustainable plans for traditional water supply systems as an alternative source to address water insecurity to some extent in Kathmandu metropolitan city.

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Author's Contribution Statement

Pramod Kumar Yadav: Methodology, Investigation, Formal analysis, Data curation, Writing-original draft preparation, **Supriya Kandel:** Methodology, Investigation, Formal analysis, Data curation, Writing-review and editing, **Bijaya Adhikari:** Formal analysis, Writing-review and editing, **Bindra Devi Shakya:** Formal analysis, Writing-review and editing, **Sudarshana Shakya:** Formal analysis, Writing-review and editing, **Pawan Raj Shakya:** Conceptualization, Resources, Funding acquisition, Writing-review and editing, supervision

Conflict of Interest

The authors do not have any conflict of interest throughout this research work.

Data Availability Statement

The data supporting this study's findings are available from the corresponding authors upon reasonable request.

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