Received :10 August 2023, Revision accepted: 17 September 2023
Himalayan Biodiversity 2023. 9: 29- 38 **DOI:** 10.3126/hebids.V9i1.59584 ***ISSN :2382-5200***

EVALUATING THE MAJOR SOURCES OF SURFACE WATER QUALITY IN POKHARA METROPOLITAN CITY, GANDAKI PROVINCE, NEPAL

Susmita Tiwari[1], Binit Timalsina[2], Sagar Sitaula[2], Mahesh Prasad Awasthi[2], Anjal Mahat[3] and Ramesh Raj Pant[2*]

[1]Goldengate International College, Tribhuvan University, Kathmandu, Nepal

[2]Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal

[3]Patan Multiple Campus, Patandhoka, Tribhuvan University, Lalitpur, Nepal

[*]Corresponding author: Ramesh Raj Pant: rpant@cdes.edu.np

ABSTRACT

The Mardi Watershed serves as a crucial source of drinking water for Pokhara Metropolitan City (PMC), Gandaki Province, Nepal, offering a wide range of ecosystem services including fishing, tourism, transportation, livestock support, and, notably, clean drinking water. However, the main river and its tributaries face degradation due to a blend of human and natural impacts. This comprehensive study rigorously examines the physicochemical and biological attributes that define water quality within the watershed. Recognizing the global importance of water quality for human well-being, this investigation specifically evaluates the suitability of water for drinking purposes. Twenty-three samples were collected and subjected to analysis for the twenty-one distinct physicochemical parameters. The analysis covers physicochemical parameters such as pH, water temperature, conductivity, total dissolved solids, alkalinity as well as concentrations of ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), ammonium (NH_4^{+}), nitrate (NO_3^{-}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), and phosphate (PO_4^{3-}), free carbon dioxide (CO_2), chloride (Cl^{-}), total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), iron (Fe^{2+}), turbidity (Turb.) Simultaneously, biological markers including total coliforms were assessed. The overall water quality aligns with the World Health Organization (WHO) guidelines, a significant exception lies in microbial indicators. Microbial presence, likely a result of increasing anthropogenic pressures, is relatively elevated in most samples. Furthermore, the cumulative outcome reveals a Water Quality Index (WQI) of 22.04, indicating excellent suitability for drinking. Since, effective management strategies are crucial for ensuring a consistent and sustainable supply of potable water to the urban population, information obtained through this study can contribute to the sustainable management of water quality and maintaining a reliable supply of safe drinking water to urban communities.

Keywords: Water quality assessment, Hydrochemistry, Total coliform, PMC, Mardi watershed

INTRODUCTION

Water, the essence of life, lies at the core of human health and well-being. The access of clean drinking water as a fundamental human right underscores its critical importance. Despite the Earth's copious reserves water, a persistent global shortage of safe drinking water persists (Pant *et al.*, 2020). The consequences of this scarcity are increasingly evident in public health concerns worldwide. Paradoxically, while the awareness of water's significance grows, rivers, lakes, and oceans continue to suffer pollution (Pant *et al.*, 2020; Siasu, 2007). Compounded by a soaring global population over the last century, this has exacerbated pressure on already strained water resources. As a result, potable water quality has emerged as a pressing issue in developing nations (Pant *et al.*, 2018; Siasu, 2007).

Water, as a sustainer of life, can also spread diseases through waterborne pathogens. With over 80% of disease attributed to waterborne transmission, repercussions are profound. Children bear the brunt of inadequate water and sanitation, as diarrheal illnesses claim 1.73 million lives annually and more than 54 million disability-adjusted life years, constituting 3.7% of the global disease burden (Herschy, 2012). In this context, ensuring water quality extends to a global scale. Astonishingly, only 71% of the global population has access to safely managed drinking water systems, while over 2 billion people consume water tainted by human waste. The tragic toll includes an estimated 297,000 children under five who succumb to water-related illnesses annually, amplifying the urgency of addressing water quality (Biswas and Tortajada, 2019).

The significance of water quality reverberates profoundly in Nepal, a nation blessed with 2.27% of the world's water resources. Paradoxically, it grapples with water pollution, scarcity, and poverty (Thakur *et al.*, 2017). As water scarcity escalates, particularly among the impoverished, global attention shifts towards equitable access to this dwindling resource. In Nepal's rural areas and municipalities, drinking water systems grapple with inadequate coverage, insufficient quantities, and poor quality (Pant *et al.*, 2021). The Kathmandu Metropolitan Area, for instance, experiences degradation across physical, chemical, and microbial dimensions of water quality (Prasai, 2007). Alarming contamination levels plague drinking water sources and distribution reservoirs, as indicated by studies in the Dharan area (Pant *et al.*, 2016). In this context, water management becomes a multifaceted challenge particularly in developing nations like Nepal. The populace increasingly turns to processed water, highlighting a shifting preference. Yet water quality research remains relatively underrepresented, particularly in urban centers like Pokhara (Pant *et al.*, 2021, Pant *et al.*, 2023). The World Health Organization's endorsement of chlorination as a cost-effective and feasible treatment method emphasizes the urgency of action. Simultaneously, it underscores advocacy for advanced technologies to address evolving challenges (Shrestha, 2020). Amidst these challenges, the Water Quality Index (WQI) emerges as an important tool for assessing water suitability. This modern index synthesizes vast qualitative data into an accessible format, aiding in formulating effective policies and regulations to assessment, manage, and monitoring for water quality (Saeedi *et al.*, 2010).

The impending 2030 sustainable development goal (SDG) targets set the stage for urgent action, propelling governments, researchers, and communities to collaborate and innovate in their pursuit of sustainable water resources for all (Goal no. 6) (Torres *et al.*, 2020). As, water scarcity and contamination resonate as global concerns, Nepal's experiences offer valuable insights into navigating these issues on a broader scale. Therefore, this paper addresses the spatial variations and the underlying processes governing water chemistry and quality in Mardi Watershed, Gandaki Province, Nepal.

MATERIALS AND METHODS

Study area

Pokhara Metropolitan City (PMC), renowned for its natural allure, stands as Nepal's second-largest city in terms of population (Sadadev, 2020), encompassing 464.24 square kilometers (Pant *et al.*, 2021). Its elevation ranges from 780 m in the south to 1350 m in the north, situated at coordinates of 83˚58'30" to 84˚02'03" East Longitude and 28˚10'00" North to 28˚16'00" North Latitude (Sadadev, 2020). The city is now divided into 33 wards. With an annual average rainfall of approximately 3,600 millimeters, Pokhara experiences the highest rainfall in Nepal (Chalise, 2016). Fed by glaciers on the southern slopes of the Annapurna Himal, watercourses like Seti and its main tributary, Mardi, traverse the region (Fig. 1). This study focuses on these crucial water sources as well as other bodies of water within Pokhara. Regarding climate, summer averages span 25 to 35 °C, while winter sees a range of 2 to 15 °C. Abundant rainfall characterizes both Pokhara and its surrounding areas (Chalise, 2016). Geologically, Pokhara is characterized by two distinct formations: quaternary deposits along Seti River terraces and exposed bedrock across the valley's inclining regions. This bedrock undergoes weathering through solar radiation, precipitation, and chemical processes (Paudel, 2019). The environmental characterization of the study sites is presented in Table 1.

Table 1: Environmental characterization of water sampling stations in the major surface water sources of Pokhara Metropolitan City, Gandaki Province, Nepal

S.N.	Sample-ID	Station name	Latitude (N)	Longitude (E)	Location	Land use
1	R1	Mardi Binda Resevoir	28.23888889	83.9825	Reservoir	Settlement
2	B1	Bhote Khola	28.28833333	83.95583333	Tributary	Agriculture /settlement
3	B2	Bhote Khola	28.29027778	83.96027778	Tributary	Agriculture /settlement
4	B3	Bhote Khola	28.293275	83.968138	Tributary	Agriculture /settlement
5	Ba1	Baldhara	28.22833333	83.97583333	Reservoir	Forest
6	Ba2	Baldhara Public Tap	28.22361111	83.97888889	Public Tap	Settlement
7	L1	Lekhnath Guije Reservoir1	28.14888889	84.08055556	Reservoir	Settlement
8	L2	Lekhnath Guije Reservoir2	28.20444444	84.02972222	Reservoir	Forest
9	G1	Ghatte Khola	28.29083333	83.85444444	Tributary	Settlement
10	G2	Ghatte Khola	28.28722222	83.86527778	Tributary	Settlement
11	G3	Ghatte Khola	28.28861111	83.85888889	Tributary	Forest
12	L3	Lekhnath Tap	28.24694444	84.05722222	Public Tap	Forest
13	L4	Lekhnath	28.1325	84.089444	Public Tap	Settlement
14	K1	Khali Khola	28.26972222	83.9825	Tributary	Settlement
15	K2	Khali Khola	28.28	83.98722222	Tributary	Settlement/ Agriculture
16	K3	Khali Khola	28.28611111	83.99416667	Tributary	Settlement/ Agriculture
17	K4	Mardi River	28.30722222	83.90888889	Tributary	Settlement/ Agriculture
18	M1	Mardi River	28.30388889	83.91888889	Main River	Agriculture
19	M2	Mardi River	28.29944444	83.91861111	Main River	Agriculture
20	M3	Mardi River	28.29722222	83.93027778	Main River	Agriculture
21	M4	Mardi River	28.30638889	83.91472222	Main River	Agriculture
22	Ma1	Majkuna	28.29158889	84.0013275	Tributary	Forest
23	Ma2	Majkuna	28.3005287	84.0027372	Tributary	Forest

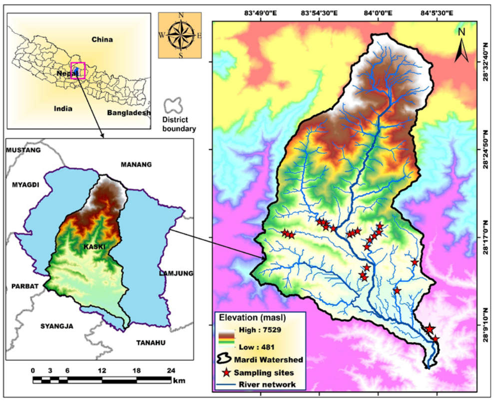

Figure 1: Map indicating the Watershed boundary, sampling locations, and river network in the major surface water sources of Pokhara Metropolitan City, Gandaki Province, Nepal

Sampling protocol and analytical methods

During the monsoon of 2022, a comprehensive water sampling campaign was conducted, encompassing a total of 23 water samples sourced from diverse origins including reservoirs, rivers, tributaries, and springs along the Mardi River Basin (Fig. 1). These samples were collected using the grab sampling technique, employing 1-liter high-density polyethylene (HDPE) bottles. The bottles were sealed securely and stored at temperatures below 4°C, awaiting transfer to the laboratory for subsequent analysis. In-situ measurements were promptly taken for crucial parameters including temperature, pH, electrical conductivity (EC), turbidity, and total dissolved solids (TDS). Additionally, specific methods were employed to assess other water quality parameters (APHA, 2017). Temperature, pH, EC, and TDS were promptly measured on-site using a versatile multipurpose meter (Instrument: SN. 11003290111). The concentration of calcium (Ca^{2+}), magnesium (Mg^{2+}), total hardness (TH), and calcium hardness (CaH) were determined through the EDTA titration method. The hardness of magnesium was determined by subtracting the calcium hardness from the total hardness.

Alkalinity levels were assessed utilizing a titration-based method. The bicarbonate ion (HCO_3^-) concentration was calculated using the formula of alkalinity. Free CO_2 content was measured via a titration-based approach. Turbidity, an indicator of water clarity, was measured using a digital turbidity tester (Instrument: Photocerm-SGZ-200BS). Concentrations of potassium (K^+) and sodium (Na^+) were measured using a flame photometer (Instrument: ESICO International-1382). Iron (Fe^{2+}), ammonium (NH_4^+), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), and nitrate (NO_3^-) were quantified using a spectrophotometer (Instrument: UV2101, SSI, UK). The presence of total coliform bacteria was detected through the membrane filtration technique. This process involved a laminar airflow system (Envair Ltd., England), an autoclave, and a colony counter (Sonar). The detailed methodology provided is sourced from the American Public Health Association (APHA, 2017).

Data Analysis

The Water Quality Index (WQI) was initially conceptualized by Horton in the United States in 1965. This pioneering effort entailed selecting ten frequently measured water quality factors, including pH, coliform levels, EC, alkalinity, and Cl^- and others. The application of the WQI has been instrumental in assessing the quality of water in specific locales (Chaturvedi and Bassin, 2010). The Weighted Arithmetic Water Quality Index (WAWQI), which hinges on frequently measured water quality variables, classifies water quality based on purity levels. The index is computed using the formula:

$$WQI=[\sum_{i=1}^{n} W_i Q_i / \sum_{i=1}^{n} W_i] \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here, Qn represents the quality rating of the nth water quality parameter, while, W_i signifies the corresponding unit weight and Qn is calculated by using equation (2)

Where, qn and Wn are the quality rating and unit weight of nth water quality parameter. The quality rating (qn) is calculated using the relation given in equation (2).

$$Qn = \frac{Vn - Vi0}{Sn - Vio} * 100 \ldots\ldots\ldots\ldots\ldots (2)$$

Where, Vn, and Sn are the estimated value, ideal value and standard permissible value of the n^{th} parameter. For all parameters, ideal values (Vio) were taken as zero for drinking water except for pH = 7.0. The unit weight (Wn) is calculated using equation (3).

$$Wn = \frac{K}{Sn} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, K= proportional constant and it is calculated by using equation (4).

$$K = \frac{1}{\sum\left(\frac{1}{Sn\ 1,2,3}\right) \ldots\ldots\ldots\ldots\ldots (4)}$$

The water quality classification is presented in Table 2, assigning WQI values to different status categories, each indicative of a particular grading and possible usage (Acharya *et al.*, 2020).

Table 2: Water quality index (WQI) range, status, grading, and their corresponding possible uses in the major surface water sources of Pokhara Metropolitan City, Gandaki Province, Nepal

S. N.	WQI value	Status	Grading	Possible Uses
1	0-25	Excellent	A	Drinking, irrigation, and industrial
2	26-50	Good	B	Drinking, irrigation, and industrial
3	51-75	Fair	C	Irrigation and Industrial
4	76 -100	Poor	D	Irrigation
5	101-150	Very poor	E	Restricted for irrigation
6	>150	Unfit for drinking	F	Proper treatment is required before use

RESULTS AND DISCUSSION

General hydrochemistry

In this study, a comprehensive hydrochemical analysis was conducted, yielding valuable insights into the water quality of the Mardi River and associated water sources in Pokhara Valley. Table 3 presents a range of key parameters, including minimum, maximum, and average values, standard deviations, and comparisons against WHO guidelines. The recorded mean temperature at the site stood at 23.04°C. The water samples extracted from various sources exhibited a moderate alkaline nature, showcasing pH levels ranging from 7.1 to 8, with an average pH of 7.56. Notably, observed turbidity values ranged between 1.8 and 6 NTU, all falling comfortably below the recommended WHO threshold. EC and TDS averaged at 135 µS/cm and 71 mg/L, respectively. Furthermore, free CO_2 content varied within the narrow range of 0.1 to 8.8 mg/L, significantly lower than the WHO-designated limit for safe drinking water. The mean TH was determined to be 92.43 mg/L. Ca^{2+} concentrations exhibited variability, ranging from 2.1 to 59.8 mg/L.

The calculated mean and standard deviation were 27.22 ± 19.3 mg/L, with all recorded Ca^{2+} levels well below WHO recommended 100 mg/L threshold. Similarly, Mg^{2+} concentrations spanned from 0.79 to 12.83 mg/L, maintaining a mean and standard deviation of 5.94 ± 3.72 mg/L. This falls comfortably within the WHO acceptable potability limit of 50 mg/L. The

HCO_3^- showed concentrations ranging from 14.64 to 73.2 mg/L. The calculated mean and standard deviation stood at 37.5 ± 19.6 mg/L, all conforming to WHO's prescribed drinking water limit of 600 mg/L. Conversely, Cl^- concentration ranged from 0.3 to 4.5 mg/L, averaging at 2.1 mg/L, significantly below WHO established limits. SO_4^{2-} concentrations within the sampled water ranged from 4.5 to 21.94 mg/L. The mean and standard deviation were recorded as 5.58 ± 20.22 mg/L, well below the WHO guideline of 250 mg/L (WHO, 2011). Concentrations of NO_3^- and NH_4^+ were observed within the range of 0.17 to 0.37 mg/L (mean: 0.25 ± 0.05) and 0 to 0.9 mg/L (mean: 0.03 ± 0.02 mg/L), respectively.

Meanwhile, the average concentrations of PO_4^{3-} and Fe^{2+} were established as 0.13 mg/L and 0.08 mg/L, respectively. In terms of cation distribution, the mean concentrations followed the order: $Ca^{2+} > Mg^{2+} > Na^+ > K^+ > Fe^{2+} > NH_4^+$. For anions, the mean concentrations were ranked: $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > PO_4^{3-}$, effectively characterizing the hydrochemical profile of the study area. The detailed status of average concentration of measured hydrochemical variables is represented in figure 2. The result of this study is consistent with majority of other Himalayan river basins in Nepal (Pant *et al.*, 2018; Pant *et al.*, 2021; Pant *et al.*, 2023).

Table 3: Descriptive statistics of physicochemical parameter in the major surface water sources of Pokhara Metropolitan City, Gandaki Province, Nepal

Parameters	Min	Max	Mean	SD	(WHO, 2011)
Tem.	21	26	23.04	1.43	_
pH	7.1	8	7.6	.21	6.5-8.5
EC	16	370	135	98.9	1500
TDS	8	199	71	55.1	500
CO_2	0.0	8.8	4.50	3	6
Cl^-	0.32	4.5	2.17	1.01	250
HCO_3^-	14.6	73.2	37.5	19.6	600
TH	12	188	92.43	57.6	150
CaH	5.2	149.6	68.05	47.81	
MgH	3.2	52.8	24.38	15.30	
Ca^{2+}	2.10	59.8	27.22	19.13	100
Mg^{2+}	.79	12.83	5.94	3.72	50
PO_4^{3-}	.01	.35	0.13	0.08	1
NO_3^-	.17	.37	0.25	0.05	50
NH_4^+	.00	.09	0.03	0.02	0.5
Na^+	.84	7.80	3.28	1.86	200
K^+	.53	5.5	2.9	1.59	100
SO_4^{2-}	4.5	21.9	5.58	20.2	250
Fe^{2+}	.00	.36	0.08	0.08	0.3
Turb.	1.8	6	4.4	0.9	5
Alk.	5	25	12.8	6.7	200

All the parameters have mg/L unit, except pH, Teperature (°C), Turbidity (NTU), and EC (µS/cm)

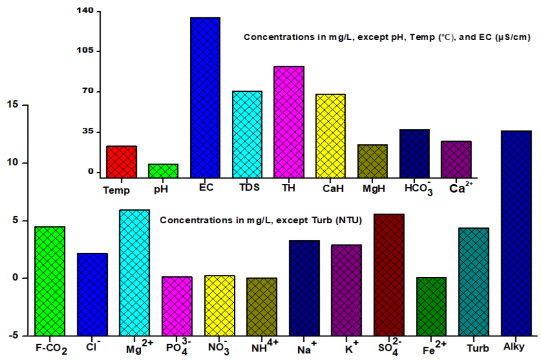

Figure 2: Average concentrations of physicochemical parameters in Mardi River and associated water sources, Gandaki Province, Nepal

The total coliform count serves as a microbiological measure to assess the presence of coliform bacteria in a given water sample as represented in figure 3. The coliform bacteria, including the notable *Escherichia coli (E. coli)*, naturally inhabits the intestinal tracts of warm-blooded animals and their excreta. They play a pivotal role as indicators, offering insights into the potential fecal contamination within water sources. Analyzing the microbiological data on water quality from a range of supply sources in Pokhara has yielded worrisome revelations. A substantial majority of the examined samples displayed pollution levels that exceeded the established benchmarks of the standard guidelines. Each of the 23 samples underwent meticulous microbial scrutiny, employing the membrane filter method to comprehensively enumerate coliform bacteria. Results indicated that, all samples exhibited contamination by total coliform bacteria except the R1 site (Fig. 3). This underscores a probable source of environmental and fecal contamination, consequently contributing to the degradation of river water quality. The tabulated coliform counts offer a precise gauge of contamination severity within each sample. Elevated coliform counts correlate with an increased probability of fecal contamination, thereby signaling potential health hazards if these samples are utilized for potable water or for other applications where cleanliness is imperative. This dataset holds the potential to oversee water quality and facilitate decisions concerning the safety of diverse water sources.

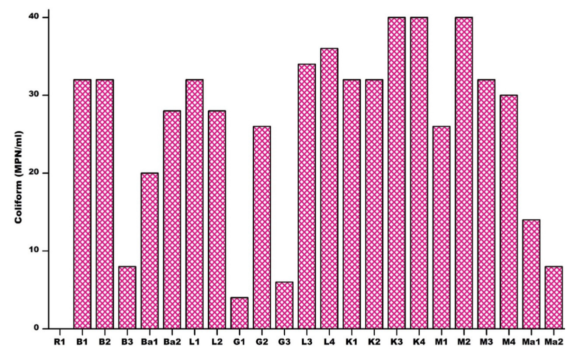

Figure 3: Total coliform count in the water samples in Mardi River and associated water sources, Gandaki Province, Nepal

Water Quality Index

Pokhara, the second-largest city in the country with a population of 487,950 faces the common challenge of managing drinking water to meet urbanization demands, typical of many developing cities. Drinking water quality in Pokhara is found to be poor, with heightened turbidity during the monsoon season. Parameters, such as *E. coli*, Nitrate, Calcium, TDS, etc., are monitored monthly in accordance with Nepal Standards, both in the reservoir and the catchment area. The primary water source, the Mardi River, supplies 84% of Pokhara's water and, while meeting most WHO guidelines (WHO, 2011), necessitates treatment for *E. coli* before consumption. The WQI stands as a pivotal tool for informing concerned stakeholders and decision-makers about the state of water quality. In the rural watershed of Western Nepal, the water quality spans from poor to good conditions, as indicated by the WQI (Pant *et al.*, 2023).

This suggests that with appropriate treatment, water from these sources can be employed for domestic purposes (Gurung *et al.*, 2019). Likewise, the WQI evaluation for diverse water sources in Pokhara indicates Grade B water quality, signifying good conditions. However, the quality has shown a decline from excellent to good, suggesting a need for purification before consumption (Sadadev, 2020). The computed WQI values for all relevant water quality parameters are presented in Table 4. Remarkably, the calculated WQI value for drinking purposes at different sites is 22.04, denoting excellent water quality during the study period, suitable for consumption (Table 2). This excellence is attributed to the low chemical parameter values and minimal anthropogenic impact on drinking water quality at these sites.

Table 4: Water quality index of water parameters in Mardi River and associated water sources, Gandaki Province, Nepal

Parameters	Sn	1/Sn	∑ 1/Sn	K	Wi	Vo	Vn	Vn/Sn	Qn	WiQn/∑Wi
pH	8.5	0.118	5.2	0.19	0.02262	7	7.5	0.88	88.23	1.996
EC	1500	0.00067	5.2	0.19	0.00013	0	135	0.09	9	0.001
TDS	1000	0.001	5.2	0.19	0.00019	0	70.5	0.07	7.05	0.001
Cl	250	0.004	5.2	0.19	0.00077	0	2.17	0.008	0.86	0.001
TH	150	0.0067	5.2	0.19	0.00128	0	92.5	0.61	61.6	0.079
Ca	100	0.01	5.2	0.19	0.00192	0	27.2	0.27	27.2	0.052
Mg	50	0.02	5.2	0.19	0.00385	0	5.94	0.12	11.8	0.046
Na^+	200	0.005	5.2	0.19	0.00096	0	3.28	0.02	1.64	0.002
K^+	100	0.01	5.2	0.19	0.00192	0	2.98	0.03	2.98	0.006
Fe^{2+}	0.3	3.33	5.2	0.19	0.64095	0	0.08	0.26	26.67	17.092
NH_4^+	1.5	0.67	5.2	0.19	0.12819	0	0.03	0.02	2	0.256
NO_3^-	50	0.02	5.2	0.19	0.00385	0	0.25	0.01	0.5	0.002
HCO_3^-	600	0.0017	5.2	0.19	0.00032	0	37.5	0.06	6.25	0.002
PO_4^{3-}	1	1	5.2	0.19	0.19228	0	0.13	0.13	13	2.500
SO_4^{2-}	250	0.004	5.2	0.19	0.00077	0	11.2	0.045	4.48	0.003
		5.2			1					22.04

*Excluding total coliforms

The findings of this study provide a comprehensive overview of water quality data in the PMC, contributing to global water quality knowledge. Notably, this research bridges a gap by extending its focus to the hilly urban areas of Western Nepal, which are often underrepresented, compared to other regions in water quality studies. The outcomes of this study hold relevance for water suppliers in the region, informing their activity plans, monitoring efforts, evaluation of pipe schemes, and guiding future projects aimed at enhancing water quality in the study area. The insights generated by this research have broader applicability, especially for cities facing similar challenges.

CONCLUSIONS

The physicochemical properties of water samples collected from the drinking water sources within the Pokhara Valley adhered to the prescribed limits set by the WHO benchmarks. This alignment implies that the water is suitable for consumption in terms of physicochemical parameters. However, the microbial examination did not meet WHO guidelines. The significant presence of total coliform colonies was noted in the samples. This observation underscores the potential hazards associated with consuming this water, given the presence of bacteria like *Escherichia coli*. Direct consumption of this water may expose individuals to waterborne illnesses such as diarrhea. Consequently, the bacteriological analysis underscores the inadvisability of consuming this water without proper treatment. Despite the microbial parameter, the Water Quality Index (WQI) values unveiled the water's high suitability for drinking. Nonetheless, this study concludes by emphasizing the necessity for thorough water treatment before consumption, particularly to eliminate total coliform bacteria present in the river. Stringent measures should be enforced to prevent the amalgamation of sewage and human waste with river and other associated sources of waters, safeguarding against contamination.

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