

Assessment of Groundwater Quality of the Chaka Watershed: A Study from the Extended Part of the Chhotanagpur Granitic Gneiss Complex, India

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Abstract

Millions worldwide face a critical issue related to clean and safe water access. The urgency to address potential groundwater contamination from weathered rock materials cannot be overstated in the hard rock terrain, where people primarily rely on groundwater for drinking. Many people, lacking the minimum knowledge about drinking water quality, have been ingesting it for a long time. The present study, conducted on the Chaka watershed, a tributary river Kumari situated in the Purulia district primarily characterized by granite gneiss, semi-arid climate, and undulating topography, underscores the severity of the situation. A total of 26 groundwater samples were gathered, and various water quality parameters were evaluated in the laboratory using standard procedures. ArcGIS (10.3) software prepared several thematic maps of physicochemical characteristics. A water quality index (WQI) was also constructed following the Brown Method. The results are alarming; around 46% of groundwater samples are poor to very poor, and only 19% fit good to excellent water quality. Only 18% of the Chaka watershed (34.95 km²) enjoys good to excellent water quality. Around 39% of the samples of this study area are identified with fluoride contamination, affecting around 3065 households, which poses a severe health risk to the population. This situation underscores the importance of adopting suitable measures to mitigate the problem of the watershed.

Keywords: Chaka Watershed, Groundwater, Physico-chemical Parameters, Water Quality, Fluoride

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1. Introduction

Groundwater systems are essential for global water supplies for drinking, agricultural, and industrial needs (Adimalla et al., 2018). Groundwater is widely recognised as an essential natural resource, mainly in village regions where it frequently serves as the only source of clean water due to a lack of surface water (Alam et al., 2011). Every day, groundwater continues to rise in importance as a water source for agriculture, industry, and domestic use (Agarwal et al., 2013). India leads the world in annual groundwater extraction, exceeding the combined withdrawals of the USA and China (Adimalla et al., 2018). Around 90% of people in rural areas and 50% in urban areas rely on groundwater for domestic purposes (Murmu et al., 2019). It is primarily used for agricultural purposes, accounting for 70% of its usage (Murmu et al., 2019). The leading causes of groundwater decrease include overexploitation, irregular precipitation, high runoff, and evapotranspiration (Adimalla & Taloor, 2020; Ghosh et al., 2020a, 2020b; Mandal et al., 2023). The usage of groundwater, especially for drinking, requires consideration of various physicochemical and biological properties, which may be adversely affected by both human and natural activities (Bhat et al., 2018; Aouiti et al., 2021; Kate et al., 2020; Naik et al. 2021a, 2022a, 2022b; Mandal et al., 2023). According to the National Institute of Hydrology, India is the top groundwater user in the world (Kumar & Krishna, 2016; Mandal et al., 2023). Groundwater is consumed directly by one-third

of the global population, accounting for nearly one-fifth of total water demand (Raghunath, 1982; Nag and Das, 2017; Ghosh et al., 2020). According to the United Nations Food and Agriculture Organisation (FAO), nearly two billion individuals may face critical water scarcity, even though most people may suffer water stress (Central Water Commission, 2010; Ghosh et al., 2020). The primary and secondary porosity of the geological stratum primarily determines groundwater availability and recharge (Kanagaraj et al., 2019). However, 65% of India's area is made of solid rock with less than 5% permeability, resulting in insufficient water availability (Saraf & Choudhury, 1998; Ghosh et al., 2020). Water pollutants impact both water quality and human health. Contaminated water could come from geological conditions, industrial and agricultural applications, or water treatment systems (Rahmanian et al., 2015). As the world's second most populous country, India faces significant challenges in providing safe drinking water (Mandal et al., 2023). However, groundwater contamination has dramatically increased in arid and semi-arid places worldwide (Adimalla & Venkatayogi, 2018; Adimalla & Li, 2018; Adimalla & Wu, 2019). Consequently, poor groundwater quality has significant health implications and reduces agricultural productivity (Adimalla et al., 2018a; Todd, 1980; Adimalla & Wu, 2019). The quality of groundwater can vary due to hydrogeological and anthropogenic causes (Vasanthavigar et al., 2010). Thus, assessing groundwater's quantity and quality is essential for advancing civilization and planning water resource development (Vasanthavigar et al., 2010). Rare water quality assessments, primarily made up of tube wells and hydraulic pumps, including boreholes used for drinking purposes, cause a variety of ailments.

Drinking water must be thoroughly checked to avoid the risk of health problems. Numerous chemicals, biological, and physical features can be used to evaluate water quality, and many scholars have developed a composite index of water quality using several methods (Akhtar et al., 2014; Kumar et al., 2016; Arulbalaji &

Gurugnanam, 2017; Khan & Jhariya, 2017; Kumar et al., 2017; Roy et al., 2018; Li et al., 2019; Zhang et al., 2020; Aouiti et al., 2021; Naik et al., 2021a; Naik et al. 2022a, 2022b; Mandal et al., 2023). Increased water transfer and intake, rapid rate of urbanisation, industrialisation, excessive use of pesticides and fertilisers in agricultural regions, human and animal wastes, and irregular drainage networks deteriorate water quality (Adimalla et al., 2018). Understanding hydrochemistry is essential for evaluating groundwater quality to determine whether it suits residential, agricultural, and commercial uses (Ali & Ali, 2018). Regional geology, climatic conditions, and human activities significantly influence the chemical and physical parameters that determine groundwater quality (Adimalla et al., 2018). The current study was conducted in the cratonic part of eastern India, generally represented by granite gneiss, uneven topography, semi-arid climatic conditions, and water shortage. (Ghosh et al. 2020a, 2020b, 2021a, 2021b; Karmakar et al. 2021; Mandal et al. 2023). The primary goal of this study is to assess the groundwater quality based on physico-chemical parameters and to construct a Water Quality Index (WQI) to determine the drinking suitability of water in the Chaka watershed.

2. Study Area

The study was done in the Chaka watershed, a tributary of the river Kumari, which drained over the Purulia district. The longitudinal and latitudinal extensions of the study area are $86^{\circ} 19' 51''$ E to $86^{\circ} 33' 36''$ E and $23^{\circ} 3' 17''$ N to $23^{\circ} 13' 39''$ N, covers Purulia-1, Pancha, Manbazar-1, Barabazar, and Arsha Community Development (C.D.) blocks (Fig. 1). A total number of 12 Gram Panchayats are situated in this study area. Various primary and secondary sources show that this region witnesses groundwater scarcity mainly during the summer season, and people of the region have been ingesting groundwater without knowing its quality. The total population

of this study area was around 103,959 (Census of India, 2011). The area of interest comes under the Chotonagpur Granitic Gneiss Complex (CGGC). The Pediment Pediplain Complex mainly characterizes the geomorphological features of this study area. Purulia enjoys an arid to semi-arid climate, and the southwest Monsoon determines rainfall that occurs predominantly in July and September (Ghosh et al., 2020a; Modak et al., 2022). Because of rolling topography and lower rock permeability, surface runoff in the watershed maintains the regional slope (Mandal et al., 2023). Purulia district enjoys a mean annual temperature of almost 5 to 45° C, and the precipitation amount is, on average, 1300 mm (Government of West Bengal 2014, 2015).

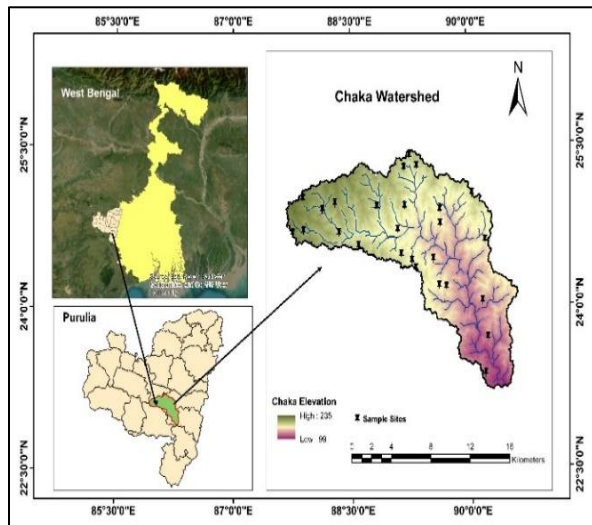


Fig. 1: Location map.

3. Data Source and Methods

A total number of 26 groundwater samples were gathered across the Chaka watershed to carry out this study. A 1L polyethene bottle was used to collect the water sample. Moreover, water

samples were collected and preserved following the standard protocols of the American Public Health Association (2017). Different physicochemical parameters of water samples, such as pH, Electrical conductivity (EC), Total Dissolved Solids (TDS), Turbidity, hardness, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Total Alkalinity (T- alkalinity) etc., were tested in the laboratory. The results of the drinking water quality parameters are compared with the WHO standard (2011, 2017). A WQI is prepared following the Brown Method. The WHO guidelines (2017) examined the permissible water limit for drinking purposes. Various types of thematic maps were prepared to identify and represent different parameters (Fig. 2).

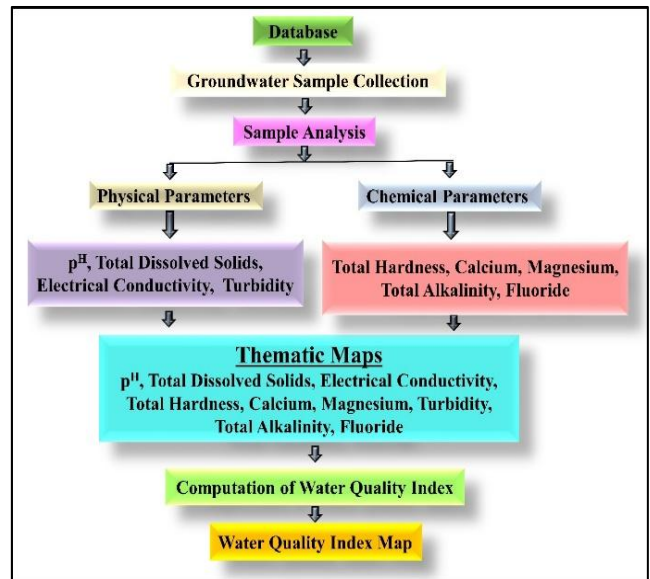


Fig. 2: Schematic representation of the methodological flow chart.

Sample ID	pH	TDS (mg L ⁻¹)	EC (μs cm ⁻¹)	Turbidity (NTU)	T-alkalinity (mg L ⁻¹)	Hardness (mg L ⁻¹)	Ca ²⁺ (mg L ⁻¹)	Mg ²⁺ (mg L ⁻¹)	F ⁻ (mg L ⁻¹)
1	6.88	501	1000	4	206	272	81.6	16.524	1.45
2	6.93	124	248	1	90	54	18.4	1.94	1.73
3	6.71	338	677	9	158	144	44.8	7.78	1.52
4	6.86	578	1155	4	222	616	225.6	12.64	0.18
5	6.64	181	362	1	138	96	28.8	5.83	0.18
6	7.62	203	405	1	174	92	31.2	3.4	1.89
7	7.05	284	568	2	178	180	51.2	12.64	0.45
8	7.03	526	1052	4	214	708	272	24.3	1.37
9	7.1	352	704	8	222	244	59.2	23.33	1.52
10	7.13	101	205	6	98	36	11.2	1.94	2.78
11	7.03	538	1078	8	274	270	59.2	29.65	1.43
12	6.86	372	740	31	146	228	46.4	27.22	0.47
13	6.92	190	380	1	118	136	45.6	5.35	1.02
14	7.06	686	1372	1	272	380	118.4	20.41	0.64
15	6.7	658	1316	6	222	336	84.8	30.12	1.17
16	6.84	540	1084	4	284	288	86.4	17.5	0.95
17	7.49	288	576	1	224	150	42.4	10.69	1.87
18	7.07	854	1713	1	444	298	92	16.52	1.38
19	7.32	222	445	1	512	142	48	5.35	2.12
20	7.02	535	1070	1	1052	348	96	26.24	0.64
21	7.1	668	1335	1	2380	350	124	9.72	2.43
22	7.05	649	1298	1	1800	310	96	17.01	2.63
23	7.12	843	1687	4	2050	730	188	63.18	0.78
24	7.36	244	492	1	900	152	40.8	12.15	0.89
25	6.63	184	369	6	424	92	24	7.78	1.32
26	7.08	148	297	3	554	44	16	0.97	2.4

Table 1: Physicochemical characteristics of water samples.

4. Results and Discussion

4.1. Physico-chemical Parameters of Groundwater

The potential hydrogen, popularly known as pH, depicts the basicity and acidity of an aqueous solution. A logarithmic scale ranging from 0 to 14 at a temperature is used to understand the pH value, where pH 7 accounts for pure or neutral

(Mandal et al., 2023). Human mucous membranes may be harmed if drinking water has a higher pH than the acceptable limit (Arulbalaji & Gurugnanam, 2017; Roy et al., 2018; Mandal et al., 2023). All the water samples from the Chaka watershed are neutral to slightly acidic, which is the WHO's accepted limit (Fig. 3). TDS is the inorganic salts that are dissolved in groundwater, predominantly

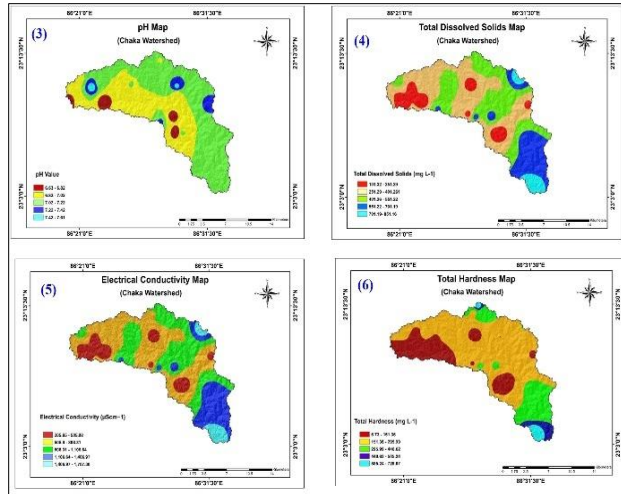


Fig. 3-6: Showing the distribution of pH, TDS, EC and TH of the study area.

chlorides, and sulphates (WHO, 2011; Subba Rao et al., 2017; Adimalla et al., 2018c). WHO (2017) sets a maximum permitted value of 1000 mgL⁻¹ for TDS in drinking water. In the Chaka watershed, the TDS value of all water samples falls under the permissible limit of the WHO. The groundwater can be categorized into different classes based on quality (Fig. 4). Here, all the water samples are observed to be fresh (TDS < 1000 mg L⁻¹). EC generally represents the level of pollution of various minerals as well as excessive water hardness. The higher EC values are mainly influenced by the amount of total dissolved ions and salinity in water (Mandal et al., 2023). According to the guidelines of WHO (2017), the suggested EC level for drinking water is 1500 μScm⁻¹ (Kumar et al., 2015). Only two water samples were recorded beyond the WHO's acceptable limit (Fig. 5). The maximum allowable limit of TH in drinking water is 500 mg L⁻¹. TH is calculated by adding the calcium and magnesium concentrations, represented as calcium carbonate in mg/L. The minimum and

magnesium, calcium, potassium, sodium, bicarbonates,

maximum concentrations of TH in water samples are 36 and 730 mg L⁻¹, with a range of 694 mg L⁻¹. Only three samples exceed the highest permissible limit of WHO in this watershed (Fig. 6). Ca²⁺ is a necessary ingredient for optimal bone formation. It is found in alkaline environments. Ca²⁺ is prevalent in most rocks and has a higher solubility; hence, it is commonly found in groundwater.

A lack of Ca²⁺ (below the necessary limit) in drinking water can cause rickets (Roy et al., 2018) and abnormal bone growth (Ali & Ali, 2018; Narasaiah & Rao, 2021). Higher levels can raise the risk of kidney issues, hypertension, stroke, colon cancer (WHO, 2011), and stomach sickness. (Khan & Jhariya 2017; Mandal et al. 2023). The maximum allowed value of Ca²⁺ in drinking water is 200 mg L⁻¹ as per the WHO guidelines, 2017. Only two water samples exceed the permissible limit of WHO (Fig. 7).

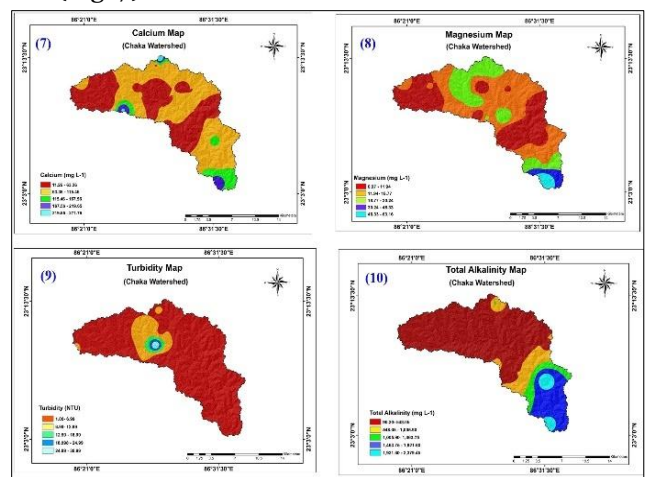


Fig. 7-10: Showing the distribution of Ca²⁺, Mg²⁺, Turbidity and T-Alk of the study area.

Parameters	pH	TDS	EC	Turbidity	T-Alkalinity	Total Hardness	Calcium	Magnesium	Fluoride
pH	1								
TDS	-0.101	1							
EC	-0.100	1.000	1						
Turbidity	-0.300	-0.029	-0.030	1					
T-Alkalinity	0.182	0.494	0.493	-0.219	1				
Total Hardness	-0.077	0.780	0.779	0.005	0.383	1			
Calcium	-0.064	0.683	0.683	-0.084	0.309	0.964	1		
Magnesium	-0.076	0.704	0.703	0.264	0.384	0.737	0.536	1	
Fluoride	0.393	-0.193	-0.192	-0.202	0.249	-0.342	-0.275	-0.369	1

Table 2: Correlation coefficient matrix of different groundwater quality parameters.

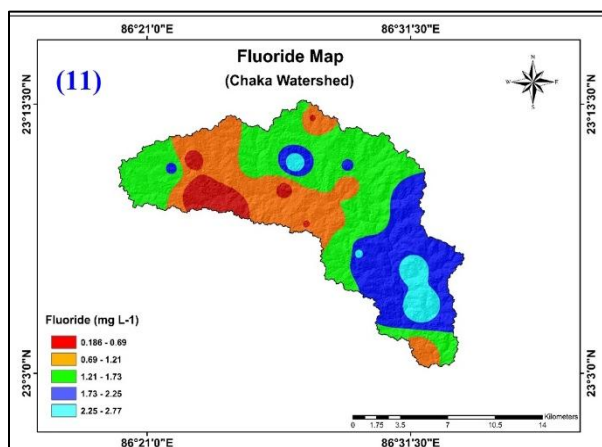


Fig. 11: Showing the distribution of fluoride in the study area.

Mg²⁺ is the eighth-most prevalent component in our planet's substrate and a natural water ingredient (Meride & Ayenew, 2016). Mg²⁺ is a critical ion for cell function and enzyme activation. However, at larger doses, it produces an emptying agent (WHO, 2011; Adimalla & Qian, 2016). As an essential element for humans, Mg²⁺ is highly beneficial in developing a standard structure of bone (Khan & Jhariya, 2017). It similarly serves as a critical enzyme energiser and initiates and maintains various metabolic reactions in the body. Excessive Mg²⁺ intake can be soothing and dehydrating (Roy et al., 2018). Mg²⁺ is commonly less abundant on earth than Ca²⁺ due to the slow dissolution

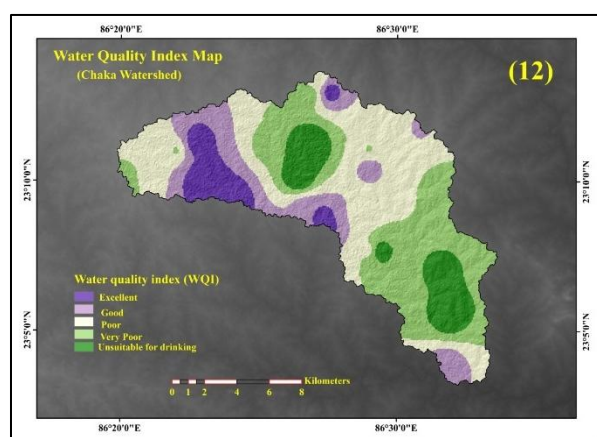


Fig. 12: Water quality index map.

process of Mg²⁺ rich rocks. (Ali & Ali, 2018; Mandal et al., 2023). According to WHO standards (2017), the permissible range of magnesium in water should be 100 mg L⁻¹. No water sample exceeds the permissible limit of WHO (Fig. 8). The precipitation of inert chalk or clay grains and certain insoluble reduced oxides can cause turbidity in groundwater. The optimal turbidity value is < 1 NTU. However, the turbidity level should not exceed 5 NTU (WHO, 2011). Around 27% of the water samples exceeded the permissible limit, with the greatest turbidity reported at 31 NTU in Dhadkidih village (Fig. 9). Carbonates, bicarbonates, and hydroxides are the primary alkalinity sources in natural waters. In the Chaka Watershed, around

20% of samples surpass the highest permissible level of 600 mg L⁻¹ (WHO, 2017) (Fig. 10). Fluorine is found as fluoride in different fluoride-bearing minerals, such as fluorapatite, fluorospar, micas, and cryolite. It is the single most common substance on earth in rock-forming minerals. Volcanic activity is the main factor responsible for the occurrence of fluoride. Fluoride dynamics primarily entail the dissolution and precipitation of F-bearing minerals and the digestion or retention of metal oxides/hydroxides and clay minerals (Mandal et al., 2023). As per the WHO (2017) standards, the maximum tolerable value for F⁻ in drinking water is 1.5 mg L⁻¹. Significantly, fluoride ingestion through drinking water can cause various health issues, including skeletal and dental fluorosis. The results of the water samples indicate that all the samples possess F⁻, and only ten samples (around 39%) exceed the highest permissible limit of F⁻ contamination i.e. 1.5 mg L⁻¹ (Fig. 11).

Category	Range	Sample ID	Count	%
Excellent	< 25	5	1	3.85
Good	25-50	7	4	15.38
Poor	50-75	4, 13, 14, 20, 24	5	19.23
Very Poor	75 -100	1, 2, 6, 15, 16, 17, 18, 23, 25	7	26.92
Unsuitable for drinking	> 100	3, 8, 9, 10, 11, 12, 19, 21, 22, 26	9	34.62

Table 3: Classification of water quality index based on WQI value.

4.2. Water Quality Index (WQI)

The groundwater suitability for human consumption is required to be determined regularly, and the Water Quality Index (WQI) is

widely used (Adimalla & Venkatayogi, 2018; Verma et al., 2018; Khan & Jhariya, 2017; Wu et al., 2017; Adimalla & Qian, 2016). The WQI is an effective tool for evaluating the entirety of groundwater quality (Adimalla et al., 2018c; Khan & Jhariya, 2017). It allows for proper

Water Quality type	Area (km ²)	Area (%)
Unsuitable for drinking	5.07	2.64
Very Poor	57.18	29.73
Poor	25.13	49.46
Good	27.66	14.38
Excellent	7.29	3.79

Table 4: Distribution of area according to water quality index.

knowledge of the water quality and manages the vast amount of data into a single quantity (Adimalla & Qian, 2016). Based on the water's quality, five categories WQI are framed: type I, which is excellent (WQI < 25); type II, which is good in quality (WQI 25 to 50); type III, which is poor (WQI 50 to 75); type IV, which is very poor in quality (WQI 75 to 100); and type V, which is unsuitable for drinking (WQI > 100)

(Ramakrishnaiah et al., 2009; Kumar et al., 2015; Ghouili et al., 2018; Adimalla & Qian, 2019; Mandal et al., 2023). In this work, a WQI is prepared following the Brown Method. Based on WQI, around 54% of groundwater samples are poor to very poor, and only 7.69% belong to good to excellent water quality. Around 39% of the samples in this study area are identified with fluoride contamination (Fig. 12).

5. Conclusion

The Chaka watershed comprises hard rocks, mainly of CGGC and Singbhum groups of

Archean to Protorezoic eon, where the groundwater quality is not up to the mark. It was found that around 35% of water samples are not at all suitable for drinking,

where around 46% of samples belong to very poor to poor water categories. Only 19% of water samples fall under the good to excellent categories.

In contrast, around 39% of water samples exceed the maximum permissible limit for F-contamination in drinking water. The long-term ingestion of this water may have some severe health impacts on the residents. Around 18% of the Chaka watershed (34.95 km²) enjoys good to excellent water quality, while 79.19% area (152.31 km²) experiences poor to very poor water quality. The remaining 2.68% (5.07 km²) of the watershed experiences water unsuitable for drinking. It is imperative to take suitable measures before using water for drinking purposes.

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