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Assessment of Ambient Water Quality Deterioration in Proximity to Municipal Solid Waste Dumpsites in Urban Areas of Chattogram, Bangladesh

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Abstract

This study aims to assess the impact of waste dumping on groundwater quality within the Chattogram City Corporation area. Monitoring eight groundwater sampling points over four years, various physical and chemical parameters were analyzed, utilizing the APHA method. Parameters assessed include pH, temperature, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), salinity, biological oxygen demand (BOD), chemical oxygen demand (COD), Turbidity, Total Hardness, Ca-Hardness, Alkalinity, TSS, Chloride, Phosphate, Sulphate, Nitrite, Nitrate, Fluoride, Iron, Arsenic, Zinc, Copper, and Chromium. The findings were compared to the Department of Environment's (DoE) recommended values, as well as the Bangladesh standard and World Health Organization (WHO) values. During sample collection, deep tube wells near the dumping site points were prioritized. According to the investigation CNB, Ananda Bazar Halishahar and Arefin Nagar, deep pump water carries too many irons in their groundwater. Iron levels exceed both WHO and Bangladesh standards across all samples. Specifically, Arefin Nagar and Ananda Bazar Halishahar area sampling points S6, S7, and S8 surpass standards in TDS, Total Hardness, Turbidity, TSS, Chloride, and Iron. Water Quality Index (WQI) calculations suggest unsuitability for drinking purposes in all sampled water, with S5 and S8 demonstrating particularly high values, indicating their unsuitability for human consumption. Heavy Metal Pollution Index (HPI) calculations reveal a decrease at CNB sampling points S1 and S2, where waste dumping ceased in 2017. However, HPI values at other points show an increasing trend, indicating the leaching of heavy metals from solid waste into groundwater. S5 and S8 exhibit notably high HPI values (Average 464.99 and 319.59), suggesting an accumulation of heavy metals in the groundwater. Carcinogenic Risk Analysis of Arsenic highlights the failure of most sampled water to meet Carcinogenic Risk (CR) standards, signalling a potential cancer risk with prolonged use of this water.

***Keywords**: Chattogram City Corporation (CCC), WQI, HPI, Heavy metals, Solid waste dumping site*

1. Introduction

Water is undoubtedly one of the most vital resources for all living organisms, shaping the foundation of life on Earth. The significance of pure water cannot be overstated, as it is essential for human health, agriculture, industry, and the overall balance of our ecosystems. It is the lifeblood of our planet, a fundamental resource essential to all living organisms. Its purity and quality play a critical role

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in sustaining life and ensuring the well-being of both humans and the environment [1]. Access to clean and safe water is a basic human right, and it underpins countless aspects of our daily lives, from drinking and agriculture to industrial processes and ecological balance.

A growing number of situations involve a direct threat to human well-being, as water is a crucial component of both economic development and overall human well-being. For long-term sustainable development to be achieved, the freshwater crisis needs to be resolved [2]. Undoubtedly, the biggest social and development concern facing the world today may well be the lack of access to clean drinking water [3]. Ineffective water management poses a huge danger to the advancement of sustainable development and severely impedes attempts to reduce global poverty. Only 3% of the water on Earth is freshwater, and regions with high population densities frequently have the lowest water levels [4]. The fresh water on Earth is mostly frozen into ice, with the remaining portion being submerged [5]. All life on Earth is supported by a tiny percentage of the planet's water. Safe, clean drinking water is hard to come by. Currently, almost 1 billion people live in poor nations without access to it [6].

Science and engineering are based on the physics and chemistry of water. The CRC Handbook of Chemistry and Physics contains fundamental information about the characteristics of pure water [7]. Water is a universal solvent, and naturally occurring fluids contain dissolved environmental materials. Every solute in the diluted solutions alters the characteristics of water. The Lang Handbook of Chemistry [8] gives the solubility of various gases and salts in water.

In our modern world, water pollution, particularly from industrial activities often release a complex mixture of pollutants into our water bodies, contaminating the resources that we depend on [9]. These pollutants can include heavy metals, toxic chemicals, and organic compounds, and their presence can have dire consequences for aquatic life, public health, and the environment [10]. In this context, it is now essential to comprehend the factors that determine water quality and to take action against industrial waste-related water pollution to preserve the environment and improve public health in general.

Less than one-third of the Earth's surface is made up of land, thus, the remaining two-thirds is covered by the ocean [11]. People are placing more and more strain on the planet's water resources as the population grows. Our interior, coastal, and river systems are being "squeezed" by human activity, not so much that they occupy less space, but so much that their quality declines. Water contamination results from lower water quality.

In recent decades, industrialization has brought about unparalleled advancements, but it has also led to the discharge of harmful pollutants into our water bodies. Industrial waste, laden with chemicals, heavy metals, and toxins, poses a grave threat to both aquatic life and human populations [12]. The pollution of water by industrial effluents not only deteriorates the water quality but also disrupts entire ecosystems, leading to far-reaching consequences for biodiversity and human societies [13,14].

The importance of pure water is not merely a matter of convenience; it is a matter of survival. The quality of water is determined by a range of parameters, including its chemical composition, physical characteristics, and microbiological properties. These parameters include factors such as pH levels, turbidity, dissolved oxygen, temperature, and the presence of various contaminants [15]. The maintenance of optimal water quality is vital for preserving human health, protecting ecosystems, and supporting countless industrial and agricultural activities. Water quality is determined by various parameters that reflect its suitability for different purposes. These parameters encompass physical, chemical, and biological characteristics, providing a comprehensive understanding of water purity. Monitoring these factors is crucial to assessing the health of aquatic ecosystems and the safety of water, especially for consumption and also for other uses [16].

Groundwater refers to the water present within the pores, cracks, and fissures of subsurface soil, rock, and geological formations beneath the Earth's surface. Groundwater makes up around 30% of the freshwater that is readily available worldwide [17]. The replenishment of groundwater occurs through surface runoff originating from natural springs and seeps, marshes, and oases. Building and maintaining extraction wells is another typical technique for drawing groundwater for use in industry, municipalities, and agriculture. Hydrogeology, often known as groundwater hydrology, studies groundwater distribution and movement [18].

Though technically speaking, groundwater can also include soil moisture, permafrost (frozen soil), immobile water in very low permeability bedrock, and deep geothermal or oil formation water. Generally, groundwater is conceived of as water that flows through shallow aquifers [19]. It is theorized that lubrication from groundwater can affect how faults move. There is probably some water beneath on Earth, combined with other fluids in certain places. Compared to surface water, groundwater is frequently less expensive, more practical, and less prone to pollution. It is therefore frequently utilized for public water supply. For instance, California withdraws the most groundwater annually of any state, and groundwater is the nation's primary source of useable water storage [20,21]. The combined volume of water in underground reservoirs exceeds that of all surface reservoirs and lakes in the United States, including the Great Lakes. Groundwater is the only source of water for many cities. It is the main source of water for more than 2 billion people globally [22].

Groundwater use by humans contributes to environmental issues. For instance, contamination in groundwater is more difficult to remove and less obvious than that in rivers and lakes. The most common cause of groundwater pollution is inappropriate land-based waste disposal. The main sources of groundwater pollution are underground leaking of oil storage tanks and pipelines, sewage sludge, septic systems, industrial waste lagoons, excessive fertilizers and pesticides used in agriculture, tailings and process wastewater from mines, industrial fracking as well as industrial garbage landfills [23].

Furthermore, unsustainable groundwater extraction can result in land subsidence and sinking cities like Bangkok, as well as elevation loss similar to the many meters lost in the Central Valley of California. Groundwater is also vulnerable to saltwater intrusion in coastal areas [24]. Sea level rise and other climate change effects, especially those that affect the water cycle, exacerbate these problems. The axial tilt of Earth has altered by thirty-one inches due to groundwater extraction by humans [25,26]. Surprisingly, surface water bodies make up just roughly 3% of all the water on Earth. Groundwater storages provide fresh water for the survival of humans, animals, and plants.

Chattogram is one of the important cities not only in Bangladesh context but also in the context of Asia and the globe, it is a port city and a hub of international communication [27]. However, regarding a comprehensive assessment of water quality parameters of the surface water has yet to be made. The goal of this study is to present facts about the changes in groundwater quality of Chattogram City Corporation (CCC) caused by various waste dumping sites around the city that are accurate in detail, balanced in perspective, and can be accepted as reliable by its users, whatever their points of view.

2. Materials and methods

2.1. Selection of the study area

There are 41 wards in Chattogram City Corporation; it was not possible to investigate any of them, and there were no other viable possibilities. Thus, the primary sampling location for this study was the final disposal site. This four-year study was conducted between 2016 and 2019. These areas, which include CNB (Kalurghat, Chandgaon), Ananda Bazar (Halishahar), and Chinnomul (Arefin Nagar), were chosen for study to learn about the scenarios of the degradation in ambient water quality of other areas near solid waste disposal zones.

2.2. Sample collection and preservation

Eight groundwater samples were collected from 2016 to 2019 from different sites near the dumping zone, presented in Table 1 and Figure 1.

Table 1. Sampling Area

Sample ID	Depth Sampling Point(In feet)	Latitude	Longitude	Name of area/Local area
S1	150	22 23'14.20	91 51'52.68"	CNB Kalurghat Chandgaon
S2	215	22 23'12.78"	91 51'51.08"	CNB Kalurghat Chandgaon
S3	240	22 23'14.15"	91 47'48.66"	Chinnomul (Arefin Nagar)
S4	400	22 23'20.02"	91 47'54.71"	Chinnomul (Arefin Nagar)
S5	450	22 23'20.02"	91 47'54.71"	Chinnomul (Arefin Nagar)
S6	120	22 18'16.91"	91 46'25.94"	Ananda Bazar (Halishahar)
S7	70	22 18'49.55"	91 46'15.92"	Ananda Bazar (Halishahar)
S8	180	22 18'19.01"	91 46'33.50"	Ananda Bazar (Halishahar)

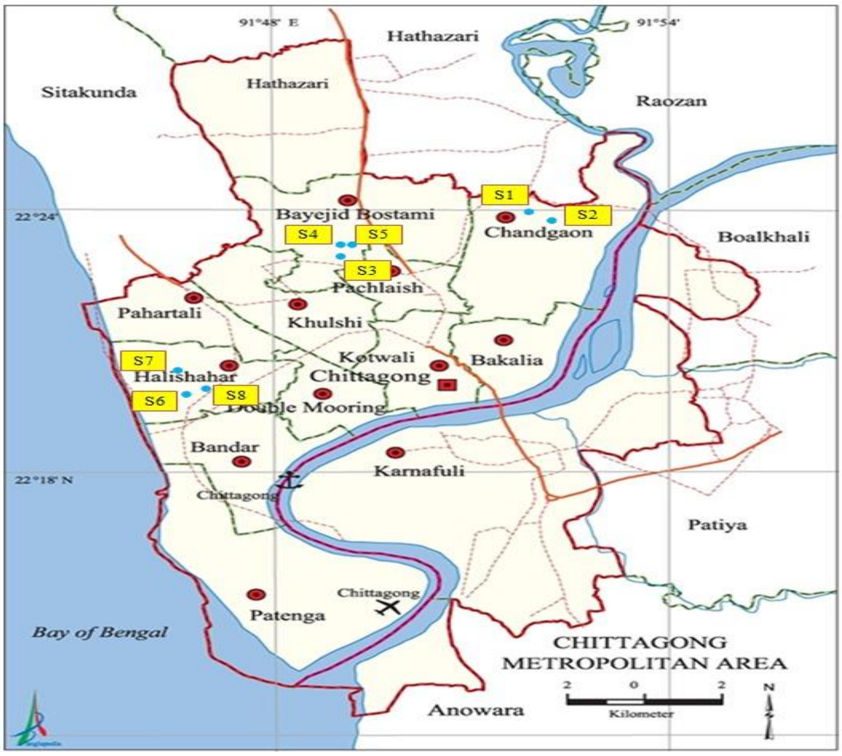

Figure 1. Sampling Area in map

2.3. Sample analysis

Temperature, pH, TDS, DO and conductivity measurements were performed in situ with a portable meter (Combo Meter, Model- HI 98194, HANNA). TSS measurement was conducted by a simple gravimetric method. Alkalinity was measured by titrimetric method and hardness values were determined via complexometric titration. Salinity was determined by a BIOBASE 900 Multi-parameter Meter and turbidity was determined with a Portable Turbidity Meter, HACH. Heavy metals and anions were determined using a direct reading spectrophotometer, Model DR/5000, HACH, USA. BOD and DO measurements along with all other parameters were analyzed according to the standard of the American Public Health Association (APHA-1996).

2.3.1. Calculation of WQI

WQI was calculated by using the equation (1) [28] :

$$WQI = \sum_{n=1}^{n} q_n w_n \Big/ \sum_{n=1}^{n} w_n \tag{1}$$

Where q_n is the sub-index value and Wn is the unit weight factor.

2.3.2. Calculation of heavy metal pollution index

The Heavy Metal Pollution Index was calculated by equation (2) [29]. The calculation of HPI involves the following steps; (1) The calculation of weightage of ith parameter, Wi (unit weight) and (2) The Quality rating for each of the heavy metals, Qi.

So,

$$HPI = \frac{\sum_{i=1}^{n} \mathrm{W_i Q_i}}{\sum_{i=1}^{n} \mathrm{W_i}} \tag{2}$$

2.3.3. Health risk assessment

Because heavy metals are highly harmful at low quantities, they receive greater attention than other contaminants that can affect water resources [30]. To understanding the origins, fate, and possible health consequences of heavy metals, characterizing the concentration of heavy metals in groundwater is required [31]. Therefore, we must deepen our understanding of the groundwater contamination caused by heavy metals in the Luan River basin in the North China Plain. Thus, the goals of this research were to: (1) look into the heavy metal distribution patterns in groundwater; (2) identify potential heavy metal sources in groundwater; and (3) evaluate potential health hazards. Hazard Quotients (HQs) and carcinogenic risks were computed using a risk assessment model to evaluate possible health concerns to humans related to particular metals. The present study aims to yield information that will facilitate the implementation of appropriate preventive and corrective actions, as well as sustainable development and efficient groundwater management.

The evaluation of the risk level for exposure to metal or metalloids led to the classification of the HHRA as either carcinogenic or non-carcinogenic. The current study calculated the chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR) to assess the rate of pollutant ingestion in a human body through the oral consumption of drinking water using USEPA recommendations.

2.3.4. Health quotient

The toxicant department of the United States Environmental Protection Agency (USEPA) determined a hazard quotient (HQ) to measure the negative impacts of exposure to non-carcinogenic pollutants. The computation was done using the following equation: HQ: HQ = CDI RfD. For arsenic, the reference dosage (RfD) is 0.0003 mg/kg/day. The equation (3) is used to calculate the chronic daily intake (CDI):

$$CDI = (C \times IR \times EF \times ED)/(BW \times AT) \quad (3)$$

Where,
“C” indicates the concentration of heavy metals in the water (mg/L),
“IR” refers to the rate at which people drink water (3.53 L/day for adults, 1.0 L/day for children, and 0.25 L/day for infants,
“ED” is the duration of exposure in years (70 years for adults, 6 years for children, and 1 year for infants, according to [32].
“EF” refers to the exposure frequency in days (d) (365 days for adults, children, and infants.
“BW” indicates the average body weight in kg (50 kg for adults, 15 kg for children, and 6.9 kg for infants.
“AT” is the average time {AT = 365 × ED(d)}.

2.3.5. Hazard index

The HI of arsenic related to the HQ values is found using the following equation, where is the total of the HQ of the parameters under investigation. HI = HQ1 + HQ2 + HQ3 + HQ4........ HQn HQ values indicate that, in the cases where HQ < 1 and HQ > 1, there are no significant non-carcinogenic health impacts, respectively. A low or nonexistent risk of adverse non-cancer health is indicated by HI <1, while a high level of risk is indicated by HI > 1. For chronic risk (HQ or HI), there are four categories: low (< 1), medium (≥1 < 4), and high (≥ 4).

2.4. Physicochemical analysis of water

The evaluation of water quality relies heavily on the analysis of various physico-chemical parameters, which serve as crucial indicators. This study focused on assessing the following parameters: pH, temperature, electrical conductivity, salinity, total dissolved solids, chloride content, biological oxygen demand, and dissolved oxygen levels. These factors provide valuable insights into the overall condition and suitability of the water source for its intended purposes. The pH ranged from 6.85 to 7.89, falling within the WHO recommended range of 6.5 to 8.5 for drinking water (WHO 2017). pH can affect water chemistry, nutrient availability, and ecosystem health. Fluctuations can be caused by photosynthetic assimilation of CO_2 and bicarbonates.

Temperature ranged from 23.5°C to 25.9°C. Temperature impacts metabolic rates, oxygen solubility, and stratification. Natural seasonal cycles and climate change influence surface water temperatures [33]. Electrical conductivity (EC) exceeded the WHO limit of 300 µS/cm at all sites, with a maximum for S8 in 2017 of 6017 µS/cm for S8 in 2017. High EC indicates elevated dissolved ion content from sources like seawater, geology, and pollution. High salinity from seawater intrusion likely contributed to the high EC near site S8 [34].

Dissolved oxygen (DO) varied from 0.46 to 5.95 ppm. DO below 5 ppm can stress aquatic life (EPA 2022). Organic waste and algal blooms can cause low DO. Site S8 had the lowest DO, possibly due to pollutants depleting oxygen.

3. Results and discussion

Water samples were collected from three points, 1. CNB Kalurghat Chandgoan 2. Chinnomul (Arefin Nagar) 3. Ananda Bazar (Halishahar) waste dumping area. Sampling was carried out at eight distinct locations across three sites: CNB Kalurghat Chandgaon (S1, S2), Chinnomul Arefin Nagar (S3, S4, S5), and Ananda Bazar Halishahar (S6, S7, S8) waste dumping area. Samples were collected consistently over four years, with collection times 23 December 2016, 24 February 2017, 02 December 2018 and 02 December 2019 (Tables 2, 3, 4, and 5).

Table 2. Physical properties of different waste dumping area deep pump sampling points in 2016

Physical Parameter 2016

Parameter	pH	Temp	EC	DO	TDS	T. hardness	Salinity	Ca hardness	Mg hardness	TSS	BOD	Alkalinity	Turbidity
Unit		°C	µS/cm	ppm	ppm	ppm	ppt	ppm	ppm	ppm	ppm	ppm	NTU
S1	7.34	24.6	531	2.12	260	36	0.16	12	24	9	0.14	208	4.5
S2	6.85	24.1	336	5.18	157	32	0.08	10	22	6.54	0.2	160	3.44
S3	7.56	24.4	392	5.33	222	196	0.018	100	96	1.87	0.2	244	1.04
S4	7.38	23.5	342	5.67	196	208	0.026	108	100	31.16	0.07	220	16.4
S5	7	24.1	4590	1.03	2240	764	2.62	168	596	83.89	0	320	46.6
S6	7.13	23.6	2680	0.97	1409	636	1.4	96	540	18.94	0.16	640	9.97
S7	7.57	24	3690	5.95	1979	527	1.81	136	391	3.73	0.17	920	2.07
S8	7.25	24.3	3740	0.46	1980	616	1.72	124	492	17.23	0.14	812	8.66
Max.	7.57	24.6	4590	5.95	2240	764	2.62	168	596	83.89	0.2	920	46.6
Min.	6.85	23.5	336	0.46	157	32	0.018	10	22	1.87	0	160	1.04
Mean	7.26	24.08	2037.63	3.34	1055.38	376.88	0.98	94.25	282.63	21.55	0.14	440.50	11.59
SD.	0.26	0.38	1824.61	2.40	934.20	291.08	1.03	56.26	245.83	26.97	0.07	302.90	15.02
WHO	6.5-8.5		200		500	500	1	--	--	Max 10	0.4	Min 30	Max 5
DoE Limit	6.5-8.5	20-30		≥6	1000	500		500	30-35	Max 10	≥2	Min 30	Max 5

Notes: Max= Maximum, Min= Minimum, WHO= World Health Organization, DoE= Department of Environment, SD= Standard Deviation

Table 3. Physical properties of different waste dumping area deep pump sampling points in 2017

Physical Parameter 2017

Parameter	**pH**	**Temp**	**EC**	**DO**	**TDS**	**T. hardness**	**Salinity**	**Ca hardness**	**Mg hardness**	**TSS**	**BOD**	**Alkalinity**	**Turbidity**
Unit		°C	µS/cm	ppm	ppm	ppm	ppt	ppm	ppm	ppm	ppm	ppm	NTU
S1	7.82	25.8	610	4.75	290	48	0.02	16	92	3.8	0.03	196	1.9
S2	7.35	25.7	378	5.3	179.4	44	0.1	12	32	5.31	0.1	148	2.95
S3	7.4	25.8	424	3.11	202	208	0.05	128	80	43.9	0.15	248	24.4
S4	7.4	26.1	378	3.16	181.1	208	0.03	112	96	28.4	0.02	198	15.8
S5	7.89	25.9	4071	2.78	2225	192	0.02	104	88	112	0.06	264	71.1
S6	7.41	25.8	4036	3.52	2240	840	1.86	96	742	117.8	0.17	1170	58.9
S7	7.54	25.4	4047	1.96	2320	612	1.85	120	492	18.9	0.16	952	10.5
S8	7.34	25.7	6017	3.88	3210	668	3.38	112	556	128.7	0.14	742	71.5
Max.	7.89	26.1	6017	5.3	3210	840	3.38	128	742	128.7	0.17	1170	71.5
Min.	7.34	25.4	378	1.96	179.4	44	0.02	12	32	3.8	0.02	148	1.9
Mean	7.52	25.78	2495.13	3.56	1355.94	352.50	0.91	87.50	272.25	57.35	0.10	489.75	32.13
SD.	0.22	0.20	2282.77	1.07	1261.30	307.05	1.29	46.37	278.17	53.19	0.06	403.14	30.11
WHO	6.5-8.5		200		500	500	1	--	--	Max 10	0.4	Min 30	Max 5
DoE Limit	6.5-8.5	20-30		≥6	1000	500		500	30-35	Max 10	≥2	Min 30	Max 5

Notes: Max= Maximum, Min= Minimum, WHO= World Health Organization, DoE= Department of Environment, SD= Standard Deviation

Table 4. Physical properties of different waste dumping area deep pump sampling points in 2018

Physical Parameter 2018

Parameter	**pH**	**Temp**	**EC**	**DO**	**TDS**	**T. hardness**	**Salinity**	**Ca hardness**	**Mg hardness**	**TSS**	**BOD**	**Alkalinity**	**Turbidity**
Unit		°C	µS/cm	ppm	ppm	ppm	ppt	ppm	ppm	ppm	ppm	ppm	NTU
S1	7.29	25.1	580	2.98	292	38	0.21	14	24	7	1.06	198	4.8
S2	7.01	24.9	347	5.28	165	30	0.12	12	18	6.82	0.46	168	3.68
S3	7.26	24.8	402	5.31	218	190	0.024	108	96	55.2	0.24	238	1.21
S4	7.17	24.6	356	5.48	207	202	0.034	124	100	27.2	0.21	218	17.2
S5	7.05	24.8	4568	1.23	2218	754	2.42	172	582	89.2	0	304	46.8
S6	7.18	24.4	2692	1.1	1358	632	1.48	98	534	122.5	0.21	612	10.2
S7	7.47	24.6	3492	5.94	2021	522	1.78	142	380	22.8	0.48	926	2.24
S8	7.2	24.8	3782	0.82	2156	608	1.7	128	480	22.5	0.44	856	8.92
Max.	7.47	25.1	4568	5.94	2218	754	2.42	172	582	122.5	1.06	926	46.8
Min.	7.01	24.4	347	0.82	165	30	0.024	12	18	6.82	0	168	1.21
Mean	7.20	24.75	2027.38	3.52	1079.38	372	0.97	99.75	276.75	44.15	0.39	440	11.88
SD.	0.14	0.21	1791.82	2.23	954.61	288.41	0.97	57.96	240.85	41.88	0.32	311.67	15.04
WHO	6.5-8.5		200		500	500	1	--	--	Max 10	0.4	Min 30	Max 5
DoE Limit	6.5-8.5	20-30		≥6	1000	500		500	30-35	Max 10	≥2	Min 30	Max 5

Notes: Max= Maximum, Min= Minimum, WHO= World Health Organization, DoE= Department of Environment, SD= Standard Deviation

Table 5. Physical properties of different waste dumping area deep pump sampling points in 2019

Physical Parameter 2019

Parameter	pH	Temp	EC	DO	TDS	T. hardness	Salinity	Ca hardness	Mg hardness	TSS	BOD	Alkalinity	Turbidity
Unit		°C	µS/cm	ppm	ppm	ppm	ppt	ppm	ppm	ppm	ppm	ppm	NTU
S1	7.42	24.8	634	2.82	324	42	0.18	16	26	12	0.37	226	4.6
S2	7.53	24.7	398	4.62	197	38	0.08	14	24	7.22	0.24	196	3.72
S3	7.63	24.3	422	4.89	246	202	0.031	102	100	68.8	0.27	264	1.08
S4	7.03	24.5	378	5.12	224	206	0.032	116	90	39.2	0.11	254	16.8
S5	7.68	24.4	4824	1.36	2482	668	2.14	186	482	121.2	0.37	336	42.2
S6	7.01	24.1	3032	1.25	2312	742	1.62	102	640	136.8	0.43	658	11.8
S7	7.53	24.4	3982	5.24	2378	622	1.84	136	486	36.2	0.42	982	2.34
S8	7.39	24.3	4346	0.72	3456	624	2.1	132	492	36.5	0.4	874	10.21
Max.	7.68	24.8	4824	5.24	3456	742	2.14	186	640	136.8	0.43	982	42.2
Min.	7.01	24.1	378	0.72	197	38	0.031	14	24	7.22	0.11	196	1.08
Mean	7.40	24.44	2252.00	3.25	1452.38	393.00	1.00	100.50	292.50	57.24	0.33	473.75	11.59
SD.	0.25	0.23	1982.69	1.93	1335.44	298.55	1.00	59.08	254.98	48.26	0.11	316.74	13.48
WHO	6.5-8.5		200		500	500	1	--	--	Max 10	0.4	Min 30	Max 5
DoE Limit	6.5-8.5	20-30		≥6	1000	500		500	30-35	Max 10	≥2	Min 30	Max 5

Notes: Max= Maximum, Min= Minimum, WHO= World Health Organization, DoE= Department of Environment, SD= Standard Deviation

The total dissolved solids (TDS) analysis shows concerning levels at several sampling points that exceed the WHO guideline of 500 ppm. The highest TDS was found at site S8 near the sea at 3456 ppm, while the lowest was at site S2 at 157 ppm. Elevated TDS levels at site S5 linked to waste dumping are also troubling. High TDS indicates the water has high levels of dissolved inorganic salts and organic matter. Major sources of TDS include natural mineral weathering, municipal discharge, urban runoff, and seawater intrusion. High TDS affects the water balance of aquatic organisms by altering the osmotic pressure gradients across cell membranes [35]. It can limit growth and reproduction or even cause mortality at very high levels above 10000 ppm [36]. Beyond ecological impacts, the taste of water worsens noticeably above 500 ppm TDS due to increased alkalinity and mineral content [37]. Water above the WHO threshold would likely require treatment to be palatable for drinking and domestic uses. Reducing TDS through improved waste management and mitigating seawater intrusion are recommended to improve water quality at impacted sites like S5 and S8. Additional sampling could identify major sources influencing the TDS levels observed.

The value of hardness fluctuates from 30 ppm to 840 ppm. The maximum value (840 ppm) was recorded in sampling point S6 and the minimum value (30 ppm) in sampling point S2. The mean of the hardness value was S5 (594.5 ppm), S6 (712.5 ppm), S7 (570.75 ppm) and S8 (629 ppm). S6, S7, and S8 values are high because this location was near to the sea. And S5 was high because of the dumping waste mixing in the groundwater.

Biological oxygen demand (BOD) quantifies the oxygen necessary for aerobic microorganisms to break down biodegradable organic matter and oxidize certain inorganic compounds within a water sample). In essence, it measures the amount of oxygen consumed during the decomposition of organic materials present in the water. The World Health Organization (WHO) recommends a maximum BOD level of 5 parts per million (ppm) to maintain acceptable water quality standards. The maximum BOD value observed in this study was 1.06 ppm, which indicated the BOD range was within the limit. BOD value can be affected by various types of inorganic and organic substances in water [38]. BOD remained below the DoE limit of a maximum of 2 ppm. BOD measures biodegradable organics which deplete oxygen during decomposition. The low BOD suggests minimal organic waste loads at the sampling sites.

Turbidity spanned 1.04 to 71.5 NTU, with the highest reading at site S8. Turbidity measures suspended particulates from erosion, waste discharge, algal growth etc. High turbidity degrades aquatic habitats and can transport pollutants [39]. The mean value of the Alkalinity was 168 ppm to 945 ppm. In the DoE and WHO permitted limit for Alkalinity is a minimum of 30 ppm. However, the maximum limit is not set up in DoE and WHO. So, every sampling area was a safe site in alkalinity. Total suspended solids (TSS) reached 136.8 ppm at site S6. Suspended particles like silt and organic detritus increase TSS. Elevated TSS indicates land disturbance and runoff pollution [40]. High TSS lowers the light penetration needed for aquatic plants.

Salinity was lowest (0.02 ppm) at site S5 and highest (3.38 ppm) at site S8. Salinity reflects dissolved ionic salts, often from seawater. Salt impacts organism osmoregulation and community structure [41]. The mean value of the Ca hardness was 12 ppm to 157.50 ppm. In the DoE permitted limit for Ca hardness is a maximum of 500 ppm. So, every sampling area was a safe site for drinking purposes.

3.2. Anionic parameters

Anionic parameters serve as metrics employed to assess the quality of water. The parameters analyzed in this study were Chloride, Sulphate, Phosphate, Nitrite (NO_2^-), Nitrate (NO_3^--N) and Fluoride. Chloride levels ranged from 110 to 1319 ppm, exceeding the WHO limit of 250 ppm at all sites except S3 [42]. Elevated chloride indicates pollution from sources like seawater intrusion, landfill leachate, and agricultural runoff. High chloride imparts a salty taste and can have laxative effects. Sulphate concentration spanned from 0 to 191 ppm. Sulphate in groundwater primarily originates from mineral dissolution and atmospheric deposition. Elevated levels can derive from mining and fertilizer use.

Phosphate concentration reached 9.75 ppm at S6. Phosphorus enters groundwater from overlying soils, fertilizers, animal waste, and septic systems. Excess phosphorus contributes to eutrophication [43]. Nitrite and nitrate concenrtations are at 5.18 ppm and 4.43 ppm for S6. Nitrogen compounds infiltrate from fertilizers, manure, and septic tanks. Nitrate is a health risk and signifies contamination. The Maximum Nitrate (NO_3^--N) value was (23.8 ppm) in the sampling area S8 and the minimum value was (0.3 ppm) in the sampling area S2. Nitrates are a type of contaminant that can enter groundwater from various sources such as agricultural activities, industrial manufacturing, and municipal landfills. Excessive application of nitrogen fertilizers in agriculture can lead to leaching of nitrates into groundwater, especially in areas with intensive farming practices. Recent studies have shown increasing nitrate contamination in groundwater aquifers from the Midwestern United States to China [44]. The presence of elevated nitrate concentrations in groundwater presents health risks if consumed, including methemoglobinemia in infants and an increased risk of thyroid disease or gastric cancer in adults [45, 46]. Monitoring nitrate levels and implementing best management practices for fertilizer application are important for reducing nitrate leaching to groundwater.

The maximum fluoride value was (0.64 ppm) in sampling area S8 and the minimum value was (0.1 ppm) in the sampling area S3, S4, and S5, which did not exceed the drinking water standard of 1.5 ppm recommended by the WHO (2017). Elevated fluoride concentrations above 1.5 ppm can cause dental fluorosis while prolonged exposure to levels above 10 ppm leads to crippling skeletal fluorosis [47]. Recent studies have also linked elevated fluoride exposure through drinking water to increased risk of arthritis, osteoporosis, bone fractures, and thyroid dysfunction.

Overall, the elevated anion levels highlight contamination from urban, agricultural, and industrial activities. Reducing nutrient and chloride inputs through improved waste management is needed to decrease pollution loading. Diligent monitoring of shallow groundwater for contaminant early warning is also recommended.

3.3. Heavy metals

Heavy metals are parameters used in evaluating water quality. The heavy metals analyzed in this study were iron, arsenic, copper, chromium and zinc. In our four years of results, the minimum iron value was (0.5 ppm) in the sampling areas S3 and S7 in 2016, while the maximum value was (9.21 ppm) in S5. Most of the sampling areas had iron values above the WHO drinking water standard of 0.3 ppm (WHO, 2017). Elevated iron concentrations can lead to staining, bitter metallic taste, and discoloration issues. Other heavy metals like arsenic, copper, chromium and zinc were also detected but did not exceed WHO guidelines for drinking water (WHO, 2017). Regular monitoring of heavy metals is important to ensure concentrations remain below levels hazardous to human health.

Arsenic is a known carcinogen and chronic exposure through drinking water can lead to skin lesions, peripheral neuropathy, cardiovascular disease, and various cancers [48]. The EPA drinking water standard for arsenic is 10 ppb (EPA, 2021). Sampling results showed the maximum arsenic value was (0.02 ppm) in areas S7 and S8, while S1, S2, S3 and S8, showed below the detection limit.

Copper in drinking water primarily results in gastrointestinal issues like nausea, vomiting, and diarrhoea above the EPA limit of 1.3 ppm (EPA, 2021). The maximum copper level was (0.33 ppm) in S1 and a minimum 0 ppm in S2, S3, S4, S7, and S8, again below the EPA standard. For chromium, EPA has a drinking water limit of 0.1 ppm for total chromium (EPA, 2021), while the maximum here was (0.051 ppm) in S8 and a minimum of 0.001 ppm in S1, S5, S6, and S7. Hexavalent chromium is the more toxic form and is linked to cancer at high doses (IARC, 2012).

The recommended limit for zinc is 5 ppm (WHO, 2017). The maximum zinc level was (1.01 ppm) in S1 and a minimum 0.09 ppm in S6, within the WHO guideline. Excess zinc can produce a metallic taste and result in nausea and vomiting (WHO, 2017). Regular monitoring and treatment are important to keep heavy metals below regulatory limits in drinking water.

3.4. Water Quality Index (WQI)

Groundwater chemistry is frequently employed as a means of differentiating between irrigation and drinking water quality [49, 50]. An essential metric for determining the sustainability of the water quality for human use is the water quality index or WQI [51]. WQI is a rating system that shows the combined impact of all the water quality factors on the overall water quality. The World Quality Index (WQI) is based on drinking water quality standards published by the World Health Organization in 2011. Thirteen water parameters were analyzed to calculate the WQI in thirty-two groundwater sampling areas tested periodically over four years (Figure 2). The maximum value of the WQI was 406.71 at S5 in 2019, and the minimum value of the WQI was 63.97 at S1 in 2017. The mean value indicated that S3, S4, S5, S6 and S8 WQI values of more than 100 that this sampling site water were unsuitable for human consumption.

The WQI is significant because it offers a straightforward water quality indicator that can be used to determine whether or not a particular water source is suitable for human consumption. Information about water quality is also disseminated to the public and policymakers through it. Water bodies can be tested for quality utilizing physical, chemical, and biological factors with the WQI. To expand and enhance the index in multiple aspects, WQIs ought to be connected to scientific discoveries (ecological, for instance). For usage in subsequent research, a complex WQI that considers statistical techniques, parameter interactions, and scientific and technological advancement should be developed. In the year 2016 average WQI of S1 (Located in CNB, Kalurghat, Chandgaon) was 82.0025 and the analyzed value of S1 was 97.13. According to the WQI scale, the analyzed value shows that the mentioned sample in the CNB location was very poor-quality water these areas water can be used for daily domestic work and farming, but it is not recommended for drink because of high WQI. Najafi Saleh et al. [52] also found similar high WQI values for groundwater samples around waste dumping sites in Qaem Shahr City, Iran. Subsequently, in 2017 WQI value of S1 was (located CNB, Kalurghat, Chandgaon) found at 63.97 it was lower than the 2016 value but it was still not drinkable. Periodically analyzing the data of 2018 & 2019 we find the WQI value was 75.06 & 91.85. We can see the WQI value increased gradually. This sample was collected from a depth of 150 feet of the mentioned location area. The S2 collection point is located also at CNB, Kalurghat, Chandgon area. The WQI value analyzed in 2016 was 102.32, in 2017 it was 92, in 2018 the value was 93.52 and lastly in 2019 the value of WQI found 85.89. The average WQI of S2 was 93.43. Compared to the analyzed data values S1 & S2 between 2016 and 2019 WQI decreased, because waste dumping is prohibited currently. Similar trends were observed by Ferrer et al. [53] in Spain where WQI values decreased gradually upon stoppage of waste dumping in the near vicinity. If this continues, we hope that in the next few years, the groundwater of these areas will be drinkable again.

On the other hand, the sample of S3 located in the Chinnomul area at Arefin Nagar shows the WQI analyzed in the years 2016, 2017, 2018 & 2019 was periodically 86.69, 97.05, 114.94, and 117.51. We can see that the analyzed value went slowly from high to higher. As for the S4 sample deep tube well water WQI value increased bit by bit. In 2016 WQI was analyzed at 105.21, in 2017 WQI was 104.27, in 2018 it was 120.62 & in 2019 the WQI value was 155.35, and the average value was 121.36. So, after analyzing the WQI data of S3 & S4 it is clear that the area's deep tube well water is unsustainable according to the WQI scale limit value.

Han et al. [54] also observed that near waste dumping sites, the groundwater became unsuitable for drinking in China. We can guess in the Arefin Nagar area solid waste & organic waste are being dumped which contains various heavy metals, chemicals and organic substances and it contaminates the groundwater of the area. Rana et al. [55] found groundwater samples near waste dumping sites to contain large quantities of heavy metals in various collection points in India. S5 sample water was collected from also Arefin Nagar but the groundwater of this sampling water is highly contaminated. The WQI value was very high for this sampling area and it was also slowly increased periodically. In 2016 WQI was 367.72, in 2017 WQI was 369.047, in 2018 WQI was 378.5 and in 2019 WQI value analyzed was 406.71 and four-year WQI average was 380.494, it was 3 times higher than the WQI limit scale. So, it is visible that, the water of this area is hazardous for drinking, and it will be very harmful to a human being, because of contaminant substances in these areas' water, people will be affected by various types of diseases also can be terminal illnesses like cancer, so the use of groundwater of this area should be stopped, and instead of using this water alternative water use system need to create or develop.

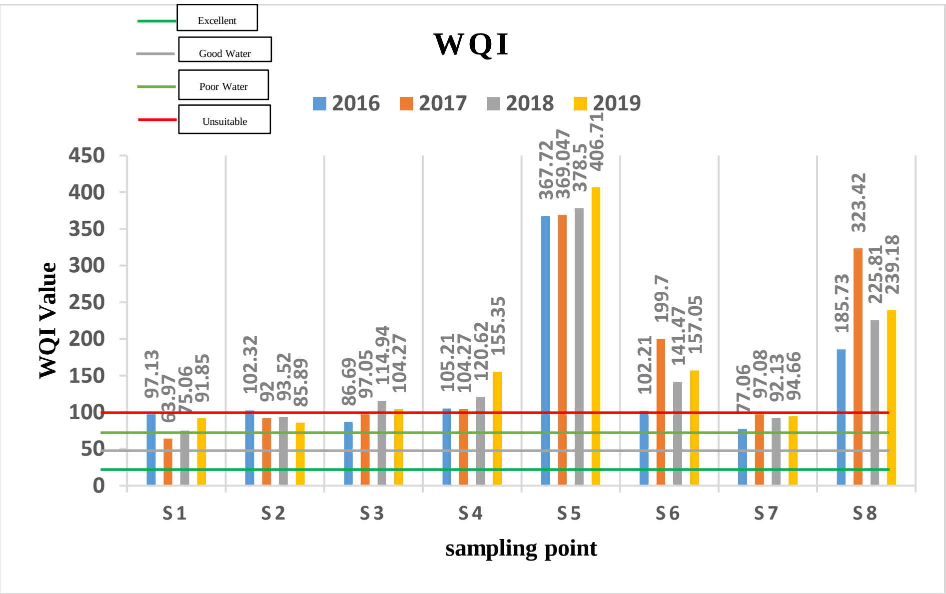

Figure 2. Yearly Basis WQI Data

S6, S7 and S8 sampling water collection points were Ananda Bazar, Halishahar. These areas groundwater WQI value also increased bit by bit. In 2016 S6 WQI was 102.21, in 2017 WQI was 199.7, in 2018 it was 141.47, and in 2019 WQI value was 157.05 and S6 average WQI was 150.108. For S7 WQI in 2016 was 77.06, in 2017 it was 97.08 where the 2018 WQI analyzed was 92.13 the 2019 WQI was 94.66, the average WQI of S7 was 90.23. On the other hand, S8 WQI in 2016 was found 185.73, WQI in 2017 S8 was 323.42, and the 2018 & 2019 WQI analyzed periodically were 225.81 & 239.18. The average WQI of 4 years of S8 sampling point was 243.535. Ramakrishnaiah et al. [56] also reported similar fluctuating and very high values for groundwater in respective areas. So, in these sampling points waters is also not drinkable thus S6 and S7 sampling points groundwater can be used for other domestic work and construction purposes rather than drinking. However, the S8 sampling point groundwater is highly contaminated. So especially in this area water must not be used for drinking or other work. It is also necessary to find alternative drinking water sources or systems for leading a healthy life.

3.5. Heavy Metal Pollution Index

The Heavy Metal Pollution Index (HPI) provides a comprehensive model for grading that assesses the collective impact of individual metals on overall water quality, as outlined by [57]. This estimation involves considering the unit weight (Wi) and recommended standard value (Si) for relevant elements, with an inverse relationship between the two. The unit weight, ranging from 0 to 1 for heavy metals, plays a pivotal role in calculating the HPI. The critical threshold for HPI is set at 100, according to [58].

In this study, the recorded HPI values exhibited a range, with the maximum value reaching 513.20 at sampling site S5 in 2019, while the minimum was observed at 75.07 at S1 in the same year (Figure 3). The mean HPI values for the various sampling sites were as follows: S1 (96.88), S2 (131.06), S3 (114.60), S4 (131.99), S5 (464.99), S6 (119.72), S7 (100.68), and S8 (319.59). HPI values exceeding 100 indicated water contamination, except S1, where the water sample demonstrated non-contaminated status. This comprehensive assessment highlights the varying degrees of water quality across the sampled sites, emphasizing the significance of the HPI model in identifying and addressing heavy metal pollution.

The HPI values for the S1 sampling area in 2016, 2017, 2018 and 2019 were 147.2481, 84.07928, 81.12456 and 75.0749 respectively. The HPI value decreased gradually over the years indicating that the water gradually became less polluted by heavy metals. The reason behind this is that the dumping of waste in this area has stopped since 2017. Chakraborty et al. [59] has observed a similar trend of delineating HPI values near landfills and waste dumping sites after dumping has ceased. The same occurrences were observed for S2 as well since the HPI values in 2016, 2017, 2018 and 2019 were 137.2344, 140.196, 129.2961 and 117.5354 respectively. However, the values, despite showing a gradual downward movement, failed to stoop below 100 and remained highly polluted and unsuitable for drinking. The HPI values for water samples collected from various dumping sites in Tanzania also exhibited similar trends as reported by [60].

S3 and S7 exhibited incoherent HPI values over the years fluctuating from non-contaminated to contaminated water throughout years as apparent from the values: for S3- 135.8472, 77.8165, 116.3903, 128.3542 and S7- 90.8961, 87.8685, 110.8964, 113.0522. The HPI values for S4 and S6 showed gradual deterioration over the years: (HPI values for S4- 102.535, 111.8213, 145.4515, 168.1603 and the HPI values for S6- 98.8532, 126.9085, 118.2899, 134.8475). The HPI values indicate that gradually the water became contaminated due to continuous waste dumping and the water gradually became unsuitable for drinking. Similar trends were found by [61] near waste dumping sites in various parts of India.

However, the HPI values for S5 and S8 remained highly polluted over the years and the values indicated that the water quality in these two dumping sites is further away from being suitable for drinking. As apparent from the HPI values- S5 (468.1726, 399.1504, 476.0538, 513.2547) and S8 (142.2354, 313.6576, 342.2638, 364.5212), the values are very high and the water is extremely polluted in these sites. [62] also observed similar high HPI values for groundwater samples near dumping sites in India and Serbia.

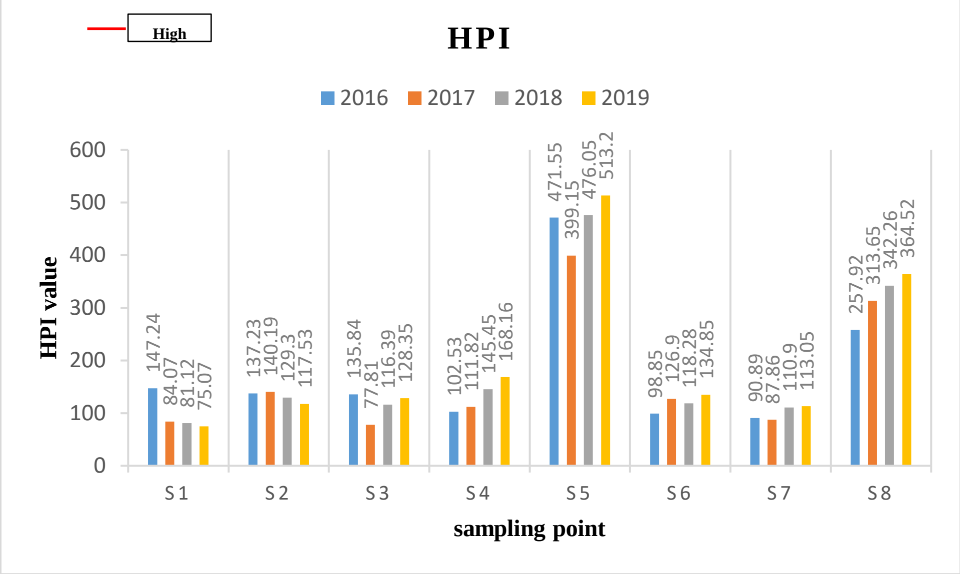

Figure 3. Yearly basis HPI data from eight sampling points.

3.6. Health risk assessment

3.6.1. Carcinogenic risk

In Chattogram City Corporation, the primary source of drinking water is groundwater, but the presence of industrial waste containing heavy metals like arsenic, cadmium, and lead poses a threat to water quality. The unique conditions o the area, including soil texture, industrial activities, and high groundwater levels, increase the likelihood of water contamination. The assessment of metal concentrations and associated risks is crucial for safeguarding the health of organisms.

The carcinogenic risk analysis revealed varying values across sampling points, with the maximum risk for adults recorded at 0.00212 in locations S5, S7, and S8 (Figure 4 and Table 6). Conversely, the minimum risk was found at S1, S2, S3, and S4. Notably, the mean risk for adults was zero at S1 and S2, while the highest mean values were observed at S7 (0.00212) and S8 (0.00212). For children, the mean carcinogenic risk at contaminated sites S7 and S8 was determined to be 0.002 (Figure 5 and Table 7). These findings underscore the importance of addressing heavy metal contamination in water sources for the well-being of both adults and children in the region.

Table 6. Yearly basis Carcinogenic risk of adult of different waste dumping area deep pump sampling points.

Carcinogenic Risk of adults (As)								
Year	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
2016	0	0	0.00212	0.00106	0.00212	0.00106	0.00212	0.00212
2017	0	0	0.000	0.000	0.00106	0.00106	0.00212	0.00212
2018	0	0	0.000	0.000	0.00106	0.00106	0.00212	0.00212
2019	0	0	0.000	0.000	0.00106	0.00106	0.00212	0.00212

Max.	0	0	0.00212	0.00106	0.00212	0.00106	0.00212	0.00212
Min.	0	0	0.000	0.000	0.00106	0.00106	0.00212	0.00212
Mean	0	0	0.00053	0.00026	0.00132	0.00106	0.00212	0.00212
SD.	0	0	0.00106	0.00053	0.00053	0.000	0.000	0.000

3.6.2. Non-Carcinogenic risk

The Hazard Quotient (HQ), which serves as the risk factor for non-carcinogens, establishes a connection between the dose received at the exposure point (Average Daily Dose - ADD) and a toxicological end point, represented by the Reference Dose (RfD) (10.10). The RfD, derived from either a NOAEL or LOAEL, is a low-dose end point. An acceptable HQ is one that is less than 1, indicating a relatively low risk.

In 2016, the maximum non-carcinogenic risk for adults, as measured by HQ, reached 4.71 at sampling site S3, while the minimum values were recorded at 0 for sampling sites S1 and S2. Similarly, for children, the maximum non-carcinogenic risk was 4.44 at sampling points S3, S5, S7, and S8, with minimum values of 0 at S1 and S2. This pattern continued in 2017 and 2018, with the maximum HQ values for adults consistently at 4.71 in sampling areas S7 and S8, and minimum values at 0 for S1, S2, S3, and S4. Children also showed a similar trend in HQ values during these years. In 2019, the HQ values for adults remained at 4.71 for S7 and S8, with minimum values at 0 for S1, S2, S3, and S4. Likewise, children's HQ values ranged from a maximum of 4.44 at S7 and S8 to a minimum of 0 at S1, S2, S3, and S4. These findings highlight the consistent potential non-carcinogenic risks in the sampled area, emphasizing the need for ongoing monitoring and mitigation efforts to ensure the safety of both adults and children in the region.

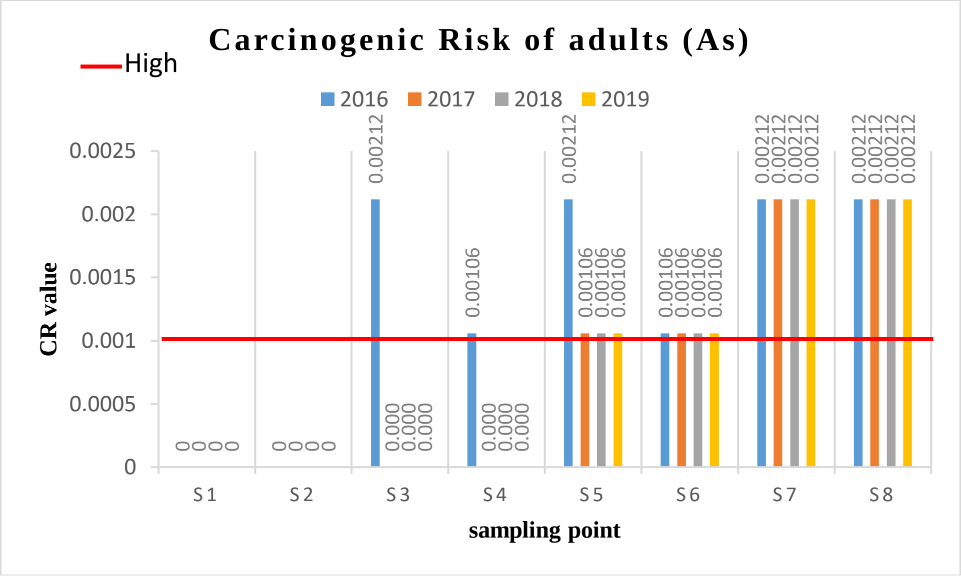

Figure 4. Carcinogenic data of adult from eight sampling points

Table 7. Yearly basis Carcinogenic risk of Children of different waste dumping area deep pump sampling points.

Carcinogenic Risk of children (As)								
Year	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
2016	0	0	0.002	0.001	0.002	0.001	0.002	0.002
2017	0	0	0	0	0.001	0.001	0.002	0.002
2018	0	0	0	0	0.001	0.001	0.002	0.002
2019	0	0	0	0	0.001	0.001	0.002	0.002
Max.	0	0	0.002	0.001	0.002	0.001	0.002	0.002
Min.	0	0	0	0	0.001	0.001	0.002	0.002
Mean	0	0	0.0005	0.00025	0.00125	0.001	0.002	0.002
SD.	0	0	0.001	0.0005	0.0005	0	0	0

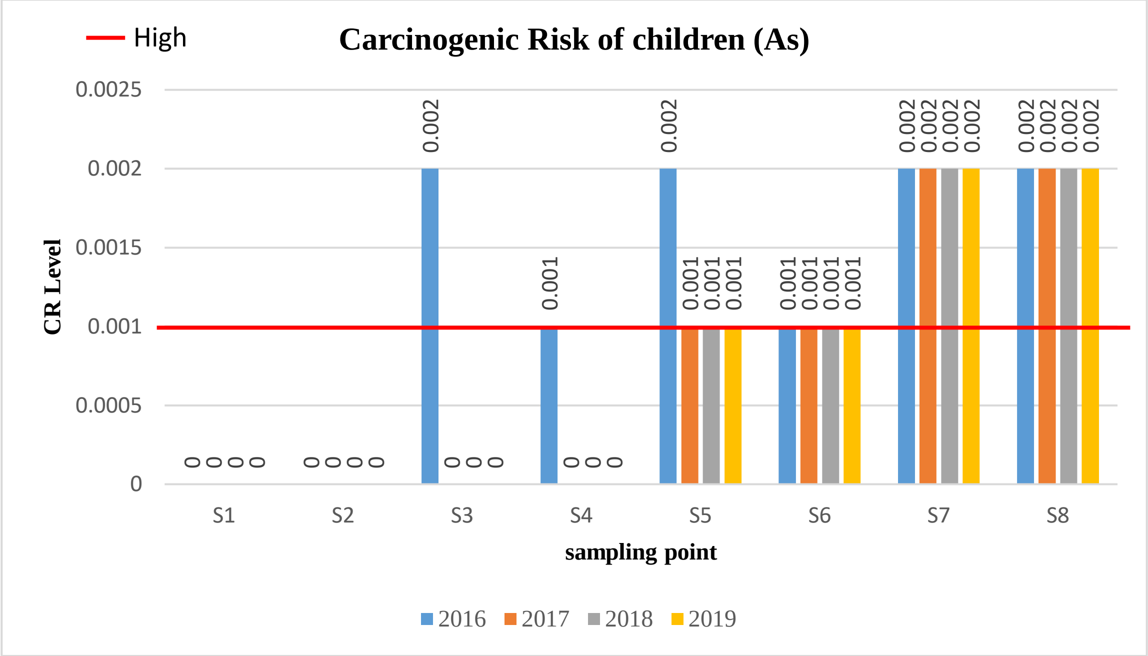

Figure 5. Yearly basis Carcinogenic risk data of Children from eight sampling points

3.7. Human health risk

According to carcinogenic risk analysis of arsenic shows that risk ranged from 0 to 0.0023 for adults and 0 to 0.002 for children and most of the sampling sites water failed to meet the CR standard and fell under the category of carcinogenic for human consumption. However, throughout the years, (2016, 2017, 2018 and 2019), the water samples of S1 and S2 exhibited zero values of arsenic which indicates that the water of these two collection points was not carcinogenic and suitable for drinking for both adults and children. The water of S7 and S8 showed very high values for arsenic consistently throughout the years. This indicates that the water of these two collection points was particularly unsuitable for drinking and highly carcinogenic.

Similar trends in arsenic pollution were observed by [63,64] in India. The assessment of non-carcinogenic risk exhibited that the risk ranged from 0 to 4.70 for adults and between 0 and 4.44 for children, with an average of 5.23 and 4.93, in 2016 respectively. In 2017 non-carcinogenic risk showed that the risk ranged from 0 to 4.70 for adults and between 0 and 4.44 for children with averages of 3.13 and 2.963. Also, in 2018 & 2019 it is shown that the risk ranged from 0 to 4.70 for adults and between 0 and 4.44 for children, with averages of 3.31 and 2.96. Non-carcinogenic risk data shows that it is also undrinkable for human beings, drinking those sampling sites' water may have long-term effects on children's and adults' health.

4. Conclusions

Deep pump water samples of different solid waste dumping sites of CCC have been studied. The pH, temperature, turbidity, TDS, TSS, salinity, chlorides, nitrates, phosphates, and hardness were found to exceed WHO guidelines for drinking water quality at several sampling sites, indicating contamination from sources like waste dumping, sewage, agricultural runoff, and seawater intrusion. Heavy metals like iron, arsenic, copper, chromium, and zinc were detected but remained below WHO limits except for iron which exceeded the limit at most sites.

The Water Quality Index (WQI) showed very poor-quality water unsuitable for drinking at sites S1, S2, S5, S6, and S8 with values exceeding 100. The WQI trended higher over time at most sites indicating deteriorating water quality. The Heavy Metal Pollution Index (HPI) categorized sites S5 and S8 as highly polluted with values over 300. Other sites showed fluctuating HPI values from non-contaminated to highly contaminated over the years. The human health risk assessment found the water at all sites except S1 and S2 to be carcinogenic due to high levels of arsenic. The non-carcinogenic risk was also high, especially for children. Overall, the groundwater quality is poor at most sampling sites located near waste dumping areas, with several parameters exceeding safe limits.

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Conflict of Interest

We declare no conflict regarding the publication of the study.

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