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EVALUATION OF WATER QUALITY AND HUMAN HEALTH RISK ASSESSMENT OF DRINKING WATER OF TALUKA BADIN, SINDH

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Article Info

Abstract

A total of 25 drinking water samples were collected in triplicate from six union councils of Taluka Badin. Various parameters were determined using standard laboratory methods. Parameters included pH, EC, TDS, chlorides, alkalinity, As, Cd, Cr, Co, Cu, Fe, Mn, Ni and Zn. Heavy metals were analyzed using Atomic Absorption Spectrophotometer. The concentration ranges of heavy metals As, Cd, Cr, Co, Cu, Fe, Mn, Ni and Zn are given as, 0.00 – 0.0145, 0.001 – 0.012, 0.013 – 0.040, 0.001 – 0.014, 0.056 – 0.329, 0.085 – 0.156, 0.030 – 0.150, 0.001 – 0.106 and 0.060 – 1.00 mg/L respectively. To assess human health risks, the chronic daily intake (CDI), Hazard Quotient (HQ), Hazard Index (HI) and cancer risks were calculated. Non-carcinogenic risk was calculated by CDI, HQ, & HI whereas, carcinogenic risks was measured for arsenic, chromium, and nickel. Based on the findings, the drinking water in the coastal areas of Taluka Badin is contaminated with heavy metals, presenting a potential health risk to the population. The calculated cancer risk and hazard indices indicate the need for measures to improve drinking water quality in the region.

Keywords: Arsenic, heavy metals, drinking water, Chronic Daily Intake (CDI), Hazard Quotient (HQ), Hazard Index (HI), Atomic Absorption Spectrophotometer.

Introduction

Safe potable water or drinking water is necessary for human health and may be described as water that doesn't cause any noteworthy health hazard over lifetime duration of usage [1]. Although, access to safe potable water is a main challenge because of a natural as well as anthropogenic factors in the coastal area of Sindh [2]. This has intended for extensive contamination of water and noteworthy public health concerns [3]. Potable water contamination in coastal area of Sindh shoots from different sources, with main contribution from human related and natural activities. The over – withdrawal of groundwater for industrial, domestic, and agricultural use has reduced the water table, permitting intrusion of salty seawater to happen, which is an important matter mostly in districts such as Karachi, Thatta and Badin. This is the main reason for the high total dissolved solids (TDS) and salinity in the region of groundwater [5].

Moreover, urban and industrial waste, frequently released without treating into water bodies, contaminates groundwater and surface water with hazardous materials, heavy metals such as arsenic, lead and chromium as well as various toxic substances [6]. The coastal area, being home to main industrial and urban centers such as Karachi is mainly affected by this. The widespread utilization of pesticides and fertilizers in farming leads to agricultural runoff that leaches into groundwater and close by water sources, bringing in detrimental nitrates, phosphates and other contaminants [7,8]. The microbial contamination is the main source of immediate health risk, which takes place when leaking lines combine with potable water supplies, leading to the extensive occurrence of pathogens such as, *E. coli* as well as other coliform bacteria. High concentration of arsenic and fluoride in the groundwater of numerous parts of Sindh, is contributed by a geogenic contamination, a natural process [9].

Human health risk assessment for polluted water in coastal area of Sindh exposes a major load of disease and a considerable warning to public health. Theses evaluations usually determine the risk of assessing the exposure of the people to pollutants and the potential for complex health effects [10, 11]. The extensive and the most immediate health risk is from waterborne diseases, with prevalent and common occurrence of hepatitis, gastroenteritis, diarrhea, cholera, and typhoid in the region mostly among infants [12]. Research reports and studies have related a large number of deaths and diseases in Pakistan to the utilization of hazardous drinking water. Different set of risks may be posed due to the long – term exposure to chemical contaminants. High content of arsenic is associated to melanosis and keratosis (skin lesions), neurological disorders, as well as different cancers like, bladder, lung and skin cancers [13]. Dental and skeletal fluorosis causing joint pain, bone deformities and tooth decay can be caused due to excessive fluoride [14]. Several heavy metals such as, nickel, chromium, and lead may cause serious damage to the central nervous system, liver and kidneys and can also be cancer causing [15]. Furthermore, high salinity due to seawater intrusion is associated to health problems such as, cardiovascular diseases, kidney dysfunction, and hypertension due to the high concentration of sodium and chloride in water [16].

The main objective of this study is to assess the quality of drinking water in the coastal area of Badin and to quantify the associated human health risks posed by heavy metals. The present work also tends to aware local inhabitants regarding water toxicity to mitigate the prevalence of waterborne diseases.

Materials and Methods

Description of Study Area

The weather in study area of Badin, Sindh, has noteworthy and direct impact on the variations of groundwater. The purpose of hot, semi-arid climate in the region is that groundwater levels are mainly stated by a cycle of natural recharge from monsoon rains and reduction via higher rates of evaporation and human induced withdrawal. The most critical weather incident for groundwater is the monsoon period, normally from June – September. Heavy rainfall presents the major source of natural recharge for the shallow freshwater aquifers during this said period. The water table is replenished, which infiltrates the ground by rainfall. The efficiency of this recharge is greatly reliant on the type of soil, sandy soil permits for proficient percolation, whereas areas with higher level of clay soils experience slower penetration [17].

Other than monsoon period, higher temperatures and lower level of humidity lead the climate. This guides to higher evaporation and evapotranspiration rates, which cause noteworthy groundwater depletion. In areas where the water table is nearer to the surface, heat of the sun takes up the water through the soil by evaporating and lowers the groundwater level and frequently enhances the salt content of topsoil. The interchange between groundwater and weather is complex by other factors. Over – extraction from agricultural boreholes for irrigation, particularly during dry season, worsens the natural depletion caused by evaporation. This excessive pumping lowers the water table and can upset the delicate balance in the coastal environment, leading to the intrusion of saline seawater into freshwater aquifers. The effects of climate change, such as more erratic and intense monsoon downpours and prolonged dry spells, intensify both the risk of flooding, which can contaminate aquifers and the pressure on groundwater resources during droughts [18].

Figure: 1(a) GIS Mapping of Coastal area of Taluka Badin and (b) location of zero point of Badin

Solutions and Reagents

Following stock solutions and reagents for the present work were prepared; 1000 mg/L of heavy metals (arsenic, cadmium, chromium, cobalt, copper, iron, manganese, nickel, and zinc). Silver nitrate ($AgNO_3$) solution, 0.025N solution, Potassium chromate (K_2CrO_4) solution, Sodium hydroxide (NaOH) solution (0.025N), Sulphuric acid (H_2SO_4) (1:19), 0.1N Solution of Hydrochloric acid (HCl), 0.1 N Solution of Sodium Carbonate (Na_2CO_3), Indicator Solution of Methyl Orange, Ammonium Chloride-Ammonium Hydroxide Buffer solution, Indicator of EBT (Eriochrome Black-T), Solution of Na_2-EDTA (0.01 N), Crystals of Barium Chloride ($BaCl_2$), Conditioning Reagent, Stock Standard Solution of Sulphate, Brucine reagent, Sulphuric Acid (H_2SO_4) Reagent (4:1 v/v), Solution (30%) of Sodium Chloride (NaCl), Stock Nitrate solution (100 mg/L), Solution (5 N) of Sulphuric Acid (H_2SO_4), The solution of Potassium antimonyltartarate, The reagent of Ammonium molybdate, Solution of Ascorbic acid ($C_6H_8O_6$), Combined reagent solution, Stock phosphate-phosphorus solution (50µg/mL), Potassium permanganate ($KMnO_4$) N/100, Oxalic acid $H_2C_2O_4.2H_2O$ N/100 , and Sulfuric Acid (H_2SO_4) 1:4.

Water Sample Collection and view of somewhere study area of Taluka Badin

Every drinking water sample was taken in triplicate from every area where locals installed various water sources. Twenty-five drinking water samples total were gathered from six Union Councils in the Badin Coastal Area and placed in 1.5-liter plastic bottles. pH and EC were measured in the field while samples were being collected. Each location's GPS was also recorded to ensure the results were genuine. Six UCs from Taluka Badin's coastline area were chosen for the study; they are listed below (Table: 1).

Table: 1 Water Sample collection and Labeling from Six UCs of Taluka Badin

S. No	Name UC	No. Samples with Codes
1	Municipal Committee Badin	BD-01 to BD-05
2	Qazia Wah Old	BD-06 to BD-9
3	Pir Fateh Shah	BD-10 to BD-13
4	Serani	BD-14 to BD-17
5	Shaikh Qirhyo	BD-18 to BD-21
6	Badin City	BD-22 to BD-25

Physicochemical Analysis of Groundwater Samples

Electrical conductivity (EC) and pH were measured at the time of sampling using conductivity meters (HANNA Instruments, HI Multi-range EC portable meter) and pH meters (HANNA Instruments, pH 210 Woon socket-RI-USA Made in Romania). Buffers with pH values of 4 and 9 were used to calibrate the pH meter. The WHO and other drinking water quality guidelines recommend a pH range of 6.5 to 8.5 for drinking water. Extreme pH values (<4 &>9) can have detrimental effects on human health. Standard techniques were used to determine additional physicochemical parameters such TDS, chlorides, bicarbonates, alkalinity, and turbidity. UV-Aware Sulphate, nitrate-nitrogen, and phosphate-phosphorus were measured using a double beam spectrophotometer model (Super Aquarius, CECIL CE-9500). Using the SPADNS Spectrophotometric Method, fluoride was measured.

Sample Preparation for Heavy Metal Analysis

For pre-concentration, a 250 mL water sample was placed in a 500 mL beaker over an electric hot plate. Two to three drops of concentrated nitric acid were then added. The temperature was kept below the water's boiling point, between 70 and 80 oC. The leftovers were dissolved in 2N nitric acid, and the mixture was then poured into a 25 mL volumetric flask. De-ionized water was used to increase the amount to 25 mL. All samples were sent right away to the National Water Quality Lab (NWQL) PCRWR Most Islamabad, where they were examined for amounts of Cd, Cr, Co, Cu, Mn, Fe, Ni, and Zn using Analytic Jena AAS. Standard solutions of the metals under investigation were used to create calibration curves, and calibration graphs were used to determine the concentration of these metals in drinking water samples.

Risk Assessment

A risk assessment of heavy metals in drinking water is a critical process to determine the potential health threats to a population. It involves an organized evaluation of heavy metal levels in water sources, the mechanisms of human exposure as well as potential health consequences. Risk assessment can be measured by using various equations such as, Chronic Daily Intake(CDI), Hazard Quotient (HQ), Hazard Index (HI) and Individual Cancer Risk (CR) and Total Cancer Risk (TCR).

Table: 2 Integrated Parameters for Human Health Risk Assessment

I. Health Risk Assessment Formulas [19]		
Risk Parameter	Acronym	Mathematical Formula
Estimated Daily Intake	EDI	$EDI = \frac{Cveg \times IRveg \times EF \times ED}{BW \times AT}$
Hazard Quotient	HQ	$HQ = \frac{EDI}{RfD}$
Total Hazard Quotient	THQ	$THQ = \sum_{i=1}^{n} HQi$
Target Cancer Risk	TCR	$TCR = EDI \times SF^{o}$
II. Definition of Variables [20]		
Variable	Value	Unit
C_w	Study Data	mg/kg
IR_w	2 L/day	L/day
EF	365	days/year
ED	70	years
BW	65	kg
AT	25550	days
RfD	See Section III	mg/kg/day
SF^{o}	See Section III	$(mg/kg/day)^{-1}$

III. Oral Reference Doses (RfD_o) for Metals [21]			
Metal	Symbol	Oral Reference Dose (RfD_o) (mg/kg/day)	Oral Slope Factor (SFo) (mg/kg/day)−1
Arsenic (Inorganic)	As	0.0003	1.5
Cadmium	Cd	0.0005	NA
Chromium (Hexavalent)	Cr(VI)	0.003	0.5
Cobalt	Co	0.0003	NA
Copper	Cu	0.04	NA
Iron	Fe	0.7	NA
Manganese	Mn	0.14	NA
Nickel (Soluble Salts)	Ni	0.02	0.91
Zinc	Zn	0.3	NA

The Table: 2 is structured into three main sections. Section I defines the four key risk parameters used to evaluate the potential health impact: the Estimated Daily Intake (EDI), which is the calculated dose an individual receives; the Hazard Quotient (HQ), which assesses non-carcinogenic risk; the Total Hazard

Quotient (THQ), which aggregates non-carcinogenic risk from multiple contaminants; and the Target Cancer Risk (TCR), which assesses carcinogenic risk. Section II lists the standardized exposure variables and their typical default values for an adult lifetime assessment (e.g., BW = 65 kg, ED = 70 years, AT = 25,550 days, and a water ingestion rate, IRw = 2 L/day), along with the toxicity reference values, RfD and SFo. Section III provides the specific toxicity values for nine common metal contaminants, including the Oral Reference Dose RfDo$) for non-carcinogenic effects (e.g., 0.0003 mg/kg/day for Arsenic) and the Oral Slope Factor (SFo) for carcinogenic effects for relevant metals like Arsenic 1.5 $(mg/kg/day)^{-1}$ and Hexavalent Chromium 0.5 $(mg/kg/day)^{-1}$, making all necessary inputs available for a comprehensive drinking water risk calculation.

Results and Discussion

Physicochemical Parameters: The analysis revealed that samples for pH, Total Hardness (TH), Electrical Conductivity (EC), Ortho-phosphate (o-p-p), Bicarbonate (HCO_3^-), Nitrate-Nitrogen (N-N), and Turbidity (NTU) are all within the WHO guideline ranges. The majority of the water samples (22 out of 25) had alkalinity levels above the recommended WHO guideline of 200 mg/L. High alkalinity can lead to scaling or the formation of mineral deposits in pipes and appliances, though it is generally not a health concern. The WHO guideline for fluoride is a range of 0.5-1.5 mg/L, only a few samples fell within this range. Sample BD-04 exceeded the upper limit with a value of 1.82 mg/L, which could increase the risk of dental fluorosis. On the other hand, 21 out of 25 samples had fluoride levels below the lower limit of 0.5 mg/L, which may indicate a lack of fluoride for dental health benefits. Three samples, BD-11 (1023 mg/L), BD-13 (1078 mg/L), and BD-21 (1033 mg/L), exceeded the WHO's recommended level of 1000 mg/L. High TDS is typically related to the taste of water and is not considered a direct health risk. Three samples—BD-02 (253 mg/L), BD-13 (255 mg/L), and BD-23 (266 mg/L)—had sulfate concentrations that were slightly above the WHO's taste threshold of 250 mg/L. Higher concentrations of sulfate can have a noticeable taste. Only one sample, BD-13, exceeded the WHO's taste threshold of 250 mg/L with a concentration of 281 mg/L. High chloride levels can also contribute to a salty taste and are typically a non-health-related concern(Table: 3, Figure: 2 & 3).

Table: 3 Physicochemical Parameters of drinking water of Taluka Badin

CODE	pH	TH (mg/L)	TDS (mg/L)	EC (µS/cm)	ALK (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	o-p-p (mg/L)	HCO_3^- (mg/L)	N-N (mg/L)	F^- (mg/L)	Turb: (NTU)
BD-01	7.1	135	512	764	270	145	88	0.01	120	3.27	0.13	1.2
BD-02	7.27	139	766	1143	404	253	113	0.005	135	0.6	0.12	2.2
BD-03	7.27	154	899	1342	315	194	189	0.005	129	4.55	0.18	1.8
BD-04	7.07	164	717	1070	337	162	158	0.023	138	0.4	1.82	1.4
BD-05	7.37	166	716	1068	337	109	113	0.098	140	0	1.27	1
BD-06	7.3	175	735	1097	282	126	137	0.017	155	0.98	1.12	1.7
BD-07	7.4	183	811	1210	304	195	182	0.03	165	0.85	0.98	1.9
BD-08	7.2	174	723	1079	348	38	166	0.05	145	1.97	0.56	1.6
BD-09	7.2	164	834	1245	282	107	176	0.011	167	0.34	0.31	1.8
BD-10	7.17	167	808	1206	204	158	200	0.007	140	1.48	0.43	1.1
BD-11	7.2	184	1023	1527	237	125	178	0.063	167	0	0.16	1.9
BD-12	7.27	168	855	1276	259	192	220	0.019	140	3.67	0.25	2.1
BD-13	7.4	188	1078	1609	237	255	281	0.042	140	0	0.17	2.3
BD-14	7.33	205	803	1198	204	180	63	0.024	140	2.83	0.34	1.5
BD-15	7.3	194	808	1206	293	55	115	0.066	130	1.97	0.47	1.3
BD-16	7.23	187	816	1218	182	203	137	0.007	130	1.54	0.36	1.2
BD-17	7.3	178	821	1225	170	158	106	0.019	130	0.27	0.13	2.3
BD-18	7.4	170	824	1230	193	150	68	0.064	130	1.36	0.19	1.4
BD-19	7.4	164	719	1073	226	168	99	0.074	130	0.25	0.33	2.2

BD-20	7.23	167	726	1084	204	158	52	0.007	140	1.2	0.21	2.1
BD-21	7.4	164	1033	1542	237	248	86	0.015	350	0	0.13	1.2
BD-22	7.27	163	696	1039	315	183	61	0.017	120	0.14	0.21	0.9
BD-23	7.37	156	988	1475	293	266	104	0.022	260	0.67	0.16	1.4
BD-24	7.33	106	863	1288	293	224	153	0.014	210	0.73	0.23	2.5
BD-25	7.5	120	610	910	237	156	97	0.017	80	0.73	0.08	1.1

Heavy Metals

Arsenic (As) and Cadmium (Cd) concentrations are of particular concern as they are classified as carcinogens. The WHO and EPA both set the permissible limit for Arsenic at 0.01 mg/L. The results indicate that various samples like BD-11, B D-12, BD-16, BD-17, BD-18, BD-21, and BD-22 show slightly higher values than permissible guideline. Likewise, for Cd, the WHO limit is 0.003 mg/L. Using the WHO's more protective standard, a substantial portion of the samples, including BD-08, BD-09, BD-10, BD-11, BD-12, BD-13, BD-15, BD-16, BD-17, BD-18, BD-21, BD-24, and BD-25, exceed the recommended concentration. This shows an extensive issue with Cd contents all over the sampled locations. The results show that measured levels of Cr and Cu, usually fall within WHO guidelines. All samples showed Cr content below than threshold limit of 0.05 mg/L given by WHO guideline, suggesting that it is not a prevalent contaminant in this environment. Copper having WHO limit of 2.0 mg/L for drinking water also declared safe limit in all samples. On the other hand, the WHO level of Ni in groundwater is suggested as 0.02 mg/L, although sample BD-25 showed content of 0.106 mg/L. the range of Ni in samples of Badin was found as 0.001 – 0.106 mg/L. The level of Mn and Zn are not usually regulated for major health concerns. The Fe and Zn are often considered as secondary contaminants, since they can cause aesthetic problems such as taste, odor or staining. The calculated values of Fe (0.085 – 0.156 mg/L) and Zn (0.06 – 1.0 mg/L) are reliable with what may be observed in natural sources. For Mn the WHO recommendation is 0.05 mg/L; however samples showing higher values included BD-01, BD-03, BD-04, BD-05, BD-07, BD-09, BD-13 and BD-14 with concentrations of 0.15, 0.07,0.14, 0.07, 0.10, 0.12, 0.08, and 0.08 mg/L respectively. Finally, for Cobalt (Co), no specific WHO or EPA guidelines were found in the available public health literature, making a direct comparison impossible, though the measured concentrations are very low (Table: 4, Figure: 4).

Table: 4 Chemical Parameters (Arsenic and Heavy metals) of drinking water of Coastal area of Taluka Badin

CODE	As (mg/L)	**Cd**(mg/L)	**Cr**(mg/L)	**Co**(mg/L)	**Cu**(mg/L)	**Fe**(mg/L)	**Mn** (mg/L)	**Ni**(mg/L)	**Zn**(mg/L)
BD-01	0.0000	0.003	0.019	0.011	0.190	0.148	0.15	0.012	0.23
BD-02	0.0050	0.003	0.016	0.008	0.072	0.102	0.03	0.018	0.06
BD-03	0.0080	0.003	0.025	0.012	0.102	0.143	0.07	0.029	0.13
BD-04	0.0070	0.001	0.018	0.010	0.059	0.111	0.14	0.036	0.63
BD-05	0.0000	0.002	0.030	0.010	0.150	0.093	0.07	0.062	0.10
BD-06	0.0040	0.001	0.030	0.008	0.063	0.124	0.05	0.041	0.14
BD-07	0.0050	0.001	0.029	0.007	0.066	0.106	0.10	0.022	0.23
BD-08	0.0100	0.008	0.025	0.014	0.067	0.140	0.03	0.004	0.37
BD-09	0.0090	0.005	0.033	0.014	0.063	0.096	0.12	0.001	0.34
BD-10	0.0000	0.005	0.032	0.010	0.129	0.100	0.05	0.036	0.15
BD-11	0.0110	0.006	0.019	0.011	0.062	0.099	0.03	0.039	0.16
BD-12	0.0120	0.006	0.018	0.010	0.061	0.095	0.04	0.001	0.64
BD-13	0.0070	0.006	0.021	0.010	0.060	0.085	0.08	0.029	0.21
BD-14	0.0090	0.002	0.020	0.010	0.056	0.087	0.08	0.001	0.14
BD-15	0.0000	0.010	0.023	0.014	0.124	0.109	0.05	0.001	0.10

BD-16	0.0130	0.012	0.037	0.012	0.064	0.106	0.13	0.026	0.25
BD-17	0.0145	0.010	0.040	0.010	0.329	0.116	0.06	0.015	0.10
BD-18	0.0114	0.005	0.021	0.009	0.114	0.156	0.04	0.017	0.10
BD-19	0.0085	0.003	0.028	0.010	0.098	0.110	0.04	0.067	0.21
BD-20	0.0089	0.003	0.036	0.010	0.110	0.111	0.05	0.005	0.12
BD-21	0.0127	0.005	0.040	0.010	0.074	0.094	0.14	0.008	0.12
BD-22	0.011p	0.002	0.024	0.009	0.079	0.121	0.08	0.007	0.06
BD-23	0.004p	0.003	0.031	0.001	0.065	0.138	0.07	0.003	0.06
BD-24	0.0068	0.010	0.013	0.010	0.067	0.102	0.15	0.048	0.13
BD-25	0.0057	0.007	0.030	0.014	0.140	0.098	0.06	0.106	1.00

Non-Carcinogenic Risk Assessment

The Chronic Daily Intake (CDI) is a measure of the average daily exposure to a substance over a person's lifetime, expressed in mg/kg-day. It's used to determine if a long-term exposure poses a health risk by comparing it to a Reference Dose (RfD), a value deemed safe by organizations like the EPA and WHO. This comparison forms a Hazard Quotient (HQ); if the HQ is less than 1, the exposure is considered safe. For non-carcinogenic elements in your dataset—specifically Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), and Zinc (Zn)—all CDI values are far below their respective RfDs. For instance, the highest CDI for Cadmium (1.4×10−4 mg/kg-day in sample BD-16) is only about a quarter of the EPA's RfD (5.0×10^{-4} mg/kg-day). Similarly, the maximum CDI values for Copper and Zinc are a small fraction of their RfDs, confirming that exposure to these elements through the measured pathway does not pose a non-carcinogenic health risk. Even the highest CDI for Nickel (1.2×10^{-3} mg/kg-day in BD-25) is well within the safety margin of its RfD of 0.02 mg/kg-day (Table: 5).

Carcinogenic Risk Assessment

For known carcinogens like Arsenic (As) and Hexavalent Chromium (Cr(VI)), the risk assessment is different. The potential for cancer is measured by the Incremental Lifetime Cancer Risk (ILCR), which is the product of the CDI and a Cancer Slope Factor (CSF). An ILCR of 1×10^{-6} (one in a million) is generally considered an acceptable risk by the EPA. While the provided data only gives CDI values and not the CSF, we can still note the exposure levels. The sample BD-17 showed maximum CDI for As 1.7×10^{-4} mg/kg-day. Though As is carcinogenic, any experience carries a risk that requires to be appropriately assessed against the ILCR recommendation [22]. For Cr, results do not identify if it is carcinogenic hexavalent form, but believing it is for a worst – case situation, the maximum CDI value is 4.7×10^{-4} mg/kg-day in samples BD-17 and BD-21, which is less than its non-carcinogenic RfD. Although, like As, its potential cancer causing effects justify vigilant and permanent screening (Table: 6).

Table: 5 CDI values (mg/kg-day) of HMs in drinking water of Coastal area of Badin

CODE	CDI (As)	CDI (Cd)	CDI (Cr)	CDI (Co)	CDI (Cu)	CDI (Fe)	CDI (Mn)	CDI (Ni)	CDI (Zn)
BD-01	0.0×10^{-0}	3.5×10^{-5}	2.2×10^{-4}	1.3×10^{-4}	2.2×10^{-3}	1.7×10^{-3}	1.8×10^{-3}	1.4×10^{-4}	2.7×10^{-3}
BD-02	5.9×10^{-5}	3.5×10^{-5}	1.9×10^{-4}	9.4×10^{-5}	8.5×10^{-4}	1.2×10^{-3}	3.5×10^{-4}	2.1×10^{-4}	7.0×10^{-4}
BD-03	9.4×10^{-5}	3.5×10^{-5}	2.9×10^{-4}	1.4×10^{-4}	1.2×10^{-3}	1.7×10^{-3}	8.2×10^{-4}	3.4×10^{-4}	1.5×10^{-3}
BD-04	8.2×10^{-5}	1.2×10^{-5}	2.1×10^{-4}	1.2×10^{-4}	6.9×10^{-4}	1.3×10^{-3}	1.6×10^{-3}	4.2×10^{-4}	7.4×10^{-3}
BD-05	0.0×10^{0}	2.3×10^{-5}	3.5×10^{-4}	1.2×10^{-4}	1.8×10^{-3}	1.1×10^{-3}	8.2×10^{-4}	7.3×10^{-4}	1.2×10^{-3}
BD-06	4.7×10^{-5}	1.2×10^{-5}	3.5×10^{-4}	9.4×10^{-5}	7.4×10^{-4}	1.5×10^{-3}	5.9×10^{-4}	4.8×10^{-4}	1.6×10^{-3}
BD-07	5.9×10^{-5}	1.2×10^{-5}	3.4×10^{-4}	8.2×10^{-5}	7.7×10^{-4}	1.2×10^{-3}	1.2×10^{-3}	2.6×10^{-4}	2.7×10^{-3}
BD-08	1.2×10^{-4}	9.4×10^{-5}	2.9×10^{-4}	1.6×10^{-4}	7.9×10^{-4}	1.6×10^{-3}	3.5×10^{-4}	4.7×10^{-5}	4.3×10^{-3}

BD-09	1.1×10^{-4}	5.9×10^{-5}	3.9×10^{-4}	1.6×10^{-4}	7.4×10^{-4}	1.1×10^{-3}	1.4×10^{-3}	1.2×10^{-5}	4.0×10^{-3}
BD-10	0.0×10^{-0}	5.9×10^{-5}	3.8×10^{-4}	1.2×10^{-4}	1.5×10^{-3}	1.2×10^{-3}	5.9×10^{-4}	4.2×10^{-4}	1.8×10^{-3}
BD-11	1.3×10^{-4}	7.1×10^{-5}	2.2×10^{-4}	1.3×10^{-4}	7.3×10^{-4}	1.2×10^{-3}	3.5×10^{-4}	4.6×10^{-4}	1.9×10^{-3}
BD-12	1.4×10^{-4}	7.1×10^{-5}	2.1×10^{-4}	1.2×10^{-4}	7.2×10^{-4}	1.1×10^{-3}	4.7×10^{-4}	1.2×10^{-5}	7.5×10^{-3}
BD-13	8.2×10^{-5}	7.1×10^{-5}	2.5×10^{-4}	1.2×10^{-4}	7.0×10^{-4}	1.0×10^{-3}	9.4×10^{-4}	3.4×10^{-4}	2.5×10^{-3}
BD-14	1.1×10^{-4}	2.3×10^{-5}	2.3×10^{-4}	1.2×10^{-4}	6.6×10^{-4}	1.0×10^{-3}	9.4×10^{-4}	1.2×10^{-5}	1.6×10^{-3}
BD-15	0.0×10^{-0}	1.2×10^{-4}	2.7×10^{-4}	1.6×10^{-4}	1.5×10^{-3}	1.3×10^{-3}	5.9×10^{-4}	1.2×10^{-5}	1.2×10^{-3}
BD-16	1.5×10^{-4}	1.4×10^{-4}	4.3×10^{-4}	1.4×10^{-4}	7.5×10^{-4}	1.2×10^{-3}	1.5×10^{-3}	3.1×10^{-4}	2.9×10^{-3}
BD-17	1.7×10^{-4}	1.2×10^{-4}	4.7×10^{-4}	1.2×10^{-4}	3.9×10^{-3}	1.4×10^{-3}	7.0×10^{-4}	1.8×10^{-4}	1.2×10^{-3}
BD-18	1.3×10^{-4}	5.9×10^{-5}	2.5×10^{-4}	1.1×10^{-4}	1.3×10^{-3}	1.8×10^{-3}	4.7×10^{-4}	2.0×10^{-4}	1.2×10^{-3}
BD-19	1.0×10^{-4}	3.5×10^{-5}	3.3×10^{-4}	1.2×10^{-4}	1.2×10^{-3}	1.3×10^{-3}	4.7×10^{-4}	7.9×10^{-4}	2.5×10^{-3}
BD-20	1.0×10^{-4}	3.5×10^{-5}	4.2×10^{-4}	1.2×10^{-4}	1.3×10^{-3}	1.3×10^{-3}	5.9×10^{-4}	5.9×10^{-5}	1.4×10^{-3}
BD-21	1.5×10^{-4}	5.9×10^{-5}	4.7×10^{-4}	1.2×10^{-4}	8.7×10^{-4}	1.1×10^{-3}	1.6×10^{-3}	9.4×10^{-5}	1.4×10^{-3}
BD-22	1.3×10^{-4}	2.3×10^{-5}	2.8×10^{-4}	1.1×10^{-4}	9.3×10^{-4}	1.4×10^{-3}	9.4×10^{-4}	8.2×10^{-5}	7.0×10^{-4}
BD-23	4.7×10^{-5}	3.5×10^{-5}	3.6×10^{-4}	1.2×10^{-5}	7.6×10^{-4}	1.6×10^{-3}	8.2×10^{-4}	3.5×10^{-5}	7.0×10^{-4}
BD-24	8.0×10^{-5}	1.2×10^{-4}	1.5×10^{-4}	1.2×10^{-4}	7.9×10^{-4}	1.2×10^{-3}	1.8×10^{-3}	5.6×10^{-4}	1.5×10^{-3}
BD-25	6.7×10^{-5}	8.2×10^{-5}	3.5×10^{-4}	1.6×10^{-4}	1.6×10^{-3}	1.2×10^{-3}	7.0×10^{-4}	1.2×10^{-3}	1.2×10^{-2}

Cancer Risk

The results on incremental lifetime cancer risk (ILCR) gives a clear depiction of potential carcinogenic health hazards from As, Cr and Ni. It is usually considered a cancer risk level of 1×10^{-6}(one in a million)by EPA guideline to be minor and tolerable ecological contaminants. The upper limit of acceptability of 1×10^{-4}(one in ten thousand) is a risk level given by EPA guideline (Table: 6).

Individual Cancer Risks

The measured carcinogenic risk values for As, Cr and Ni continuously increase the EPA's target risk of 1×10^{-6}. The range of 0.0×100 to 2.55×10^{-4} for As was observed in water samples of taluka Badin. Actually, various samples such as BD-17 and BD-16 represent a risk level in the range of 10^{-4}, which approaches the upper acceptable limit. The carcinogenic risk from Cr also falls within concerning range having values from 7.63×10^{-5} to 2.35×10^{-4}. Likewise, Ni shows a significant risk ranging from 9.90×10^{-6} to a high of 1.05×10^{-3} in sample BD-25. The carcinogenic risk of Ni was observed in the 10^{-3}range, showing the risk of one in a thousand, exceeding the EPA's tolerable limit (Table: 6).

Total Cancer Risk

Total cancer risk is the sum of individual risks from all the three elements (As, Cr and Ni). The collective risk guideline of the EPA is naturally the same as the individual risk guideline of 1×10^{-6}.The results reveal that total carcinogenic risk in all samples is extremely high, with every single sample surpassing the allowable limit of 1×10^{-6}.The range of risk values was observed as 1.45×10^{-4} to 1.32×10^{-3}, placing all samples in a range that justifies severe health alarm as well as remediation attempts. The maximum total cancer risk of 1.32×10^{-3} due to Ni was found in sample BD-25. However, the sample BD-19 declared cancer risk value of 9.75×10^{-4} which was second highest value due to Ni and Cr. The invasive high risk across all samples, made mostly by Cr and Ni indicates a universal ecological concern compared to an isolated happening (Table: 6).

Table: 6 Cancer Risk of arsenic and heavy metals of drinking water and Total Cancer Risk in Coastal area of Taluka Badin

CODE	Cancer Risk (As)	Cancer Risk (Cr)	Cancer Risk (Ni)	Total Cancer Risk (TCR)
BD-01	0.00×10^{-0}	1.11×10^{-4}	1.18×10^{-4}	2.30×10^{-4}
BD-02	8.81×10^{-5}	9.39×10^{-5}	1.78×10^{-4}	3.60×10^{-4}
BD-03	1.41×10^{-4}	1.47×10^{-4}	2.86×10^{-4}	5.74×10^{-4}
BD-04	1.23×10^{-4}	1.06×10^{-4}	3.55×10^{-4}	5.84×10^{-4}
BD-05	0.00×10^{-0}	1.76×10^{-4}	6.11×10^{-4}	7.88×10^{-4}
BD-06	7.05×10^{-5}	1.76×10^{-4}	4.04×10^{-4}	6.51×10^{-4}
BD-07	8.81×10^{-5}	1.70×10^{-4}	2.17×10^{-4}	4.75×10^{-4}
BD-08	1.76×10^{-4}	1.47×10^{-4}	3.95×10^{-5}	3.62×10^{-4}
BD-09	1.59×10^{-4}	1.94×10^{-4}	9.90×10^{-6}	3.62×10^{-4}
BD-10	0.0×10^{-0}	1.88×10^{-4}	3.55×10^{-4}	5.43×10^{-4}
BD-11	1.94×10^{-4}	1.11×10^{-4}	3.85×10^{-4}	6.90×10^{-4}
BD-12	2.11×10^{-4}	1.06×10^{-4}	9.90×10^{-6}	3.27×10^{-4}
BD-13	1.23×10^{-4}	1.23×10^{-4}	2.86×10^{-4}	5.33×10^{-4}
BD-14	1.59×10^{-4}	1.17×10^{-4}	9.90×10^{-6}	2.86×10^{-4}
BD-15	0.00×10^{-0}	1.35×10^{-4}	9.90×10^{-6}	1.45×10^{-4}
BD-16	2.29×10^{-4}	2.17×10^{-4}	2.56×10^{-4}	7.03×10^{-4}
BD-17	2.55×10^{-4}	2.35×10^{-4}	1.48×10^{-4}	6.38×10^{-4}
BD-18	2.01×10^{-4}	1.23×10^{-4}	1.68×10^{-4}	4.92×10^{-4}
BD-19	1.50×10^{-4}	1.64×10^{-4}	6.61×10^{-4}	9.75×10^{-4}
BD-20	1.57×10^{-4}	2.11×10^{-4}	4.93×10^{-5}	4.18×10^{-4}
BD-21	2.24×10^{-4}	2.35×10^{-4}	7.89×10^{-5}	5.37×10^{-4}
BD-22	1.94×10^{-4}	1.41×10^{-4}	6.90×10^{-5}	4.04×10^{-4}
BD-23	7.05×10^{-5}	1.82×10^{-4}	2.96×10^{-5}	2.82×10^{-4}
BD-24	1.20×10^{-4}	7.63×10^{-5}	4.73×10^{-4}	6.69×10^{-4}
BD-25	1.00×10^{-4}	1.76×10^{-4}	1.05×10^{-3}	1.32×10^{-3}

Hazard Quotient

A comprehensive analysis of the given results on non-cancer health risks, based on the WHO/EPA recommendations reveals that while individual heavy metals may not pose a risk on their own, the collective effect of exposure is significant concern for several sampling locations. The hazard quotient is a systematic metric that compares the daily ingestion of a single substance to a safe reference dosage. An HQ > 1 shows a potential for adverse health effects from that particular contaminant. The HI is the sum of all individual HQs and indicates the total collective risk from exposure to multiple substances. An HI >1 recommends that the cumulative effects may lead to non-cancer health problems. The individual HQ values for all HMs across all samples constantly fall below the threshold value of 1. This shows that separately, exposure to As, Cd, Cr, Co, Cu, Fe, Mn, Ni, or Zn is not liable to cause adverse non-cancer health problems. Particularly, among the individual metals, Co and As constantly indicate the maximum HQ values of 0.548 and 0.568 respectively, whereas these values are still well within the satisfactory range, they are the major sources to the overall risk calculation, emphasizing their relative significance in the samples. On the other hand, total HI reveals a severe and widespread issue. The most of the samples declared HI values >1 which include BD-08, BD-09, BD-11, BD-12, BD-16 BD-17, BD-21 and BD-25. This is risky finding because it suggests a potential for adverse non-cancer health risks because of the cumulative action of multiple heavy metals. The samples BD-17, and BD-16 showed the highest HI values of 1.349 and 1.321 respectively. This cumulative risk, while not stemming from a single element, guarantees critical concern and justifies a more detailed hazard management strategy.

This collective risk is what the EPA and WHO recommendations aim to identify, as it can often be disregarded when evaluating contaminants separately (Table: 7).

Table: 7 Hazard Quotient (HQ) form drinking water of Taluka Babin

CODE	HQ (As)	HQ (Cd)	HQ (Cr)	HQ (Co)	HQ (Cu)	HQ (Fe)	HQ (Mn)	HQ (Ni)	HQ (Zn)	HI
BD-01	0.000	0.035	0.074	0.431	0.056	0.002	0.013	0.007	0.009	0.627
BD-02	0.196	0.035	0.063	0.313	0.021	0.002	0.003	0.011	0.002	0.645
BD-03	0.313	0.035	0.098	0.470	0.030	0.002	0.006	0.017	0.005	0.976
BD-04	0.274	0.012	0.070	0.391	0.017	0.002	0.012	0.021	0.025	0.824
BD-05	0.000	0.023	0.117	0.391	0.044	0.002	0.006	0.036	0.004	0.624
BD-06	0.157	0.012	0.117	0.313	0.018	0.002	0.004	0.024	0.005	0.653
BD-07	0.196	0.012	0.114	0.274	0.019	0.002	0.008	0.013	0.009	0.646
BD-08	0.391	0.094	0.098	0.548	0.020	0.002	0.003	0.002	0.014	1.172
BD-09	0.352	0.059	0.129	0.548	0.018	0.002	0.010	0.001	0.013	1.132
BD-10	0.000	0.059	0.125	0.391	0.038	0.002	0.004	0.021	0.006	0.646
BD-11	0.431	0.070	0.074	0.431	0.018	0.002	0.003	0.023	0.006	1.057
BD-12	0.470	0.070	0.070	0.391	0.018	0.002	0.003	0.001	0.025	1.050
BD-13	0.274	0.070	0.082	0.391	0.018	0.001	0.007	0.017	0.008	0.869
BD-14	0.352	0.023	0.078	0.391	0.016	0.001	0.007	0.001	0.005	0.876
BD-15	0.000	0.117	0.090	0.548	0.036	0.002	0.004	0.001	0.004	0.802
BD-16	0.509	0.141	0.145	0.470	0.019	0.002	0.011	0.015	0.010	1.321
BD-17	0.568	0.117	0.157	0.391	0.097	0.002	0.005	0.009	0.004	1.349
BD-18	0.446	0.059	0.082	0.352	0.033	0.003	0.003	0.010	0.004	0.993
BD-19	0.333	0.035	0.110	0.391	0.029	0.002	0.003	0.039	0.008	0.950
BD-20	0.348	0.035	0.141	0.391	0.032	0.002	0.004	0.003	0.005	0.962
BD-21	0.497	0.059	0.157	0.391	0.022	0.002	0.012	0.005	0.005	1.148
BD-22	0.431	0.023	0.094	0.352	0.023	0.002	0.007	0.004	0.002	0.939
BD-23	0.157	0.035	0.121	0.039	0.019	0.002	0.006	0.002	0.002	0.384
BD-24	0.266	0.117	0.051	0.391	0.020	0.002	0.013	0.028	0.005	0.893
BD-25	0.223	0.082	0.117	0.548	0.041	0.002	0.005	0.062	0.039	1.120

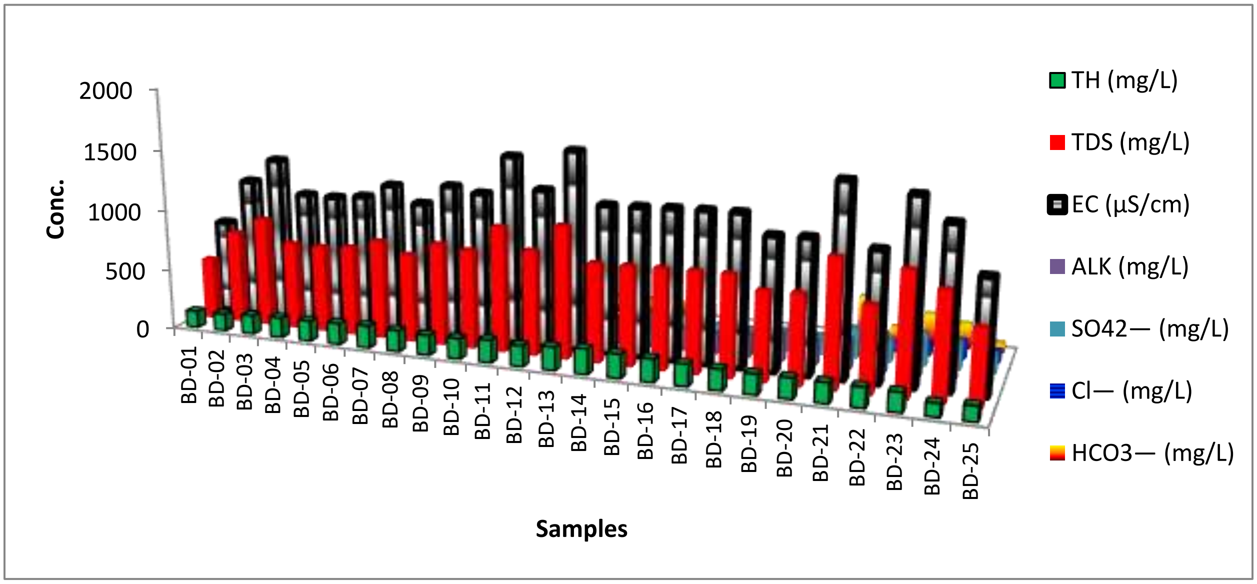

Figure: 2 Concentration of Physicochemical parameters of drinking water of Taluka Badin

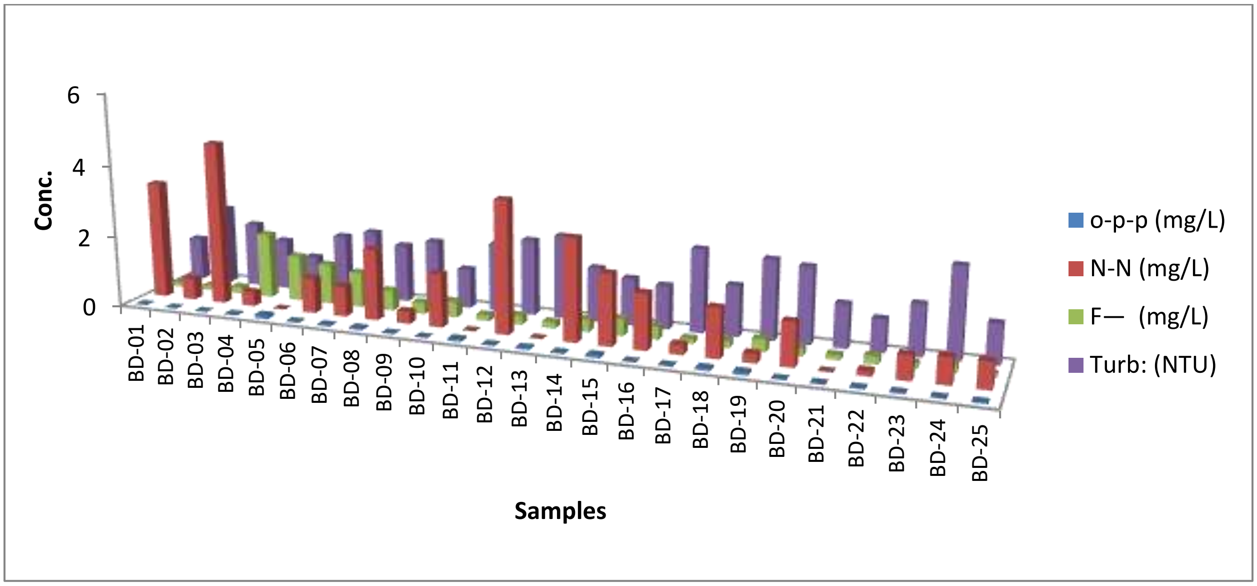

Figure: 3 Concentration of Physicochemical parameters of drinking water of Taluka Badin

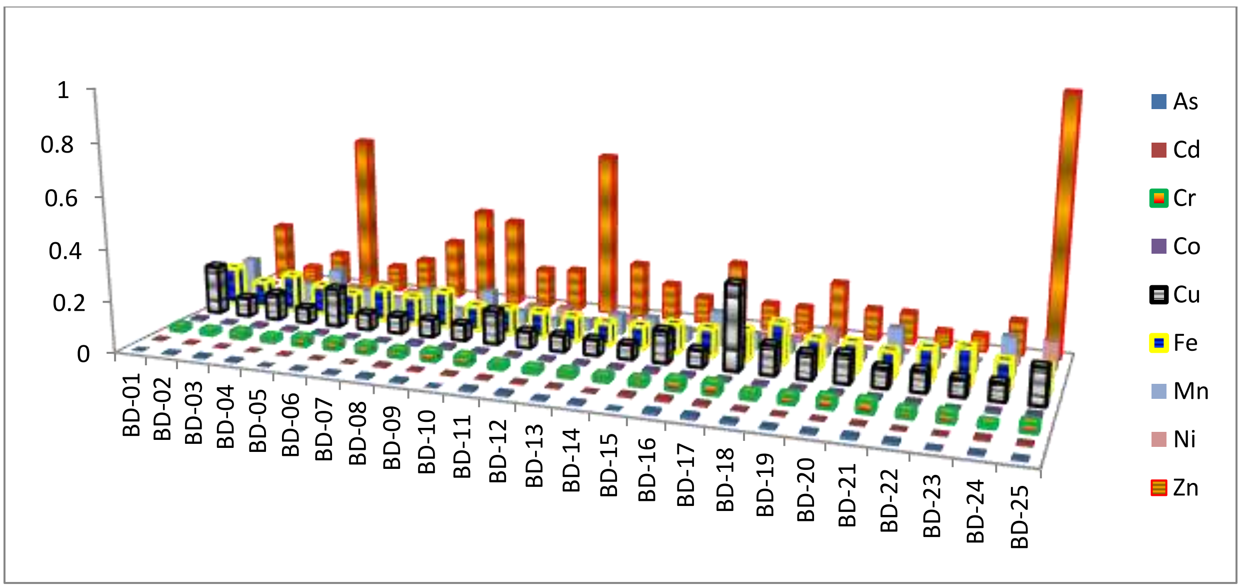

Figure: 4 Concentration of arsenic and heavy metals from drinking water of Taluka Badin

Conclusion

From this study it can be concluded that drinking water of in the coastal area of Taluka Badin is contaminated with heavy metals, posing a potential health hazard to the local people. The pH in all samples was within safe limit of WHO guidelines. Alkalinity was found above the WHO recommendation in most of the samples, whereas a fluoride was above in three samples, increasing the risk of dental fluorosis. TDS also exceeded in three samples than WHO's recommended level of 1000 mg/L. Several heavy metals in water samples exceeded health based suggested limit. Particularly, as concentration in several samples was either met or slightly exceeded the WHO/EPA limit of 0.01 mg/L. Cd, and Ni were also at alarming levels in water samples while other samples like Cr and Cu were usually within safe limits. The risk assessment confirmed that the heavy metal contamination causes a critical health hazard to the population. The calculated cancer risks for arsenic, chromium, and nickel consistently exceeded the acceptable risk level of 1×10^{-6} set by the EPA. The total cancer risk, which is the sum of individual risks from these elements, was alarmingly high in all samples, ranging from 1.45×10^{-4} to 1.32×10^{-3}. While individual heavy metals did not pose a non-carcinogenic health risk in separation, the total Hazard Index (HI) for a majority of the samples was greater than 1. The findings emphasize the need for measures to improve the region's drinking water quality.

Author Contribution

Dr. Abdul Raheem Shar conceptualized, collected samples, designed experiments, Rubina Naz Mirani and Sahib Ghanghro collected data and prepared the draft of the article Tahmina Fakhr-u-Nisa Abbasi and Rabia Parveen Memon interpreted the data Dr. Noorul Hassan Shar and Farzana Mangrio, performed water analysis, All authors read, revised, and approved the final version of the manuscript. Prof. Dr. Ghulam Qadir Shar Supervised the whole work.

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Conflict of Interest

The authors declare no conflict of interest

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