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Assessing Public Health Risks by the Use of Deterministic Method for Multivariate Interpolation of Physicochemical Characteristics for Assessing Ground Water Quality Index Using Geo-Spatial-Based AHP Technique and Calculating Saturation Index of Alluvial Aquifer of Bahawalpur City, Pakistan

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Abstract

Bahawalpur is the twelfth biggest metropolitan of Pakistan situated in South Punjab near to the bank of River Sutluj, Pakistan. This study focuses at the physico-chemical properties of drinking water of Bahawalpur which were assessed experimentally. 13 parameters were tested for 40 ground water samples. These parameters incorporate pH, EC, Total Hardness, TDS, Calcium, Magnesium, Carbonates, Bicarbonates, Chloride, Lead, Chromium, Copper and Arsenic. Testing was done for indiscriminate premises. A GPS device (GARMIN GPS) was utilized to gather samples' geospatial data. The physio-chemical results were compared with the standard values as suggested by the World Health Organization (WHO) and Pakistan Standards and Quality Control Authority (PSQCA) for drinking. Geographic Information System (GIS) was utilized to speak to the spatial conveyance of the parameters and raster maps were made using Inverse Distance Weighted (IDW) Interpolation to classify water quality in different zones. Water Quality Index (WQI) was ascertained using Analytical Hierarchy Process. The results showed that most of the inspected areas were found unsuitable for the drinking purpose. Maximum value for TDS rose to 1904 which represented elevated amount of EC and pH also. Total hardness reached to a maximum of 602.4 mg/L which is the potential indicator of high carbonate and bicarbonate content which in turn represents high positive metallic content i.e., calcium and magnesium. Arsenic was found out to be more than permissible limits in most of the samples which is associated with many diseases such as tooth decay, Knee joint pain, kidney problems, skin pigmentation, stomach ulcer and even different types of cancer etc. among the residents of that area. The data for the diseases associated was collected from Bahawal Victoria Hospital and questionnaires being filled by natives Langelier Saturation Index was calculated to observe the corrosivity and scale forming properties of water. Results showed deterioration of piping system of water supply system from commercial to domestic level. These characteristics have direct effect on the architectural structures and also are esthetically unacceptable. Prior to the initiation of the SCARP project in Pakistan before 1990's, that area was water logged and saline. Due to this potential reason the ground water quality of that area is highly deteriorated. Hence, the water was found out to be unfit for human consumption.

Keywords: IDW interpolation; Analytical hierarchy process; Geographic information system; Water quality index; Langelier saturation index; Pakistan standards and quality control authority

Introduction

In view of extending people improvement, human water enthusiasm for private, mechanical and rustic purposes to supply adequate food for the nation is growing and water transforming into an uncommon item in most bit of the world. Populace concentrations have made a gradually expanding contamination of the soil and ground water underneath the urban areas. By and by, it has been estimated that 20,000-60,000 km^2 of the region of the ground-water system in the European Communities, which adds up to 2-4 percent of the soil surface, might be contaminated inside a time of 50 years, if no move is made [1]. What's more, present day farming has transformed into a noteworthy wellspring of ground-water contamination. The Asian range continues going up against authentic water quality issues that add to freshwater lack, wiped out prosperity, and even passing [2]. In many spots quality is continuing to diminish and lacking attempts are being made to screen and cure the condition amidst institutional and social troubles [3]. In Pakistan access to safe drinking water falls underneath pleasing levels with only 25% of the people has sensible access to quality drinking water. In an indistinguishable path from other diverse countries on the planet, Pakistan is also under amazing danger as for openness of secured and clean drinking water. Citing a review, Arrangement of Safe Drinking Water, led by the Pakistan Council of Research in Water Resources (PCRWR), Serving for Science and Innovation Rana Tanvir Hussain said just 72% of water supply plans were observed to be utilitarian, and 84% of those had provided water that was not fit for utilization [4]. The water from 14% of water supply sources in Sindh and Punjab were observed to be intensely tainted with arsenic, well over the admissible furthest reaches of 50 sections for each billion.

Study Area

Bahawalpur is found at south of the Sutlej Waterway and lies in the Cholistan area close to the Thar Abandon. It is situated 420 km from Lahore, and 270 km from Faisalabad, 90 km south of Multan, one of the Modern urban groups of Pakistan and on the southern bank of river Sutlej. Bahawalpur city lies at 29°59′55″ N Latitude and 73°15′12″ E Longitude at an elevation of 521 ft above mean sea level (Figure 1).

Previous studies indicate that Groundwater quality in Bahawalpur is deteriorating like in other main cities of Pakistan. The situation is much aggravated in Islamic colony where 55% of residents have brackish water. In Satellite town, 70% of the residents have access to water without any smell [5].

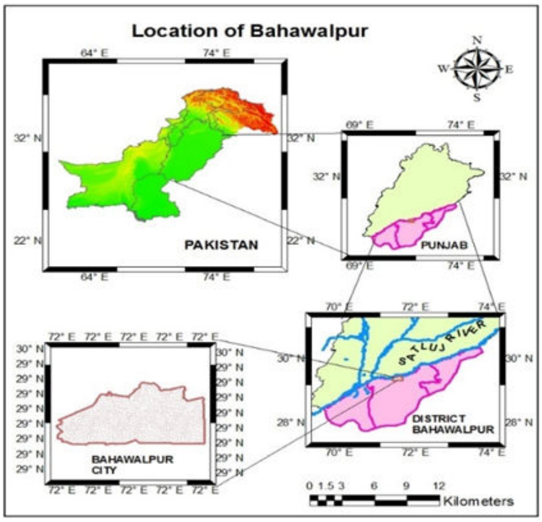

Figure 1: Location of the Study Area.

Climate and Hydrology

The most blazing months are May, June and July. The mean most extreme and least temperatures amid this period are 42 and 29 degrees centigrade separately. The winter is lovely. The coldest months are December, January and February. Amid this period the mean most extreme and mean least temperatures are 21 and 5 degrees centigrade individually. The majority of the rain falls amid rainstorm season from July to September. Winter rain is rare. Yearly precipitation is around 16 centimeters as of late, quickly expanding populace and monetary and instructive advancements of the city brought an enormous weight on normal assets including ground water, arrive utilize, farmland and so on [6].

Because of low precipitation, generally between 5 and 10 inches, the chief source of fresh-water recharge in the Bahawalpur area is the Sutlej River. Ground water moves generally southward from the river toward the desert area of Cholistan and is commonly highly mineralized; maximum concentrations of 20,000 to 25,000 ppm have been measured in test holes at or near the southern boundary of the canal irrigated area, at a distance of 25 to 35 miles from the Sutlej River [7].

Methods and Materials

Provision of safe and clean drinking water to the masses should be the foremost priority of every government as it is the basic human right. In order to identify the potential areas for future environmental health problems, regular mapping of groundwater quality is a pre-requisite for every city [8]. In a demand to study the ground water quality, forty samples of tap water were picked (Figure 2). They got admitted in Hydrology lab of College of Earth and Environmental Sciences , University of the Punjab and were treated in accordance with the instructions provided by PCRWR regional lab to find the quality status of physical and chemical parameters of the water. duly rinsed with distilled water after washing with acid water were used [9]. Latitude and Longitude of sampling site were allocated using GPS by Garmin at the spot (Table 1).

Serial No	Sample Locations	Latitude (dd)	Longitude (dd)	Elevation (ft)
1	BAKRI Haji Aslam P/S, 9 BC Hsp Road, Bahawalpur	29.37936	71.72883	261
2	Rohi Model School Musa Colony NaseerAbad	29.39161	71.74739	381
3	Water Supply System Shahrah e Quaid e Azam Govt Employees Cooperative Housing Society Bwp	29.39628	71.75894	376
4	Rehman Auto Industry, 8 KM, Hasilpur Road, BWP	29.39072	71.76972	373
5	Arabian Petrol Pump, 5 BC, HSP	29.40178	71.80961	383
6	Quaid e Azam Hotel and Restaurant Solar Park By Pass (8 KM)	29.39456	71.79931	367
7	Quaid E Azam Solar Park, BWP	29.33503	71.82064	372
8	IUB, Farm Gate	29.36894	71.76267	384
9	Sheikh Rashid Airport	29.35203	71.71083	395
10	Dar E Arqam 13 Soling Campus	29.31844	71.70858	356
11	Model Avenue Housing Scheme	29.33489	71.60828	345
12	New Vegetable Market, Ahmad Pur road	29.37153	71.64028	337

13	Bahawal Victoria Hospital	29.39119	71.68289	370
14	General Bus Stand, Bahawalpur	29.40625	71.67853	355
15	One Unit Chowk	29.38881	71.70222	358
16	Hussaini Chowk	29.38178	71.71739	350
17	Forest Colony	29.38417	71.70983	358
18	Residential Colony Department of Canals	29.38789	71.69325	360
19	Islami Colony, Airport Main Road, BWP	29.37158	71.69425	363
20	Cantt. Area	29.36383	71.69264	347
21	Sadar Pulli	29.39225	71.69292	354
22	GOVT Filter Plant, Sajid Awan colony	29.39283	71.70811	348
23	32 A- Al Majeed Paradise Qamar road	29.39906	71.71356	
24	SAMLA Basti, Rafi Qamar Road	29.38523	71.72036	
25	Govt Filter Plant, One Unit Colony	29.38689	71.70147	343
26	37 Cheema House Block 3 K Satellite Town	29.38808	71.70392	351
27	Civil Hospital Jhanghi Wala Road, Bwp	29.41261	71.72017	350
28	Jhangi Wala, Main Boulevard, BWp	29.42583	71.76392	377
29	New Model Central Jail, BWP	29.40639	71.69006	354
30	Bahawalpur, Zoo	29.40217	71.68139	357
31	Filter Plant, Model Bazar oppo Police Line Market	29.39953	71.68436	345
32	Abbasia Campus, IUB	29.39822	71.69231	357
33	Johar Town, Lane 4, Bwp	29.39336	71.72017	350
34	Akbar Colony, Street No.1, House 2, Satellite Town, BWP	29.39133	71.71694	383
35	Filter Plant, Model Town A	29.39336	71.66197	356
36	Filter Plant, Model Town C	29.40503	71.66778	349
37	Shahadra main Market Chowk, BWP	29.40639	71.66217	343
38	76 A, Hashmi Garden, BWP	29.37544	71.66886	359
39	Agriculture and Research Institute, Bwp	29.38578	71.65442	405
40	Railway Station	29.40275	71.65264	460

Table 1: location of sampling sites.

Total Dissolved Solids, Electrical Conductivity and pH were measured using TDS meter (model HI8314), Electrical conductivity meter (model HI98304) and pH meter (model HI8314) by Hanna [10]. Total Hardness, calcium and magnesium were determined titrimetrically using EDTA [11]. Chloride was estimated by performing argentometric titration [12]. Concentrations of carbonates and bicarbonates were calculated using titration method using methyl orange and phenolphthalein as an [13]. Lead, Copper, Chromium and Arsenic were measured using Atomic Absorption Spectrometer [14].

Database creation and GIS analysis

MS Excel program was used to enter and arrange data obtained from experimental analysis. Data was stored in xlxs format. Calculations were performed on the same sheet using basic formulas of mathematics. Excel data was easily transported to GIS in csv (coma delimited) format to create a shapefile. Another excel sheet was used to calculate the water quality index using Analytical Hierarchal Technique. Langelier Saturation Index was also calculated to some extent using MS Excel.

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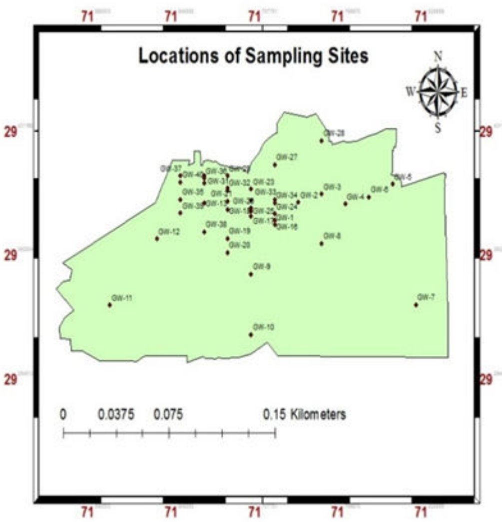

Figure 2: Sampling Locations.

IDW interpolation technique

Arc GIS 10.3 was used to create thematic maps of the original data by applying IDW interpolation technique. A point shapefile was created using excel data. Shapefile for the boundary of the targeted area was extracted from Google earth. Its spatial refences were adjusted accordingly when imported from Google earth to ArcMap. All the layers in GIS were assigned UTM coordinates. From interpolation methods, IDW was selected. This technique assigns values to the valueless points by considering neighboring values. Thematic maps were produced using this technique. These thematic maps create zonation of the whole area according to the assigned values.

Water quality index

Studies suggests WQI and GIS based overlay mapping techniques can be used to integrate multiple parameter values to a single index value and multiple layers into a single map respectively [15]. Water Quality Index shows a single value, obtained from many different parameters' values, representing the overall quality of water at a place. For calculating water quality index, AHP technique was used. Analytical Hierarchy Process is a technique based on assumptions. through reviewing and comparing with other weighting methods. The Analytic Hierarchy Process (AHP) was identified to be a suitable tool to establish the weights of water quality parameters [16]. It requires assigning values to different parameters between 1 and 9. On the basis of number of parameters, nth value for each parameter is calculated. Relative weight (Wi) is calculated from these nth values. A sensitivity analysis was performed to cross check the above process. A total of 10 parameters were used to assess the water quality of the area. When relative weights are calculated, their weightage is calculated out of 100 by multiplying each Wi with 100 (Table 2). WQI is a useful tool for providing a summary of the entire water environment system by integrating the information of various indicators [17].

	TDS	Chloride	Calcium	Magnesium	Electrical conductivity	Ph	Lead	Copper	Chromium	Arsenic	Cadmium	Bicarbonates	Total Alkalinity	Iron	Carbonate	Total Hardness	Product	nth value	weight (Wi)
TDS	1	2	3	3	3	4	2	2	2	5	3	2	3	1	1	4	622080	3.796511	0.19157479
Chloride	0.5	1	2	4	4	3	2	2	1	3	2	3	1	4	2	2	55296	2.980364	0.15039143
Calcium	0.333333	0.5	1	3	3	4	3		2	4	2	1	3	2	1	3	5184	2.352158	0.11869167
Magnesium	0.333333	0.25	0.333333	1	4	1	2	3	4	2	1	1	2	3	1	2	64	1.515717	0.0764842
Electrical conductivity	0.25	0.25	0.2	0.25	1	4	1	1	2	3	3	2	3	2	3	1	8.1	1.232675	0.0622017
Ph	0.166667	0.333333	0.2	1	0.25	1	3	2	1	4	1	4	2	1	1	1	0.533333	0.939074	0.04738639
Lead	0.5	0.5	0.25	0.5	1	0.333333	1	3	2	3	1	3	1	3	2	1	3.375	1.129347	0.0569877
Copper	0.5	0.5	0.333333	0.333333	1	0.5	0.333333	1	2	1	2	2	2	2	3	3	1.333333	1.029186	0.0519335
Chromium	0.5	1	0.5	0.25	0.5	1	0.5	0.5	1	2	4	1	3	1	2	2	0.75	0.971642	0.04902977
Arsenic	0.2	0.333333	0.25	0.2	0.333333	0.25	1	1	0.5	1	3	2	3	2	2	1	0.01	0.630957	0.03183858
Cadmium	0.333333	0.5	0.5	1	0.333333	1	1	0.5	0.25	0.333333	1	2	2	2	1	1	0.009259	0.62612	0.03159449

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Bicarbonates	0.5	0.333333	1	1	0.5	0.25	0.333333	0.5	1	0.5	0.5	1	2	1	3	3	0.015625	0.659754	0.03329168
Total Alkalinity	0.333333	1	0.333333	0.5	0.333333	0.5	1	0.5	0.3333333	0.333333	0.5	0.5	1	2	2	2	0.001029	0.502613	0.02536221
Iron	1	0.25	0.5	0.333333	0.5	1	0.333333	0.5	1	0.5	0.5	1	0.5	1	2	2	0.001736	0.529612	0.02672462
Carbonate	1	0.5	1	1	0.333333	1	0.5	0.333333	0.5	0.5	1	0.333333	0.5	0.5	1	2	0.001157	0.508568	0.0256627
Total Hardness	0.25	0.5	0.333333	0.5	1	1	1	0.333333	0.5	1	1	0.333333	0.5	0.5	0.5	1	0.000145	0.413085	0.02084459
										sum							682638.1	19.81738	1

Table 2: AHP Technique to calculate water Quality Index.

These relative weights are then used to create a water quality index map by classifying each IDW map into 5 classes and assigning their respective Wi (out of 100) in front of each reclassified map in Weighted Sum Tool of GIS. Proposed ranking of Water Quality Index is shown below (Table 3).

Excellent	WQI (95-100)
Very Good	WQI (89-94)
Good	WQI (80-88)
Fair	WQI (65-79)
Marginal	WQI (45-64)
Poor	WQI (0-44)

Table 3: Ranking of Water Quality Index.

Saturation index

Langelier Saturation Index is the measure of saturation of water with respect to concentration of calcium carbonate. It is the measure of corrosiveness and scale forming property of water. Usually this property is considered for brackish waters. Saturation index is based on approximation of the base 10 algorithm. It is calculated using concentrations of six parameters viz; pH, temperature, calcium, bicarbonate and TDS. It was calculated from the below given formulas for each sample, using MS Excel. Results include three types of saturation values which are:

- Negative, indicating that water is under saturated and of corrosive nature.
- Positive, showing that water is over saturated and scale forming by nature.
- Zero, indicating the neutral nature of water. It will neither be corrosive nor scale forming.
- LSI is given by the formula:

LSI=pH-pHs

Where:

- pH is the measured water pH.
- pHs is the pH at saturation in calcite or calcium carbonate and is defined as: pHs=(9.3+A+B) - (C+D).
- A=(Log_{10} [TDS]-1) / 10.
- B=-13.12 x Log_{10} (ToC+273)+34.55.
- C=Log_{10} [Ca_2+ as $CaCO_3$]-0.4.
- D=Log_{10} [alkalinity as $CaCO_3$].

Results and Discussion

Results of forty ground water samples from the study area for physical and chemical analyses demonstrate that concentrations of majority of parameters of the samples are high. The hardness of water is indicated by drinking and washing properties of water. This indicates high amounts of carbonates and bicarbonates in it. If so, associated cations normally calcium and magnesium should also be present which are confirmed by further experimentation.

Spatial distribution map of total hardness

Hard water is depicted with high mineral substance that are by and large not damaging for individuals.

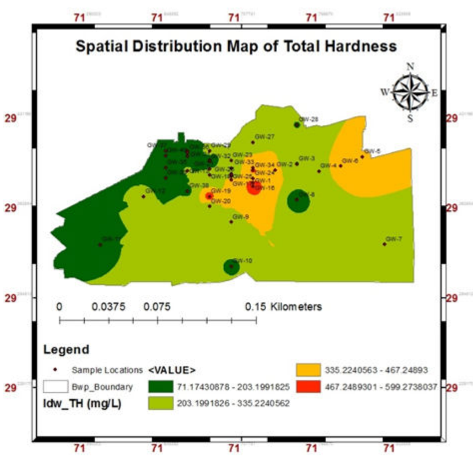

Figure 3: Spatial Distribution of TH.

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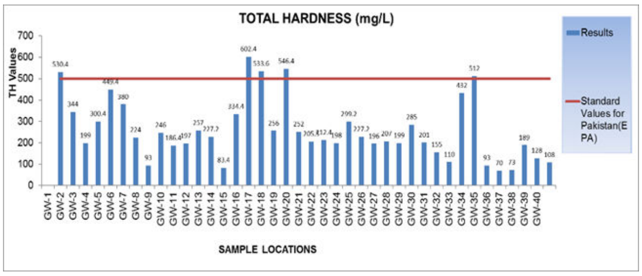
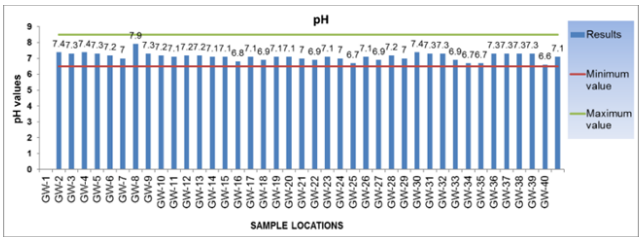
It interferes with for all intents and purposes each cleaning task from washing and dishwashing to showering and individual preparing. As demonstrated by World Health Organization (WHO) hardness of water should be 500 mg/L (Graph A). In study areas, hardness ranges from 93 mg/L of IUB, Homestead Door to 530 mg/L in Bakri oil station (Figure 3).



Graph A: Concentration comparison of TH.

Spatial distribution map of pH

As indicated by the University of Rhode Island, pH is "a standout amongst the most well-known examinations in water testing and is the standard measure of how acidic or soluble an answer is."



Graph B: Concentration comparison of pH.

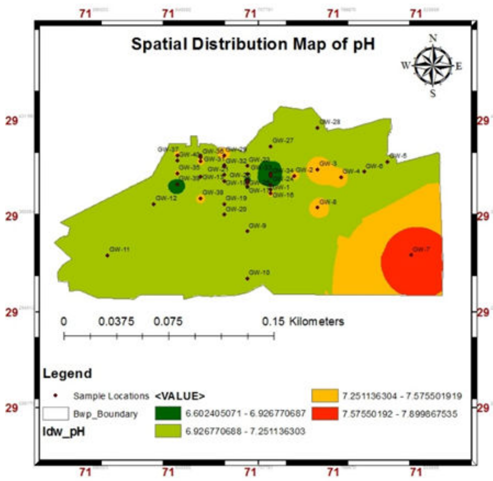
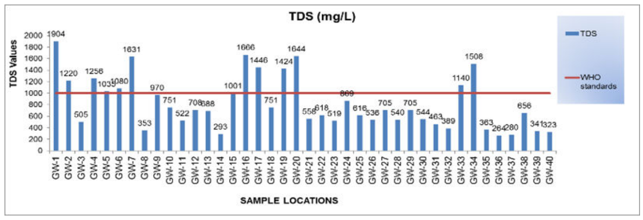


Figure 4: Spatial Distribution of pH.

The normal range given by WHO for pH of drinking water is 6.5 to 8.5, and water with a pH<6.5 is acidic while pH>8.5 is basic. It reaches from 6.6 to 7.4 in different territories of study area (Graph B). Subsequently, in study regions the pH qualities were not surpassed as far as possible however these were falling in fundamental or soluble range (Figure 4).

Spatial distribution map of TDS

TDS stands for Total Dissolved Solids. It effects the Electrical properties of water. It depicts amount of impurity present in water. The EPA and WHO sets a limit of 500 mg/liter for TDS. Right when TDS levels beat 1000 mg/L it is by and large observed as unfit for human utilize. TDS is extents from 264 mg/L to 1904 mg/L in different regions of the city (Graph C). Thus, it was observed to be unfit for drinking in many regions (Figure 5).



Graph C: Concentration comparison of TDS.

Spatial distribution map of EC

Electrical Conductivity is the ability of the water to conduct electricity. Pure water has an electrical conductivity in a much less decimal value. As shown by WHO measures EC regard should not outperformed 400 µS/cm (Graph D).

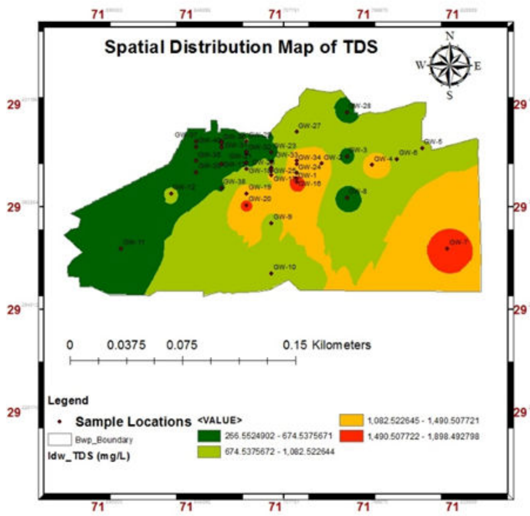


Figure 5: Spatial Distribution of TDS.

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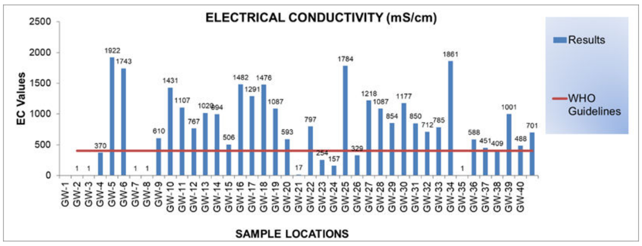


Graph D: Concentration comparison of EC.

Polished issues of water with an EC as high as 150 µS/cm, are that it tastes salty and water with an EC higher than 300 µS/cm, disregard to smother the thirst. The EC was found out to be in between 1 µS/cm and 1922 µS/cm (Figure 6).

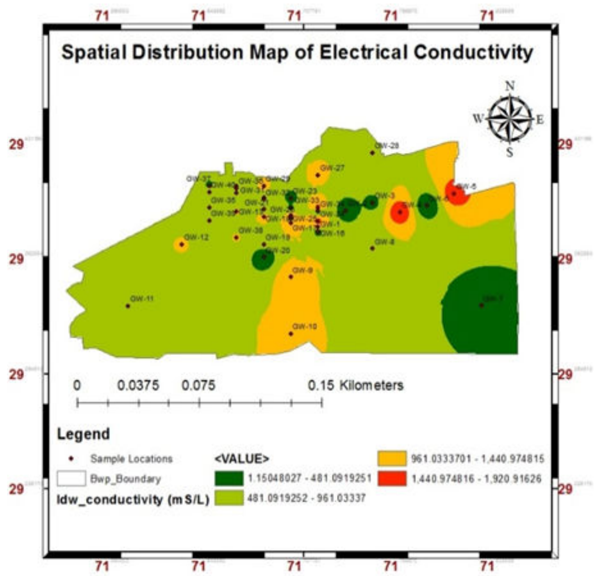
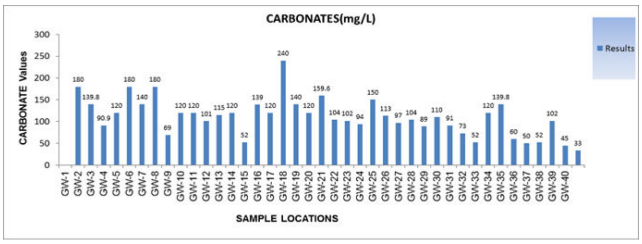


Figure 6: Spatial Distribution of EC.

Spatial distribution map of carbonates

The carbon dioxide that is broken down by normally circling waters shows up in concoction examination basically as bicarbonate and carbonate particles.



Graph E: Concentration of Carbonates.

Carbonate that takes after this way speaks to a linkage between the carbon cycle and the hydrologic cycle. The grouping of carbonates in characteristic waters is an element of broke up carbon dioxide, temperature, pH, cations and other disintegrated salts concentration levels are shown in Graph E. Carbonate concentration ranges from 33 to 180 in various areas of the city (Figure 7).

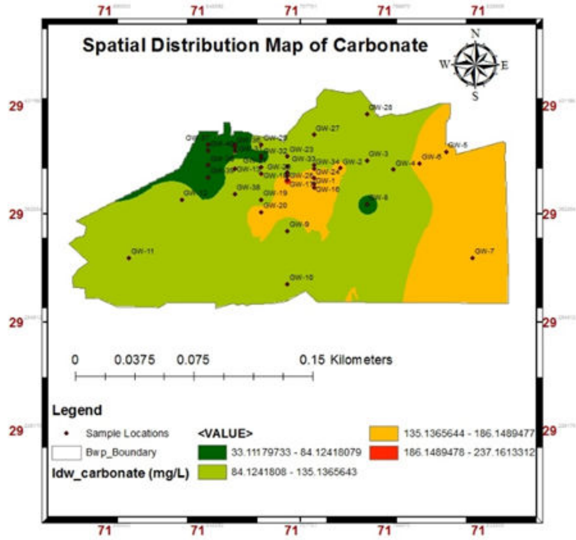


Figure 7: Spatial Distribution of Carbonate.

Spatial distribution map of bicarbonates

The Bicarbonate (HCO_3) particle is the central antacid constituent in all water supplies. Bicarbonate alkalinity is brought into the water by CO_2 dissolving carbonate-containing minerals. Bicarbonate is a characteristic part of every mineral water.

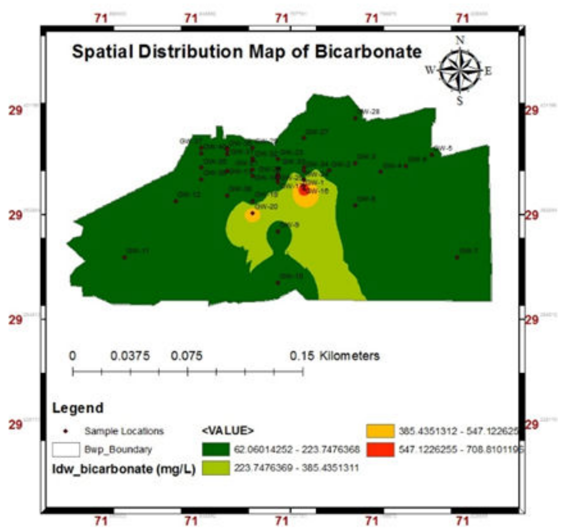


Figure 8: Spatial Distribution of Bicarbonates.

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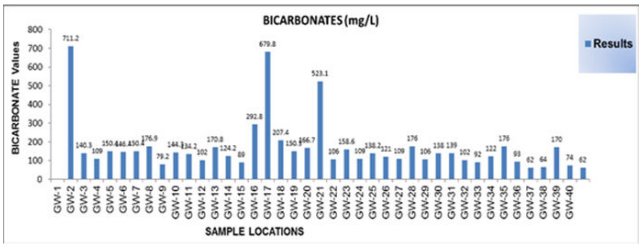
Mineral waters that are sourced from limestone-rich regions commonly have a high bicarbonate content. WHO and EPA has not set ideal breaking points for bicarbonates independently. However, carbonates and bicarbonates adds to relative alkalinity of water. The limit for bicarbonates in water ranges from 62 mg/L to 711 mg/L in different zones of the city (Graph F). Bicarbonates concentration in water relies on upon pH and is for the most part under 500 mg/l in groundwater (Figure 8).



Graph F: Concentration of Bicarbonates.

Spatial distribution map of calcium

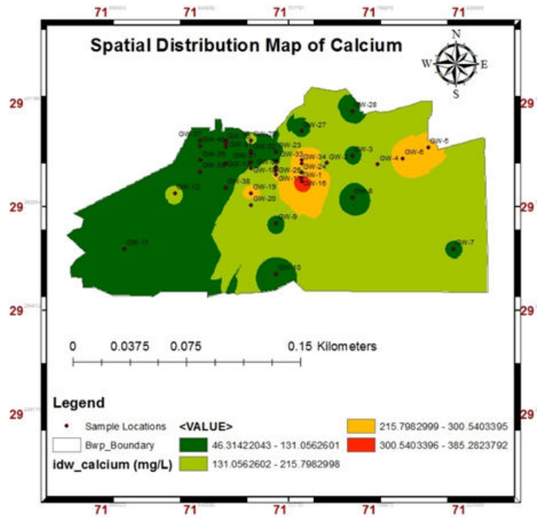
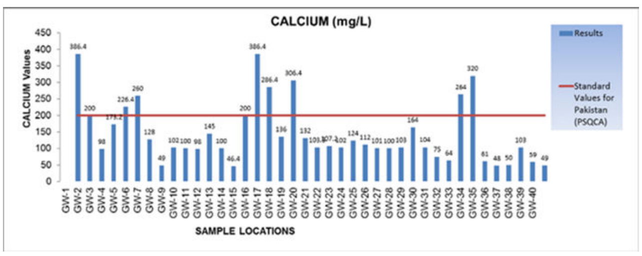


Figure 9: Spatial Distribution of Calcium.

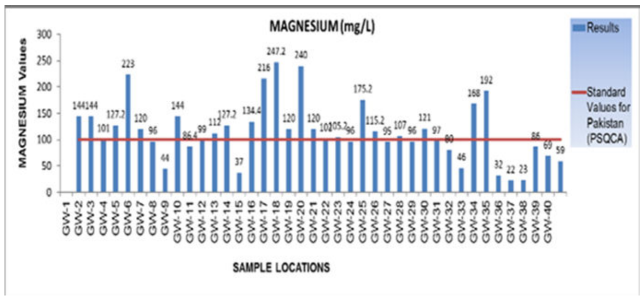


Graph G: Concentration of Calcium.

Both calcium and magnesium are fundamental minerals and gainful to human wellbeing in a few regards [18]. Lacking admission of either supplement can bring about unfavorable wellbeing results. Permissible limits given by PSQCA for calcium are 200 mg/L (Graph G). WHO and EPA have not any advisable limits for it. Calcium ranges from 46 mg/L to 386.3 mg/L in the targeted areas (Figure 9).

Spatial distribution map of magnesium

Appreciating water in which magnesium is accessible at high obsessions (above around 250 mg/l each) can have a diuretic affect, notwithstanding the way that data prescribe that purchasers acclimate to these levels as exposures continue. Permissible limits given by PSQCA for magnesium are 100 mg/L (Graph H). WHO and EPA have not any advisable limits for it. Magnesium ranges from 22 mg/L to 247.2 mg/L in the targeted areas (Figure 10).



Graph H: Concentration of Magnesium.

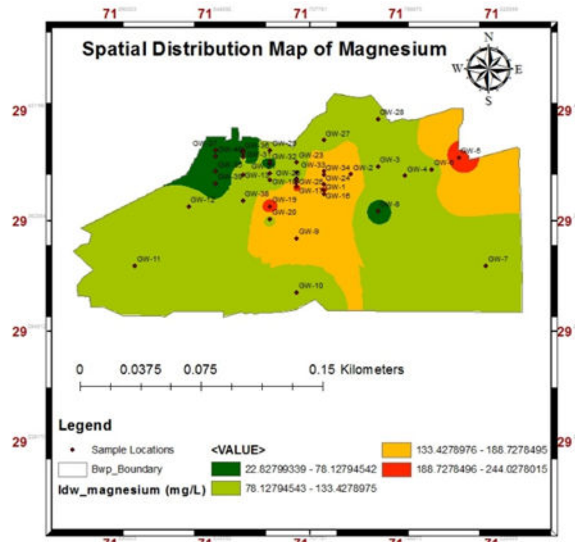


Figure 10: Spatial Distribution of Magnesium.

Spatial distribution map of chloride

With atomic number 17 on the periodic table, Chlorine is rich in nature in its chloride molecule shape found in countless salts that are in the earth. Chloride in surface and groundwater from both typical and anthropogenic sources, for example, keep running off containing street de-icing salts, the utilization of inorganic excrements, landfill leachates, septic tank effluents, creature encourages, mechanical

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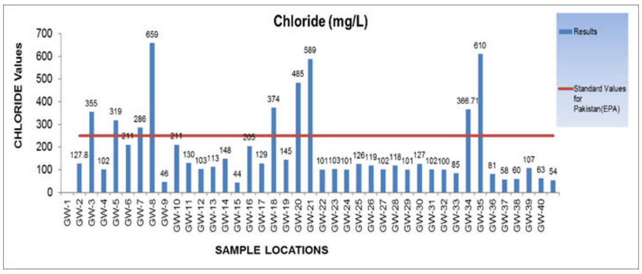
effluents, water structure spillage, and seawater impedance in shoreline front degrees [19]. Chloride develops the electrical conductivity of water and along these lines fabricates its harming inclination. WHO has set its permissible limits for chloride as 250 mg/L (Graph I). Chloride ranges from 54 mg/L to 659 mg/L (Figure 11).



Graph I: Concentration of Chloride.

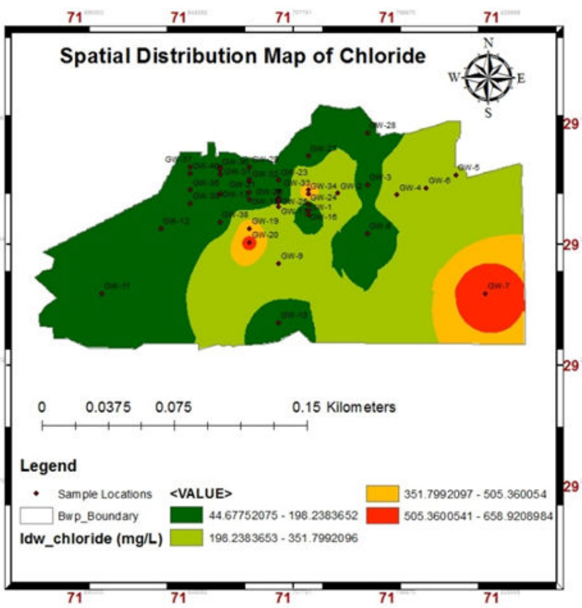
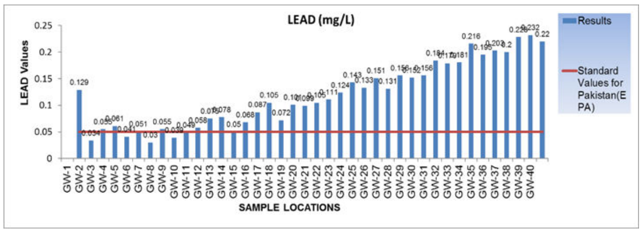


Figure 11: Spatial Distribution of Chloride.

Spatial distribution map of lead

Lead is the commonest of the brain boggling portions, addressing 13 mg/kg of Earth's covering. Inorganic lead is not used as a piece of the body. Unabsorbed dietary lead is disposed of in the waste, and lead that is used however not held is discharged unaltered by techniques for the kidneys or through the biliary tract. WHO has set its permissible limits for lead as 0.01 mg/L while EPA, Pakistan has set its limits up to 0.05 mg/L (Graph J). Lead ranges from 0.03 mg/L to 0.21 mg/L in sampling zones (Figure 12).



Graph J: Concentration of Lead.

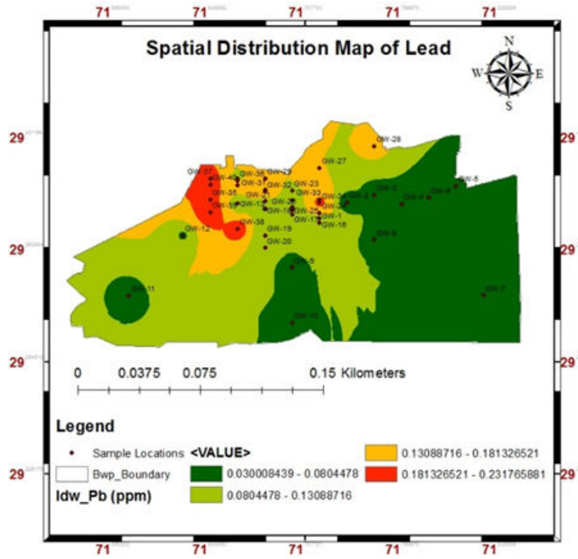
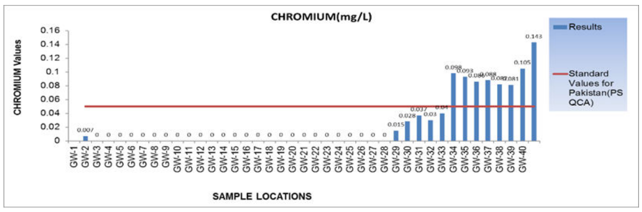


Figure 12: Spatial Distribution of Lead.

Spatial distribution map of chromium

Chromium is generally scattered on the planet's covering. It can exist in oxidation conditions of +2 to +6. The reliably chromium requirement for grown-ups is evaluated to be 0.5–2 μg of absorbable chromium (III).

WHO has set its permissible limits for Chromium as 0.05 mg/L (Graph K). Chromium ranges from 0.01 mg/L to 0.1 mg/L in some areas of city while some areas contain chromium at Below Detection Level (Figure 13).



Graph K: Concentration of Chromium.

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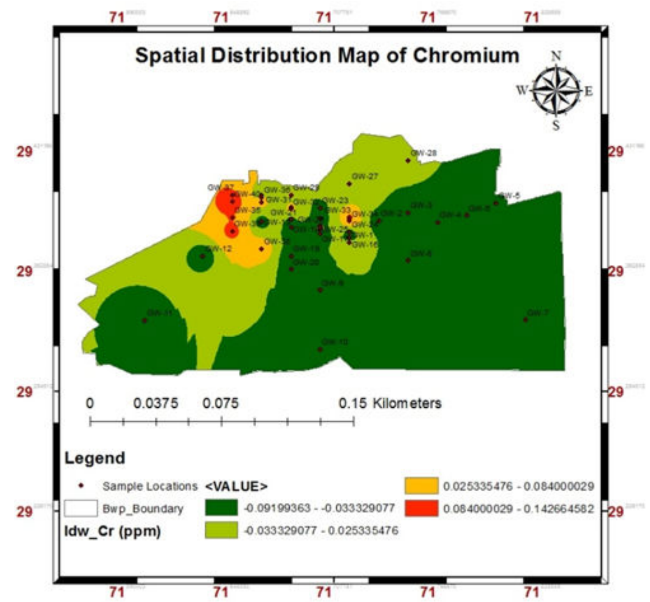


Figure 13: Spatial Distribution of Chromium.

Spatial distribution map of copper

In immaculate water, the copper (II) atom is the more common oxidation state. At lower estimations, copper particles can accomplish signs essential of nourishment harming (headache, nausea, regurgitating, the runs).

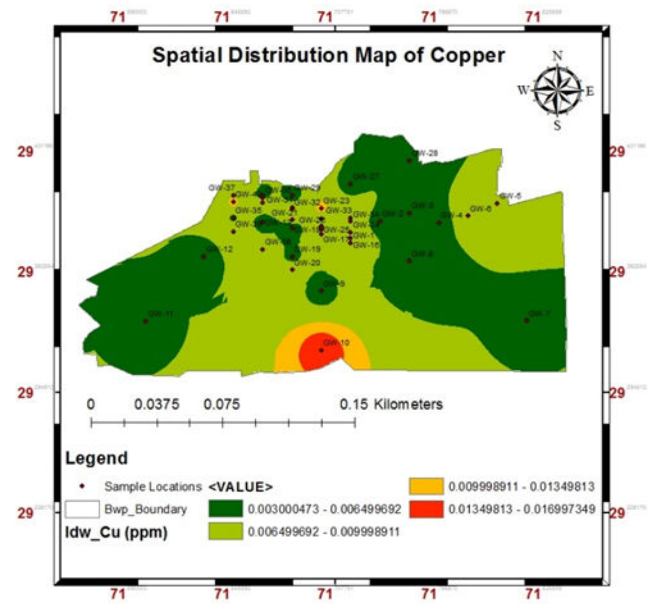
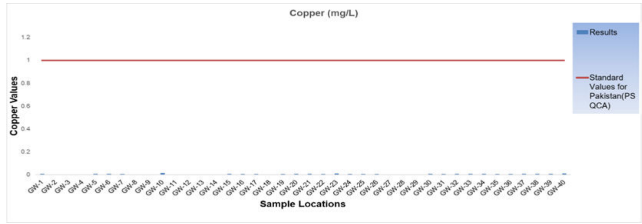


Figure 14: Spatial Distribution of Copper.



Graph L: Concentration of Copper.

According to WHO, optimum value for copper in drinking water is 2 mg/L while this value is 1 mg/L according to EPA and PSQCA (Graph: L). Copper ranges from 0.003 mg/L to 0.01 mg/L in study area (Figure 14).

Spatial distribution map of arsenic

Arsenic is brought into water through the breaking of rocks, minerals and ores [20], from mechanical effluents, including mining squanders, and by strategies for climatic declaration [21]. WHO advised arsenic to be permissible at 0.01 mg/L (Graph M).

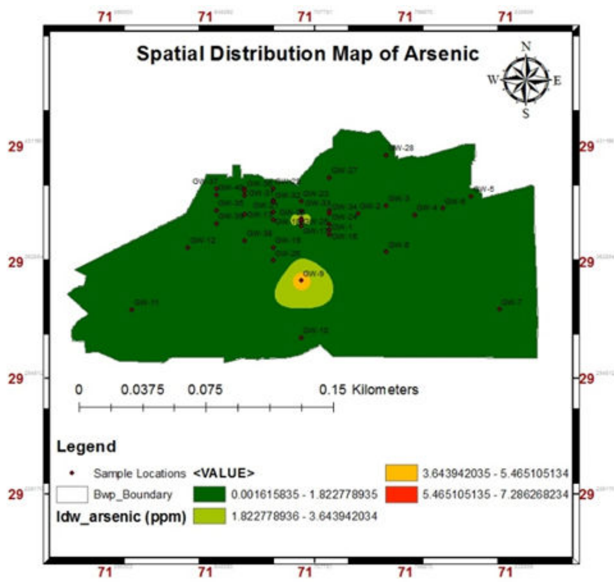


Figure 15: Spatial Distribution of Arsenic.

Not only in Southern Punjab, Arsenic contamination and its increasing contents in ground water are found throughout the Indus aquifer system starting from Punjab in Kashmir, extending to the remote areas of Asian plate. This situation needs a serious attention. Arsenic, which is the most important content to be highlighted among all the metallic and nonmetallic content of water samples, was found out to be in between 0.0003 mg/L to mg/L in observed areas (Figure15).

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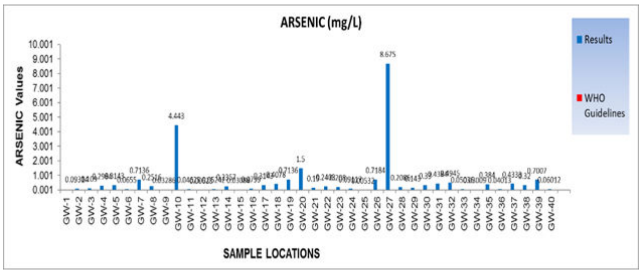

Graph M: Concentration of Arsenic.

Water quality index map

The WQI is a unit less number running from 1 to 100; a higher number is characteristic of better water quality. It includes the combined effects of many parameters. Thematic map of water quality index was developed using AHP. Thematic map shows poor water quality areas towards South East of the city while the Northern areas shows good water quality. Hence, to a general trend, it can be assumed that water quality is getting bad as we move from west to east of the city. Similarly, going from North to South a deteriorating trend in water quality is observed. North Western areas show good quality of water (Figure 16).

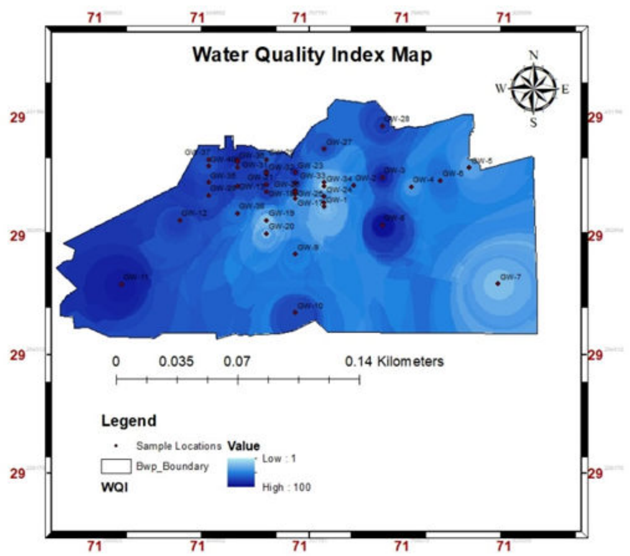

Figure 16: Water Quality Index Map.

Corrosion and scale formation

Corrosive and scale forming nature of many samples has been identified using Langelier saturation index. According to the results, architectural structures in some of the sampling sites are subjected to serious threat of corrosion due to water possessing negative saturation index. The Other areas are in a slight threat of corrosion in which some samples are scale forming while others are not. In such areas, hard water is responsible for damaging water supply structures from commercial level to domestic one. It is found to be corrosive in at some areas and causes deterioration of internal structures of pipes. A perfect sample with zero saturation index was not found anywhere (Table 4).

Serial No	GW	Langelier Saturation Index (LSI)	Indication based on Langelier (1936)
1	GW-1	1	Scale forming but non corrosive.
2	GW-2	-0.017	Slightly corrosive but non-scale forming.
3	GW-3	-0.22	Slightly corrosive but non-scale forming.
4	GW-4	-0.053	Slightly corrosive but non-scale forming.
5	GW-5	-0.019	Slightly corrosive but non-scale forming.
6	GW-6	-0.15	Slightly corrosive but non-scale forming.
7	GW-7	0.44	Slightly scale forming and corrosive.
8	GW-8	-0.72	Serious corrosion.
9	GW-9	-0.36	Slightly corrosive but non-scale forming.
10	GW-10	-0.47	Slightly corrosive but non-scale forming.
11	GW-11	-0.45	Slightly corrosive but non-scale forming.
12	GW-12	-0.092	Slightly corrosive but non-scale forming.
13	GW-13	-0.49	Slightly corrosive but non-scale forming.
14	GW-14	-0.87	Serious corrosion.
15	GW-15	-0.17	Slightly corrosive but non-scale forming.
16	GW-16	0.7	Scale forming but non corrosive.
17	GW-17	-1.1	Serious corrosion.
18	GW-18	-0.28	Slightly corrosive but non-scale forming.
19	GW-19	0.019	Slightly scale forming and corrosive.
20	GW-20	0.025	Slightly scale forming and corrosive.
21	GW-21	-0.72	Serious corrosion.
22	GW-22	-0.34	Slightly corrosive but non-scale forming.
23	GW-23	-0.6	Serious corrosion.
24	GW-24	-0.78	Serious corrosion.
25	GW-25	-0.44	Slightly corrosive but non-scale forming.
26	GW-26	-0.71	Serious corrosion.
27	GW-27	-0.24	Slightly corrosive but non-scale forming.
28	GW-28	-0.61	Serious corrosion.
29	GW-29	0.069	Slightly scale forming and corrosive.
30	GW-30	-0.19	Slightly corrosive but non-scale forming.
31	GW-31	-0.45	Slightly corrosive but non-scale forming.
32	GW-32	-0.95	Serious corrosion.
33	GW-33	-0.55	Serious corrosion.
34	GW-34	-0.35	Slightly corrosive but non-scale forming.

35	GW-35	-0.56	Serious corrosion
36	GW-36	-0.81	Serious corrosion.
37	GW-37	-0.78	Serious corrosion.
38	GW-38	-0.13	Slightly corrosive but non-scale forming.
39	GW-39	-1.4	Serious corrosion.
40	GW-40	-1	Serious corrosion.

Table 4: Calculation of Langelier Saturation Index.

Conclusion and Recommendations

Hardness of drinking water is significant for both aesthetic acceptability and operational considerations. Water for majority areas is found unfit for drinking purposes. Hardness in water prevails throughout. Water is found out to be brackish and unacceptable for drinking. High arsenic content is also found out to be dominating in the region which is the cause of stomach ulcer and even different types of cancer etc among the residents of that area who consume this brackish water. Further, the high hardness of water is the reason behind curd forming properties of soaps and detergents in that area. This causes dryness to skin. Skin pigmentation is prevailing. Skin cancer risk is enhanced. Nails become dry and hard. Hair problems are common due to washing with hard water which include split ends, dryness and loss of hair. Hair color is changed and it usually fades from the original one. Hair growth is retarded. As this hard water is affecting people externally, likewise, it causes severe ill effects internally. It is the cause of major chronicle diseases like cancer and bone deformation.

All such conditions lead to many basic problems from dish washing to dryness of skin and is also responsible for causing many diseases associated with high metallic content in water such as stomach problems, dermatological issues, cardiovascular diseases, growth retardation and reproductive failure. Water softener series can be incorporated at both commercial and domestic level. Iron curtain Filter System can be installed at a commercial level. Reverse osmosis system can be used to remove hardness of water commercially.

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