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Water Quality Index (WQI) for Assessment of Groundwater Quality Around Gevra Coalfields Area, Chhattisgarh

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ABSTRACT

Since the 1960s, the use of water quality index (WQI) as a method has been implemented to determine the status of water quality in rivers. The current study's aim is to use the weighted arithmetic water quality index method to estimate the Water Quality Index (WQI) of groundwater in the area of the Gevra coalfields project. In the months of October to December of 2020, Water samples were taken from eight stations, and sixteen water quality parameters were examined: pH, electrical conductivity, turbidity, total dissolved solids, total hardness, total alkalinity, chloride, fluoride, chemical oxygen demand, dissolved oxygen, biological oxygen demand, sulphate, iron, arsenic, lead and zinc. Public health is at risk due to environmental contamination in drinking water that could have immediate health implications. Based on geological conditions and farming, mining, and other man-made operations, groundwater supplies are vulnerable to pollution. Therefore, maintaining the quality of drinking water is a rising concern.

Graphical Abstract

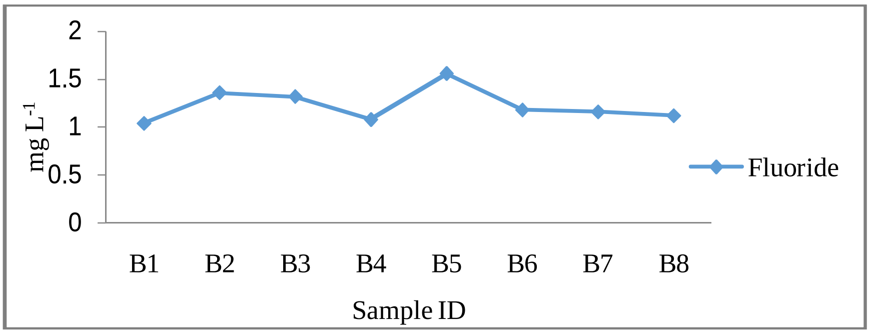

Figure 13. Comparative analysis of the fluoride content of 8 groundwater samples

Keywords: Groundwater, Parameters, Water Quality Index, Gevra coalfields project.

INTRODUCTION

Groundwater is used domestic and industrial water production and drainage all over the world [1]. Owing to rapid population growth and the accelerated pace of industrialization, the need for fresh water has grown significantly over the past few decades. Human health is at risk for most agricultural growth practices, especially in relation to the improper use of fertilizers and unsanitary conditions. Groundwater supply and quality have been impacted by rapid urbanization, especially in developed countries like India, because of its overexploitation and lack of waste disposal, particularly in urban areas. According to the World Health Organization, water is responsible for about 80% of all human diseases. Once the groundwater has been polluted, stopping the source of the contaminants would not recover the groundwater's consistency. As a result, it is critical to regularly track groundwater quality and provide safeguards to protect it. The Water Quality Index (WQI) is a useful and exclusive ranking that helps select the best treatment approach to address the problems at site [2]. WQI, however, portrays the cumulative effect of various metrics of water quality and communicates information on water quality to the public and statutory decision-makers. Despite the lack of a globally agreed-upon composite water quality index, several countries have used and continue to use aggregate data on water quality in the production of water quality index. The WQI standards for the suitability of groundwater supplies have been attempted to be established. Furthermore, this article highlights and draws attention to the growth, in a simplified format, of a recent and internationally adopted 'Water Quality Index' that can be commonly used and will accurately represent water quality.

Study Area: Korba coalfields, one of the largest clusters of coal mines in the country. South Eastern Coalfields Limited runs the three mines that form the cluster: Gevra, Kusmunda and Dipka coalmines. The study was carried out in and around areas water sample in Gevra coalfields project. The open cast coal mining project of Gevra operated by South Eastern Coalfields Ltd., located in Chhattisgarh's Korba district. The Gevra opencast project, which was opened in 1981, covers the area of the 19.03^2 Km and has been described as Asia's largest open cast mine and is the world's second largest. On average, the project generated an overburden of 0.66 million cubic meters per 1 million tons of coal per year. The Gevra opencast project is located between latitude 22° 18'00" N and longitude 82° 39'30" E at an altitude ranging from 288 m to 328 m above sea level. The climate of the area is tropical, dry to wet. In May, the temperature rises to 48°C and in December it drops to 7°C. The average rainfall is 1265 mm. For overburden dumping, large areas of the mining project were used. The soils under the forest used as reference were acidic in reaction, bright yellow in hue, and textured with a sandy clay loam. The bulk density was limited and the capacity for holding water was moderate. Soils were reported to be mainly acidic in reaction in the area under review and formed on acidic parent material due to the presence of iron and humus, Because of its deposition from erupted lava, this soil is composed of several minerals and is rich in copper, magnesia, lime and alumina. In reaction, fresh overburden dumps became acidic, but the pH increased with growing years of regeneration under tree plantation and reached a neutral value after 25 years under tree plantation.

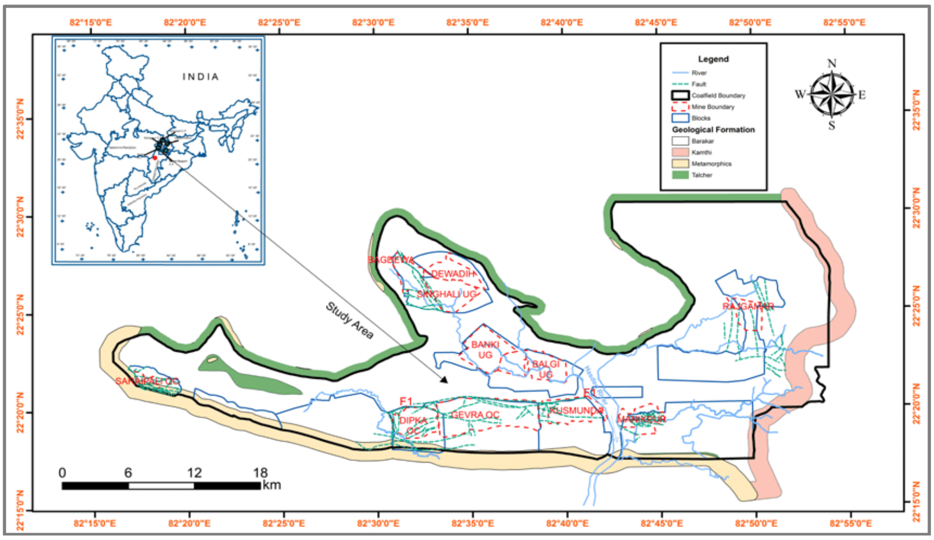

Figure 1. Location map of study area.

MATERIALS AND METHODS

During October to December, 2020, eight bore wells were used to collect groundwater samples. Each sample was collected in a 1000 mL acid-washed polyethylene container. The container was thoroughly rinsed with the respective groundwater samples prior to the collection of water in a specific container [3]. The samples of ground water were taken in sterilized containers [4]. Until performing quantitative chemical analysis, the sample position was written on the bottle and appropriate preservatives were added for preservation. The bottle was fully filled with water, meaning that no air bubbles remained in the water sample. The container was capped with double seals in order to avoid evaporation, and steps were in addition to save the sample from being irritated during transport to the lab. Samples were moved into the lab directly after selection. Using portable instruments, pH, turbidity and EC were measured in situ. Water research was carried out according to standard procedures (APHA 2005) [5]. The titration method was used to determine total alkalinity, total hardness, and chloride (Cl^-). Total dissolved solids are calculated by gravimetrical method, Fluoride can be measured using a spectrophotometer. Chemical oxygen demand, dissolved oxygen, and biological oxygen demand were analyzed by COD meter, DO meter and BOD meter respectively. Suphate were analyzed by Turbidimetric Method and heavy metals were analyzed by ICP-AES.

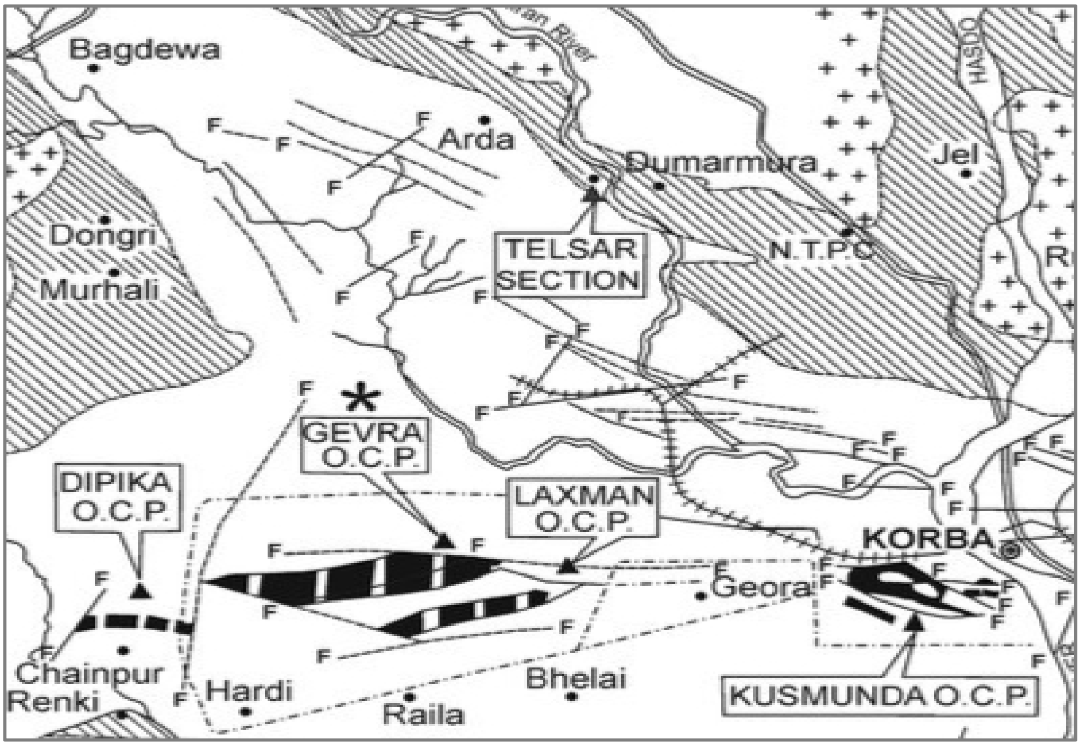

Figure 2. Sampling sites in study area.

RESULTS AND DISCUSSION

The research proposed an empirical approach to the physicochemical analysis of groundwater and measured the possible quality of groundwater supplies in Gevra coal field's area of the Korba District. To be able to identify the appropriateness of groundwater for various purposes, the data on water quality were validated using current patterns and analyzed using the best-fitting models. The inference of the chemical constituents of groundwater samples are furnished in table 1.

pH: Water samples had pH values ranging from 7.0 to 8.1 and were calculated within the limits defined by BSI.pH stands for "potential hydrogen ion concentration" which is a measurement of how acidic or alkaline a solution is. The remaining seas are a little more primitive.

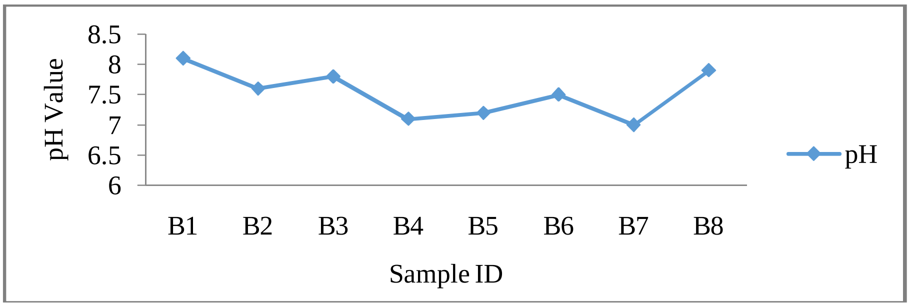

Figure 3. Comparative analysis of the pH content of 8 groundwater samples.

EC: Ion stability in solution can be shown to be closely related to overall alkalinity. This is not unexpected, as the velocity of water will be equal to the hydroxide ion (alkaline) concentration in the water The water samples had EC values ranging from 392 to 616 S cm^{-1}.

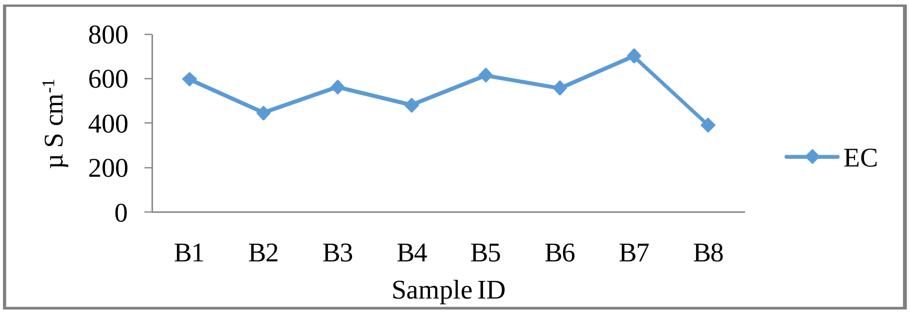

Figure 4. Comparative analysis of the EC content of 8 groundwater samples.

Turbidity: It has been inferred that over acceptable limit it plays several effect on cardiovascular disease [6]. Turbidity of water is caused by the presence of very finely separated solids that cannot be purified using conventional methods. The presence of turbidity in water would have an effect on the consumer's acceptability. Turbidity-forming particles can also interact with water treatment procedures and the effects might be severe in the case of the disinfection process. Turbidity in groundwater samples range from 3.2 to 8.5 NTU.

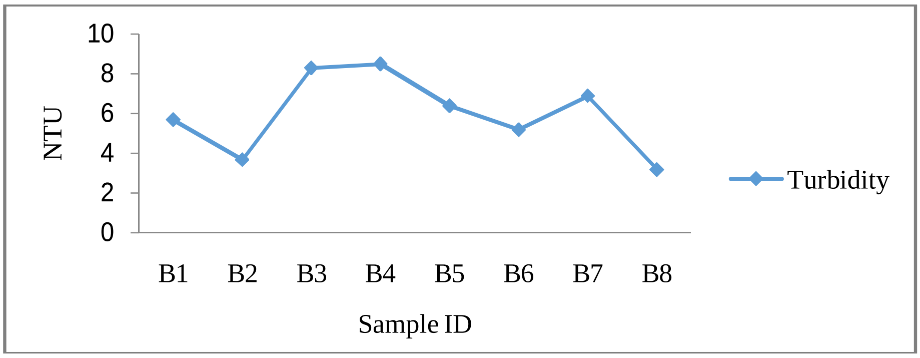

Figure 5. Comparative analysis of the turbidity content of 8 groundwater samples.

TDS: Total dissolved solid (TDS) calculation is useful for water suitability for drinking, agricultural and industrial uses. The number of potassium, calcium, sodium, magnesium, carbonates, bicarbonates, chlorides, phosphates, organic matter and other particles is TDS. Gastro-intestinal inflammation in the human body stems from elevated amounts of TDS. TDS in groundwater samples range from 698 to 958 mg L^{-1}.

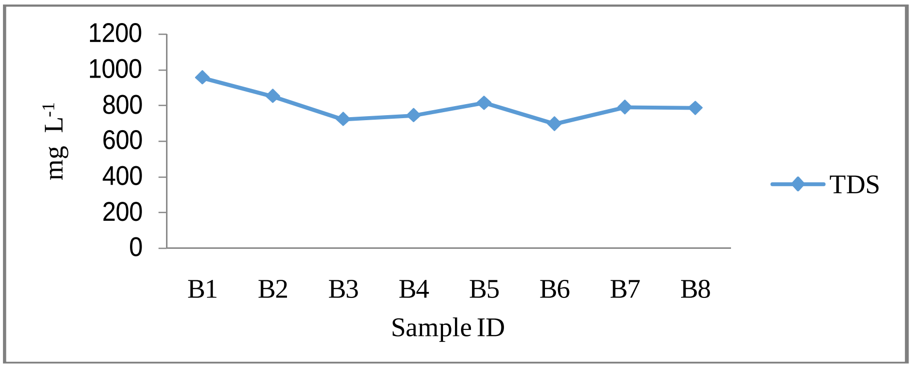

Figure 6. Comparative analysis of the TDS content of 8 groundwater samples.

Table 1. Average Variations of the Physico-chemical Parameters of Groundwater Samples during the study period

Parameters	B1	B2	B3	B4	B5	B6	B7	B8
pH	8.1	7.6	7.8	7.1	7.2	7.5	7.0	7.9
EC	598	446	562	481	616	558	702	392
Turbidity	5.7	3.7	8.3	8.5	6.4	5.2	6.9	3.2
TDS	958	854	724	746	816	698	792	788
Total Alkalinity	250	205	235	205	220	215	205	235
Total Hardness	506	428	480	394	456	482	446	490
COD	16	20	16	12	18	21	15	16
BOD	5.20	5.62	5.24	4.97	5.28	6.48	5.16	5.22
DO	7.56	5.12	7.68	8.61	7.23	4.08	7.72	7.09
Chloride	209	194	175	183	195	187	193	184
Fluoride	1.04	1.36	1.32	1.08	1.56	1.18	1.16	1.12
Sulphate	72.6	78.7	82.4	55.1	74.2	34.3	53.8	48.2
Iron	0.31	0.32	0.30	0.24	0.26	0.28	0.34	0.31
Arsenic	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.03
Lead	0.04	0.03	0.05	0.02	0.06	0.05	0.02	0.06
Zinc	2.35	3.52	3.12	4.56	5.01	5.0	4.32	4.21

Total Alkalinity: Alkalinity is an index of the buffering ability of weak acid anions, such as hydroxides, bicarbonates and carbonates, formed by water. Increased alkalinity results in a color loss that is directly proportional to the alkalinity of the water sample and is normally similar to its hardness value. Groundwater samples have total alkalinity ranging from 205 to 250 mg L^{-1}.

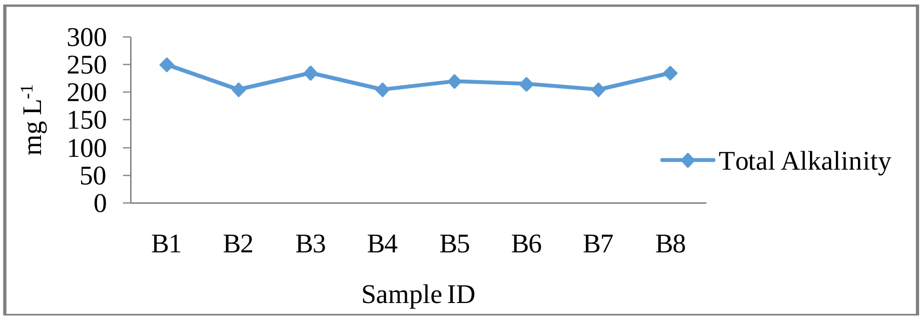

Figure 7. Comparative analysis of the total alkalinity content of 8 groundwater samples.

Total Hardness: The hardness due to calcium or magnesium bicarbonate is transient hardness, and the hardness due to calcium and magnesium chlorides, sulphates and nitrates is permanent hardness. There would be more soap use due to persistent hardness. It also causes artery calcification. It also impacts the structure of water resources through the creation of scale. Urinary concretions, stomach disorders, and kidney or bladder diseases are produced without definitive evidence by hardness. Total hardness of groundwater samples varies between 394 and 506 mg L^{-1}.

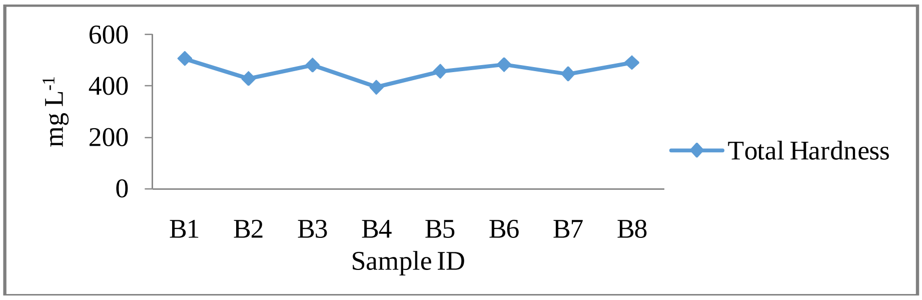

Figure 8. Comparative analysis of the total hardness content of 8 groundwater samples.

COD: COD in groundwater samples vary from 12 to 21 mg L^{-1}.COD is an indirect technique for calculating the volume of organic material present. The COD test is based on the fact that almost all organic compounds can be totally oxidized into carbon dioxide under acidic conditions using a strong oxidizing agent.

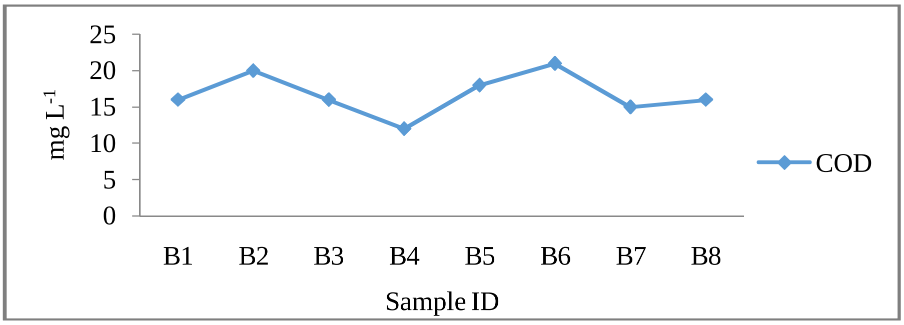

Figure 9. Comparative analysis of the COD content of 8 groundwater samples.

BOD: Aerobic bacteria use the organic matter present in waste water as "food" in the presence of free oxygen. The BOD measure is an approximation of the available "food" in the study. The more "food" in the waste, the more Dissolved Oxygen it would need. The BOD test determines the intensity of waste water by measuring the amount of oxygen absorbed by bacteria as they retain organic matter in controlled time and temperature conditions. BOD in groundwater samples range from 4.97 to 6.48 mg L^{-1}.

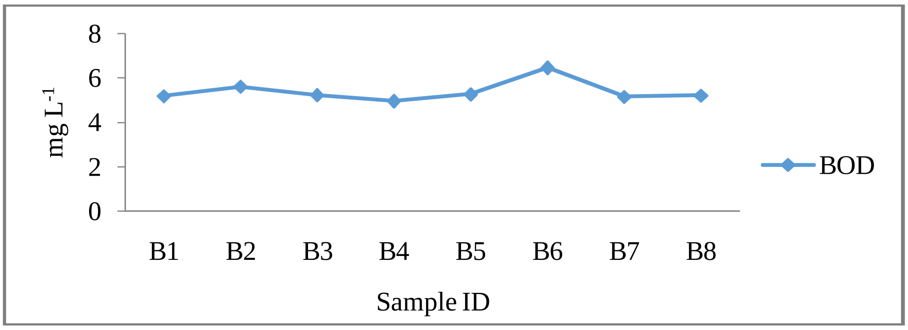

Figure 10. Comparative analysis of the BOD content of 8 groundwater samples.

DO: Dissolved oxygen (DO) the amount of oxygen available to live marine species-is an indicator of how much oxygen is dissolved in the water. In a stream or lake, the volume of dissolved oxygen will tell us a lot about the water content. TDS in groundwater samples range from 694 to 958 mg L^{-1}. DO in groundwater samples range from 4.08 to 8.61 mg L^{-1}.

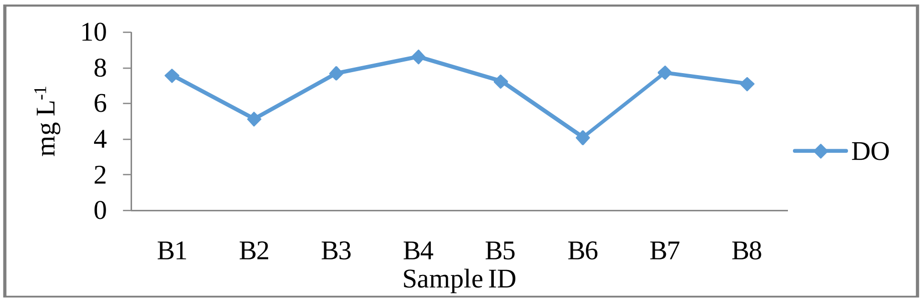

Figure 11. Comparative analysis of the DO content of 8 groundwater samples

Chloride: Chloride can be found in a variety of natural waters [7]. Chloride in groundwater samples range from 173 to 209 mg L^{-1}. Due to leaching of chloride containing rocks and soils, chlorides are present in natural water due to discharges of effluents from chemical plants, ice cream factory effluent, wastewater treatment, irrigation drainage. Higher chloride concentrations are detrimental to people's heart and kidney disorders and are also impaired by indigestion, taste, palatability and corrosion. The highest chloride value at B1 is found to be 209 mg L^{-1} and the lowest value at B3 is 175 mg L^{-1}. However, chloride levels are observed to be below the appropriate standards prescribed for drinking water (BIS, 2012) in all sites.

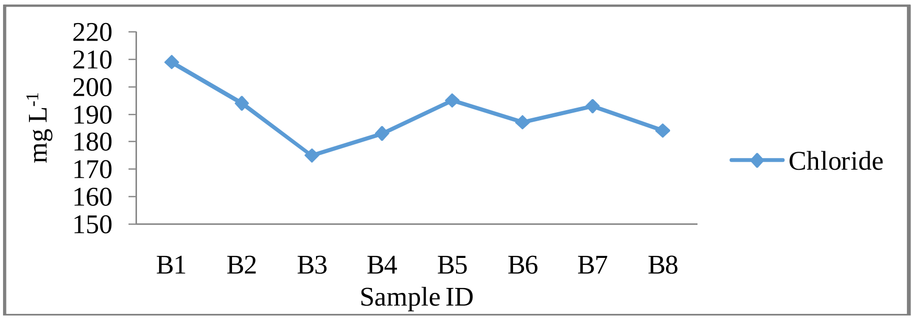

Figure 12. Comparative analysis of the chloride content of 8 groundwater samples.

Fluoride: A geochemical contaminant is fluoride. Fluoride affects the dental environment in small doses. Dental and skeletal fluorosis is caused by greater fluoride concentration. Fluoride levels are found at average of all sites to be 1.22 mg L^{-1}. The fluoride levels are, however, found to be below the appropriate standards for drinking water recommended in all locations. One sample was found to be above the acceptable limits, which is B5 its concentration of fluoride is 1.56 mg L^{-1}.

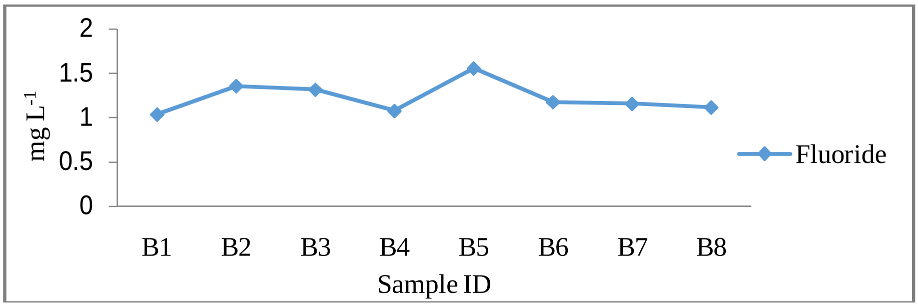

Figure 13. Comparative analysis of the fluoride content of 8 groundwater samples.

Sulphate: Contaminated water and waste water contain high amounts of sulphate. Gastrointestinal inflammation is caused by high sulphate concentrations. The highest sulphate value for B3 is 82.4 mg L^{-1} and the lowest value for B6 is 34.3 mg L^{-1}. However, sulphate levels are found to be below the acceptable limits recommended for drinking water at all locations.

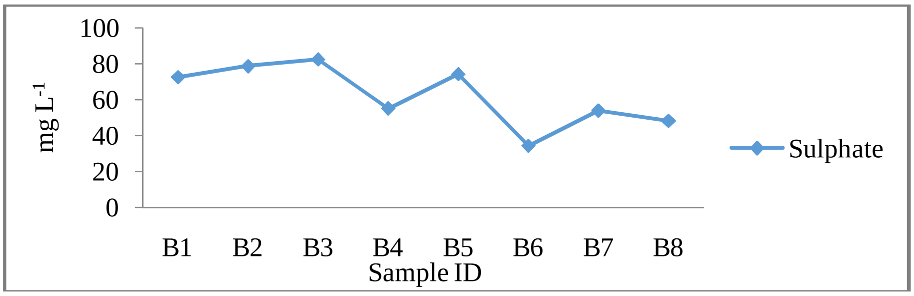

Figure 14. Comparative analysis of the sulphate content of 8 groundwater samples.

Iron: Iron is a fearful heavy metal, especially because dietary iron supplements can cause acute poisoning in small children. Since iron is rapidly absorbed by the gastrointestinal tract, most of the toxic effects of iron are caused by ingestion [8]. The amount of iron in groundwater samples varies between 0.24 mg L^{-1} and 0.34 mg L^{-1}. The occurrence of high iron concentrations in groundwater is very common, particularly in tropical climates. Groundwater-reduced soluble divalent ferrous iron (Fe^{2+}) normally contains iron in the oxidation state. When groundwater comes into contact with oxygen from the atmosphere, the Fe is oxidized to the ferric state and precipitated as a Fe-mineral. The factors of subsurface depletion have a important effect on the high content of iron in groundwater.

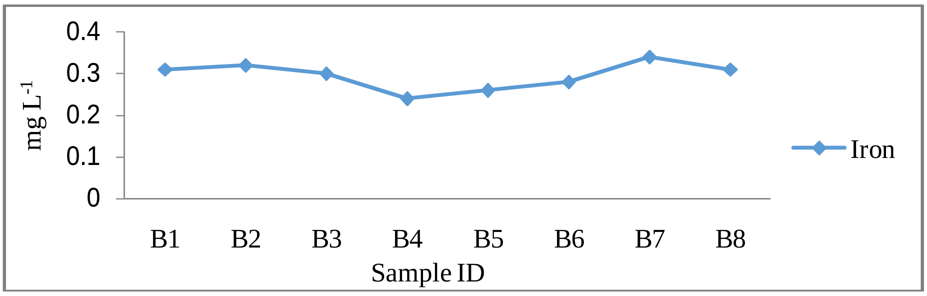

Figure 15. Comparative analysis of the iron content of 8 groundwater samples.

Arsenic: The presence of arsenic in drinking water is one of the most pressing issues, as it can cause cancer and skin lesions [9].When aquifer drawdown allows the aquifer to be infiltrated by atmospheric oxygen, arsenic is emitted into alluvial sediments by oxidation of arsenical pyrite. Arsenic anions sorbed to aquifer minerals are displaced into solution by an equal exchange of phosphate anions derived from over application of fertilizer to surface soils. Anoxic conditions allow

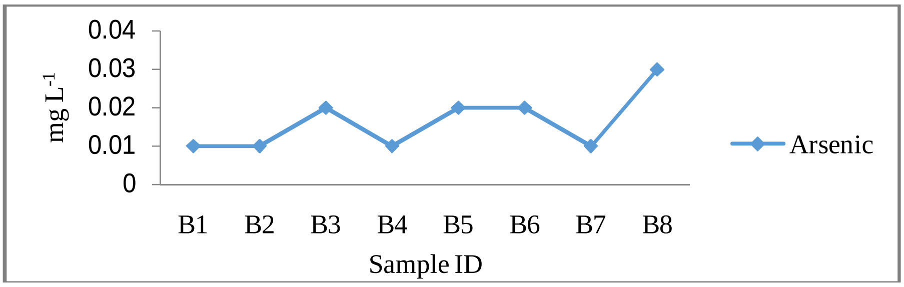

Figure 16. Comparative analysis of the arsenic content of 8 groundwater samples.

for the reduction of iron oxyhydroxide and the introduction of sorbed arsenic into the solution. The concentration of arsenic in groundwater samples ranges from 0.01 to 0.03 mg L^{-1}.

Lead: Lead (Pb) salts are typically water-soluble, but their ability to form chloride, hydroxyl, and organic complexes can improve their mobility through soil profiles. The increased mobility, in particular, may increase Pb concentrations in groundwater. Contamination of groundwater by lead, which may be linked to agricultural practices. Lead in groundwater samples range from 0.02 to 0.06 mg L^{-1}.

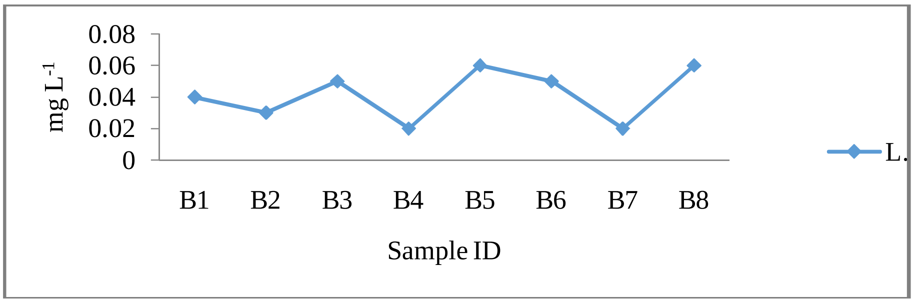

Figure 17. Comparative analysis of the lead content of 8 groundwater samples.

Zinc: Zinc in groundwater samples range from 2.35 to 5.1 mg L^{-1}. Zinc is important for animal feeding, while metals are components of a large variety. Variety of industrial waste pollution, such as pollution from the pulp and paper factories, insecticide factories, viscose contamination factories, tanneries, oil refineries, electroplating industries, metallurgical factories, etc.

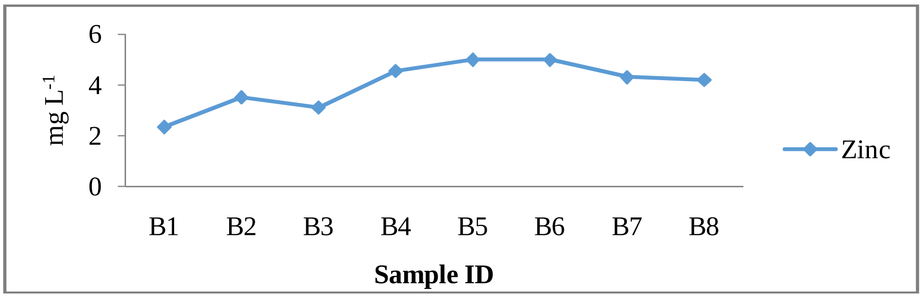

Figure 18. Comparative analysis of the zinc content of 8 groundwater samples.

Figure 3-18 indicates comparative analysis of 8 groundwater samples of physicochemical parameters contents. The pH value of all groundwater samples greater than 7 except for B7. Fluoride concentration of B5 (1.56) is found to be higher than permissible level. Iron exceeds 0.3 mg L^{-1} in B1, B2, B7 and B8. The concentration of lead is found to be 0.06 mg L^{-1} in B5 and B8. Upon investigation of zinc, 5.01mg L^{-1} was obtained in B5 and all samples were less than permissible level.

Water Quality Index (WQI): Groundwater composition is affected by a mixture of chemical constituents and their quantities, mostly obtained from field geological evidence [10]. Basically, a Water Quality Index (WQI) is a simplified expression of more or less complex parameters that function as water quality indicators [11]. To represent the index, a number, a range, a verbal definition, a symbol or color may be used. WQI provides single-value water quality data. It's a representation of the combined effect of different quality metrics on total water quality that's commonly used for water pollution detection and evaluation [12]. In various parts of the world, some researchers used WQI to measure the consistency of groundwater. The total Water Quality Index was determined by linearly aggregating the quality ratings (Table 2).

Table 2. WQI was developed by Brown et al (1972)

Class	Value of WQI	Status of Water Quality
I	0-25	Excellent Water Quality
II	26-50	Good Water Quality
III	51-75	Poor Water Quality
IV	76-100	Very poor Water Quality
V	>100	Unsuitable to drink

Calculation of Water Quality Index: The WQI was calculated using the drinking water quality guidelines proposed by the Bureau of Indian Standards (BIS 1991). The WQI was calculated using the weighted arithmetic index method (table 2) in the following steps. The WQI was calculated in three steps after the samples were analyzed [13]. First, a weight was assigned to each of the 16 parameters based on its relative significance in the overall quality of drinking water [14].

Calculation of Quality Rating (Q*n*): Assume that n are water quality parameters, and that the quality rating or sub-index (Qn) referring to the n^{th} parameter is a number expressing the relative value of this parameter in polluted water in comparison to its acceptable standard value [15].When the most common quality variables were examined in the lab according to APHA 2005 standard techniques, this method was used [16].The expression below is used to calculate the value of Qn.

$$Qn = 100[(Vn - Vi) / (Sn - Vi)] \quad \ldots(1)$$

Where, Qn = the n^{th} parameter of water quality is given a quality rating, Vn = the n^{th} parameter's observed value at the designated sampling station, Sn = the n^{th} parameter's standard acceptable value. Vi = the n^{th} parameter's ideal value in pure water, In certain cases, Vi = 0, with the exception of such parameters such as pH=7.0 (DD water) and acceptable value pH=8.5 (contaminated water), as well as DO=14.6 mg L^{-1} and fluoride=1.0 mg L^{-1}, and so on. Determination of quality rating for pH, Fluoride, and DO is as follows.

QpH = 100 (VpH– 7.0)/(8.5-7.0), QF^- = 100 (VF^-– 1.0)/(1.5-1.0), and QDO = 100 (VDO– 14.6)/(5.0-14.6).

Unit Weight Calculation (Wn): Calculations of unit weight (Wn) for various water quality parameters are inversely proportional to the given conditions for the corresponding parameters.

$$Wn = K / Sn \quad \ldots(2)$$

Where, *Wn*= For the n^{th} parameter unit weight, *Sn* = the standard permissible value of the n^{th} parameter, K = the proportionality constant. [17].

$$K = 1/[1/S1+1/S2+\ldots\ldots\ldots+1/Sn]$$

The unit weight (Wn) values used in this analysis were taken from (Krishnan J.S.R et al.1995) [18].

Calculation of WQI: The water quality index blends various metrics and their dimensions into a single ranking [19]. Using the most frequently calculated water quality parameters, the weighted arithmetic water quality index method [20] classified water quality based on purity levels. Various scientists have used the tool in the background, and the following equation was used to calculate the WQI [21].

$$WQI = \sum_{n=1}^{n} QnWn / \sum_{n=1}^{n} Wn \quad \ldots(3)$$

Table 3. Calculation of water quality index

Parameters	(Sn)	(Wn)	(Vn)	(Qn)	(WnQn)
pH	8.5	0.0026	7.525	34.60	0.090
EC	300	7.425	544.37	181.45	0.013
Turbidity	10	0.0022	5.987	59.87	0.133
TDS	500	4.4553	797	159.4	0.007
Total Alkalinity	200	0.0001	221.25	110.62	0.012
Total Hardness	300	7.4256	460.25	153.41	0.011
COD	20	0.0011	16.25	83.75	0.093
BOD	5	0.0044	5.396	107.92	0.480
DO	5	0.0044	6.886	80.35	0.357
Chloride	250	8.9107	190	76	0.006
Fluoride	1.5	0.0148	1.227	45.40	0.674
Sulphate	150	0.0001	62.412	41.60	0.006
Iron	0.3	0.0742	0.295	98.33	7.301
Arsenic	0.05	0.4455	0.016	32.50	14.479
Lead	0.05	0.4445	0.041	82.50	36.756
Zinc	5	0.0044	4.011	80.22	0.357

Water Quality Index out of 16 samples was computed for the study area in Oct.–Dec. 2020 is presented in table 3. The computed WQI indicate that the overall WQI was 60.78. The high value of WQI during the season is due to high TDS, alkalinity, hardness, and EC concentrations in ground water. During the study season, the water quality of the samples appears to be low. Chemical treatment systems for water purification in the home are readily available in the world [22]. Various salts of aluminum, iron, lime, and other inorganic or organic chemicals are chemically coagulated, as well as other inorganic or organic chemicals, is a commonly used method for removing turbidity, stiffness, and microorganisms from water.

APPLICATION

WQI integrates data from different dimensions of water quality into a mathematical equation that measures water quality health using a variety of parameters (Brown et al. 1972). The water body WQI was calculated using the weighted arithmetic index system.

CONCLUSION

Chemical components in the water can cause a variety of problems in surviving objects. In order to increase its efficiency, it is important to understand that it is the most efficient and safeguarding means of conducting routine checks and taking appropriate precautions over a fixed time it takes for it to be supplied to living objects. The physicochemical parameters of groundwater samples collected from various locations in the Gevra coalfields areas were studied, and the majority of the parameters were found to be above WHO, ICMR BIS, and other agencies' overall permissible limits. The following results, on the other side, are classified as exceptions to the WHO standards. The result suggests a much lower average concentration of the associated ions, most of which are below the permitted range, in the case of heavy metal ions, As, Zn, and Pb. For a sample with a permissive disposition, immediate action is expected, with special attention paid to improving the quality of drinking water, on a physicochemical basis, most parameters of water samples were found to be outside the limits of drinking water quality standards and safe for dirt and other domestic uses. However, more environmental water contaminants, such as pesticides, microbial and radiological products, may also be examined for a prolonged period of time in order to determine the overall water quality. According to the calculated WQI, the overall WQI was 60.78. The high seasonal WQI value is due to high TDS, alkalinity, hardness and EC content in ground water. Water sample consistency continues to be poor during the study season.

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