INTRODUCTION

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1.1 Iron in water bodies

Uttarakhand is a state in India's northern Himalayas that is blessed with magnificent natural splendor and abundant mountain springs. Even so, during the summer, there is a severe lack of potable water in clusters of hilly villages. There is a severe water shortage, particularly in the summer and in years with less rainfall. In Uttarakhand, the springs serve as the natural source of domestic water. The ionic chemistry of surface and groundwater can vary significantly due to several factors, the most significant of which are urbanization, industrialization, and agricultural development. The strategy for the development and management of water resources as part of the water resources development program includes an evaluation of the impact that industrialization and urbanization have had on water resources. As a result, in the Haridwar district of Uttarakhand, comprehensive research on the sub-surface and groundwater quality has been carried out to evaluate the water's quality and determine whether or not it is suitable for drinking, residential, or agricultural use [1-3].

Metals are naturally occurring inorganic components in water bodies. Some of these metals are required for the healthy growth and maintenance of certain species at optimal concentrations. Water is an essential source of these metals. When rainwater filters down through rocks and dissolves trace amounts of metals into the water, these metals reach the water bodies naturally. Water is directed towards larger reservoirs, which individuals utilize for various purposes. Iron, an abundant metallic element found naturally in water, ranks as one of the most abundant elements on Earth, occupying the fourth position in terms of overall abundance and the second position in the earth's crust [4-10].

Significant quantities of potable water are derived from underground water sources. Iron is a common component found in the underground water supplies of countries worldwide [11-16]. There are no iron concentration standards for drinking water based on health considerations. However, it is troublesome because it causes a number of operational and physical problems, including as a discoloration, foul taste, staining and deposition in distribution systems, which leads to excessive turbidity and after-growth. According to the World Health Organization (WHO), iron in drinking water should be below 0.3 mg/l. This recommendation is based on both taste and sanitation concerns [17-20].

Geological sources or the domestic garbage dumping and industrial effluents contribute to the introduction of iron into water bodies [30]. Mining, metal corrosion, and pollution from industries that produce iron and steel are the primary contributors to the presence of iron in surface waters [31]. Iron can also be found in ground water, in addition to being present in surface water. The leaching of iron-containing rocks and minerals are the primary contributor to the high concentrations of iron that can be found in groundwater [32].

Table1.1: Undesirable presence of iron in drinking water of Uttarakhand

S. No.	Name of district	Values
1.	Dehradun	0.02 to 2.35 mg/l [21]
		0.081 to 7.046 mg/l (pre-monsoon) 0.057 to 6.810 mg/l (post-monsoon) [22]
2.	Haridwar	7.540 mg/l (raw) 7.776 mg/l (supply) [23]
		11 Water quality affected habitations w.r.t. Iron [24]
3.	Almora	1.96 mg/L [25]
4.	Nainital	0.040 to 1.479 mg/l (pre-monsoon) 0.054 to 1.295 mg/l (post-monsoon) [26]
		8 to 113 mg/l [27]
5.	Udham Singh Nagar	0.12 to 3.0 mg/l [28]
		0.06 to 2.08 mg/l [29]

1.2 Iron presence standards and issues related to high iron concentration

Iron concentrations in surface and groundwater ranges from 3-4 mg/l-15 mg/l [33- 35]. Its content in West Bengal, India's groundwater ranged from 2-10 mg/l. Iron concentrations as high as 6 mg/l has been recorded in the Ganga River in the Moradabad district of Uttar Pradesh, India, near the Fazalpur industrial sector [36]. Assam, a state in eastern India, has heavily contaminated groundwater with higher iron levels [37-39]. However, the permitted iron concentration is 0.3 mg/l [40-43] in drinking water. In the beginning, exceeding this level may not cause any health problems in drinking water. However, prolonged consumption of such iron-rich water may lead to iron overload [44-46].

Hematopoiesis may be perturbed by excessive iron intake by killing progenitor cells and the microenvironment necessary for hematopoiesis. Hemochromatosis may occur if excessive iron is not eliminated [47-49]. Hemochromatosis damages several organs in the body. Weight loss, joint pain, and exhaustion are the initial signs. Eye ailments such as conjunctivitis and cancer, choroiditis retinitis and heart disease are also significant health problems associated with excessive iron concentrations in water [50]. In addition to these health-related difficulties, several others, such as abdominal pain, have been linked to excessive iron levels in the water. Females can cease menstruation, elevated blood glucose levels, Low thyroid function, hypothyroidism, loss of libido or sexual desire, and impotence in men, reduced size of the testicles; the skin becomes bronzed, similar to a tan. The following conditions may emerge over time: arthritis, cirrhosis of the liver, diabetes, hepatocellular hypertrophy, heart disease, and pancreatitis [51]. At elevated quantities, the metal imparts metallic flavor, an odor, and red hue to water [52].

Additionally, it leaves streaks on plumbing fixtures and stains on clothes. Iron precipitation can also clog softeners and pipes, resulting in adversity in water distribution systems [53]. Some bacteria may utilize elevated iron concentrations asa food source. These bacteria thrive on the surfaces of pipes, which are their ideal habitat. These bacteria achieve such a high population density that they begin to clog pipes and restrict the flow rate of water in the pipeline. Once these bacterial colonies have established themselves in a pipeline, it becomes extremely challenging to eliminate them. In addition, punctures and leaks are among the most commonly reported problems if the pipeline is made of iron [54-55]. When these bacteria die in the water mains, a foul odor, reddish brown color and metallic taste are created [56].

1.3 Iron oxidation technique

The oxidation states of iron range from –II to +VI. Predominant are only the +III ferric states and +II ferrous states are prevalent. Carbonyls, nitrosyls, phosphines, andtheir derivatives constitute the lower iron oxides from –II to I. The presence of excessive carbonate ($CO3^{2-}$) in groundwater and its exposure to air will cause the transformation of ferrous to $FeCO_3$ and the formation of brown ferric oxide deposits [57]. Due to the presence of hexaquo ferrous ion $[Fe\ (H2O)_6]^{2+}$, pure ferrous can take on a brilliant blue color in water.

Multiple variables, including as the presence of other soluble ions, temperature, elemental composition, pH and dissolved oxygen concentration, impact the amount of iron present or removed. Temperature, pH, dissolved oxygen levels have an inverse relationship with oxidation rate.

1.4 Iron extraction techniques

Iron concentrations in groundwater must be decreased for drinking, agricultural, residential and aquaculture purposes. For the elimination of small Fe concentrations, oxidation by aeration is effective. However, this technique is ineffective at eliminating biologically complex iron compounds. Additionally, this process requires a longer duration than other eradication techniques. To keep the same level of dissolved oxygen throughout the water, the aeration needs to be closely monitored and managed. Minimum detention period of 20 minutes is required after aeration [58]. Carbonates prevail among iron precipitates after aeration at elevated alkalinities, whereas quick oxidation of iron precipitates with oxidants produces hydroxide precipitates [59].

1.5 Diverse techniques for iron extraction

Chemical oxidation is commonly utilized due to the readily available chemicals and their capacity to eliminate complicated iron forms. Iron precipitates in the form of oxyhydroxides and iron oxide are produced by chemical oxidation. These chemicals are toxic and sometimes difficult to eliminate. Filtration may be used to remove the precipitated iron. However, this method has downsides like as an over abundance of backwash cycles. To eliminate precipitates, different types of granular media are used for filtration. Continuous use can clog filter bed, resulting in decreasing filter effectiveness and severe filtration problems. Many backwash cycles are required for the effective operation of the filter. Iron sequestration/chelation binds ferrous iron to other molecules in order to prevent its transition into ferric iron. Therefore, this method can be used to treat groundwater having high levels of ferrous iron. It is simple and inexpensive to install.

Phosphates, polyphosphates, and sodium silicates are the sequestering agents used. However, these agents embed ferrous iron in colloidal forms, making its removal more difficult. Biological removal benefits from elevated filtration rates and the absence of chemical oxidants. Oxidation is performed by Fe oxidizing bacteria such as *Leptothrix, Gallionella, Crenothrix,* and *Sphaerotilus* [60]. Many variables influence the biological eradication process including oxidation type, co-precipitate formation, pH, iron loading and temperature. Optimal factors for biological iron removal include a pH range of 6.5-7.2, temperatures between 50- and 75-degrees Fahrenheit and low dissolved oxygen concentrations [61]. Resins for Ion exchange can be regenerated and utilized at any pH using the proper regeneration solutions. It has the advantage of functioning at varied flow rates, but its application is limited because it has no effect on alkalinity, total solids, or water turbidity. Anion and cationion exchange can be conducted using ions with opposite charges [62].

Table 1.2: Various techniques for iron removal from water

S. No.	Methods	Illustration	Maximum Iron Removal Efficiency	Author
1.	Aeration-based oxidation	Effective at removing low iron concentrations. Most effective at pH 8	Up to 85%	[33]
2.	Utilization of chemical oxidants for oxidation	Useful for removing iron that is organically complexed O_3, ClO_2, Cl, H_2O_2 and $KMnO_4$ are effective oxidants for pH values between 7 and 9. Comparatively shorter reaction time than aeration.	Up to 95%	[34, 35]
3.	Iron encapsulation	In anaerobic conditions, polyphosphates and orthophosphates are used effectively. Works best in moving waters.	Up to 75%	[36]
4.	Biological disposal	Used for iron bacteria and low pH groundwater.	Up to 90%	[37]
5.	Ion transfer	Typically employed at the domestic level to eliminate limited amounts of iron.	Up to 80%	[38, 39]
6.	Adsorption- oxide formation	Conditions of anaerobic and low pH operation. Is an economical method.	Up to 85%	[40, 41]
7.	Membrane filtration	Contains nanofiltration and reverse osmosis. With high operating expenses.	Up to 99%	[42]
8.	Electrocoagulation	Nearly 100 percent removal efficiency. Compatible with solar energy.	Up to 100%	[43]

The iron that is adsorbed to the media particles increases its surface area, which in turn provides more surface for adsorption, making adsorptive filtering a cost-effective technique that does not require the use of chemicals and produces minimum sludge for iron removal. It makes use of the adsorption phenomena, which can be defined as the attachment of pollutants to the surface of a medium. In this stage, ferrous iron is adsorbed to the surface of the medium, and then it undergoes oxidation to become ferric iron. The removal of ferrous from groundwater, which normally has significant concentrations of the element, can be accomplished by the process of adsorption. The treatment is suitable for use in rural locations and is not very expensive. This approach achieves the desired results, but it is labor-intensive [63]. Reverse osmosis, nanofiltration, ultrafiltration, and microfiltration are all examples of filtration processes that use membranes. The use of membrane filters allows for the production of effluent water of an exceptionally high standard [64]. Particles such as solids, oils, viruses, ions of a certain size, metal hydroxides, and emulsions are unable to pass through them because they act as a barrier. Milk production, the oil-water separation, pharmaceutical industry and the paint industry are just few of the many businesses that make substantial use of it. These filters have a tiny footprint, which results in reduced expenses associated with installation.

1.6 Hypothesis

The safe and clean drinking water supply is a big concern in Uttarakhand. Asignificant state population needs access to quality drinking water even after the enormous investments and massive efforts concerning higher levels of iron contamination in rural and urban areas. The hypothesis of the proposed issue includesstudies based on analysis and reduction/elimination of iron from different water resources by implementing efficient bio-remediation techniques using appropriate microbial consortia. So far, efforts made by the different agencies have not exhibitedpositive results, and all the imported or market technologies utilized are turned out tobe disappointments because of different reasons involving usage of chemicals, absence of regional availability of regeneration material, waste dumping and remotelocations in hilly areas, etc. The proposed scheme could be utilized efficiently for meeting our drinking and domestic necessity of good quality water as per BIS.

1.7 Key questions

- If the resulting method ultimately provides an efficient biotechnological treatment process for removal of total iron content.
- If the development of the consortium of microbes in suitable designed bioreactor is able to reduce the iron load.
- If the enhanced iron load is changing the physio-chemical parameters of the river system.

1.8 Objectives

The following is a list of the goals that this particular study aims to accomplish:

1. Collection of water and soil sediment samples from 50 hand pumps and 50 Uttaranchal Koop's of Haridwar district will be collected.
2. Selection of water samples of 05 hand pumps and 05 Uttaranchal Koops i.e., from 10 sites in Haridwar district containing highest quantity of iron for further treatment will be carried out.
3. Utilization of low-cost materials like Kaolinite, bentonite, lignite and pumice will be investigated to assess their capability to remove iron.
4. Collection and screening of the soil samples from the area of high metal ion contents and the pristine areas of the Uttarakhand for the isolation of bacterial strains capable of biosorption/ bioaccumulation of metal ions will be initiated with the raw water collected from (villages/ cities) Haridwar district of Uttarakhand.

(i) Designing of Bioreactors (biologically stabilized soil filters) in fixed bed/fluidized bed/UASB

(ii) Lab scale trials (5-10 L): Laboratory process developmentexperiments and will comprise:

a. Inoculation

b. Retention Time

c. Bio absorption rate of iron

(iii) Water quality analysis for testing efficacy of the method developed for quantitative removal of iron from subsurface.

(iv) Interpretation of the data and conclusions will then be drawn.