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CHALLENGES AND SOLUTIONS IN THE SUSTAINABLE MANAGEMENT OF HIMALAYAN SPRING WATER

Suneel Singh Barheyan[a,b#], Hari Singh[a], Satish Kumar[c] , Roshan Lal[d] , and Kewal Kumar[b]

a. Department of Chemistry, RIMT University, Mandi Gobindgarh, Punjab-147301
b. Department of Chemistry, Government College for Women, Udhampur, J&K-182101
c. Department of Chemistry, Government Degree College, Udhampur, J&K-184101
d. Department of Chemistry, Government Degree College, Kathua, J&K-184101

#Corresponding author email: bsuneelsingh@gmail.com

ABSTRACT

Spring water serves as a crucial resource for drinking, household, agricultural, and industrial activities, particularly in the Himalayan region. This review delineates the challenges tied to spring water quality and availability amidst increasing environmental and anthropogenic pressures. Systematic Assessment and Purification It underscores the importance of systematic assessment and purification of Himalayan springs to ensure safe drinking water provision and overall water resource sustainability. Diverse methodologies employed in evaluating spring water quality, including both traditional and modern techniques, are explored. The review also examines various purification techniques, ranging from filtration to advanced disinfection methods. It delineates existing policies governing spring water quality while identifying gaps and proposing enhancements to these regulatory frameworks. The review further advocates for the integration of emergent technologies in water assessment and purification, along with fostering collaborative approaches for sustainable spring water management. Recommendations are offered for stakeholders, policymakers, and practitioners to support research, enact effective regulations, and implement best practices in spring water assessment and purification.

The potential of natural coagulants, such as Moringa Olifera, Strychnos potatorum, and Arachis hypogea, combined with a 20% alum solution, as well as the reduced graphene oxide-titanium oxide (rGO-TiO2) nanocomposite, are highlighted for wastewater treatment. These agents not only clarify wastewater but demonstrate antimicrobial properties and the ability to extract around 20% of heavy metals. The rGO-TiO2 nanocomposite shows prowess in organic dye removal from wastewater.

The synthesis of findings emphasises the need for a harmonised effort in employing innovative technologies, improving policy frameworks, and promoting cooperative initiatives to ensure the sustainable management of spring water resources in the Himalayan region.

Keywords: Spring Water Quality, Purification Techniques, Himalayan Region, Water Resource Management, Environmental Pressures, rGO-TiO2 nanocomposite

1. INTRODUCTION

1.1. Background of spring water as a vital resource

Spring water is a vital resource due to its importance for drinking, household use, agriculture, and industrial activities. It serves as the main source of water for many communities, especially in regions like the Himalayas[1]. However, the increasing anthropogenic pressure on the environment and changing climatic patterns pose challenges to the availability and quality of spring water. Pollution from agricultural, industrial, and domestic sources threatens the safety of spring water[2]. Studies have shown that the content of major ions and trace elements in spring water can vary based on the geological characteristics of the aquifers[3]. Additionally, the health risks associated with spring water, such as the presence of fecal coliforms, need to be assessed to ensure the well-being of the population[4]. Understanding the hydrogeological characteristics and parameters of springs is crucial for managing and protecting these valuable resources[5]. Future research should focus on advancing assessment methodologies, exploring efficient purification technologies, and investigating the impacts of environmental stressors on spring water quality to formulate robust management strategies (Figure 1).

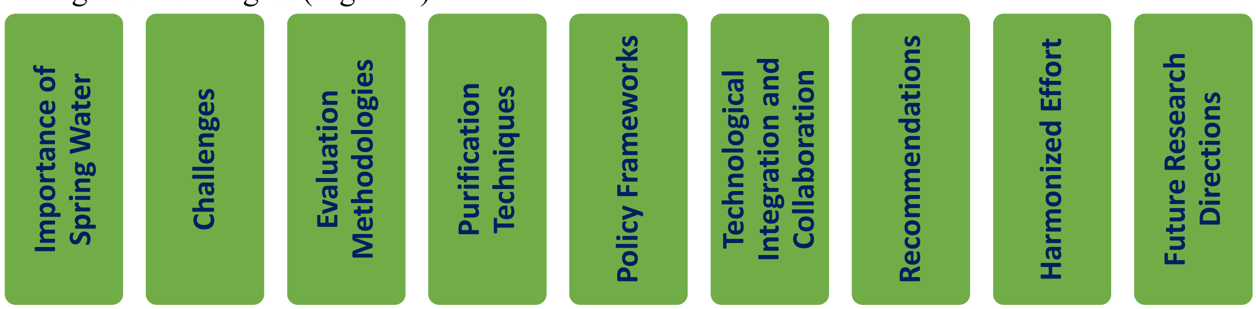

Figure 1 Himalayan Springs: Challenges, Technology and Policy Framework

1.2. Importance of quality assessment and purification

Quality assessment and purification of Himalayan springs is of utmost importance due to their role in meeting drinking water demands and maintaining water resources. The studies conducted in South Kashmir[6]and Kashmir Himalaya [7]highlight the significance of monitoring and managing these springs. The water quality of these springs is influenced by various factors such as lithology, discharge, temperature, dissolved oxygen, nutrients, and anthropogenic inputs[8]. In Nepal, the hydrogeochemistry of thermal springs was analyzed, and it was found that most parameters were within safe limits, but some heavy metals exceeded the limits [9]. In Awing, Cameroon, springs were assessed for human consumption, and while physicochemical parameters indicated good quality, the presence of faecal coliforms and pathogenic bacteria posed health risks [10]. In Pakistan, the evaluation of drinking water quality from natural springs revealed the need for assessment of specific parameters to ensure safety. These findings emphasize the need for regular assessment, purification, and treatment of Himalayan springs to ensure safe drinking water for communities.

1.3. Objectives and scope of the review

The objective of the review is to assess the water quality of Himalayan springs and explore purification techniques. The review focuses on the importance of monitoring and managing freshwater springs in meeting drinking water demands and maintaining water resources[6]. It also emphasizes the need for understanding the hydro-geochemical characteristics and

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2733-2749

physicochemical properties of springs to ensure sustainable use of their water[7]. The review examines the water quality parameters of the springs, including major cations and anions, organic compounds such as dyes and analyzes their variations during different seasons [11][12]. It also discusses the suitability of spring water for drinking and irrigation purposes, using water quality indices and parameters such as sodium absorption ratio and residual sodium carbon [5]. Additionally, the review explores the fundamentals of water purification processes and their application in ensuring safe drinking water[13].

2. METHODOLOGIES FOR SPRING WATER QUALITY ASSESSMENT

Methodologies for assessing the quality of spring water have been explored in several studies. In one study, hydrochemical quality parameters were analyzed using standard methods, and groundwater quality profiles were generated in a GIS environment[14]. The study analyzed a total of eighteen hydrochemical quality parameters using standard methods from various representative springs of Anantnag district, Kashmir Himalaya. Groundwater quality profiles were generated in a GIS environment for each parameter. Statistical methods, including Principal Component Analysis (PCA), were employed to understand the interdependence of water quality parameters.

The Water Quality Index (WQI) method was used to assess the fitness of spring water for drinking purposes. Geochemical analysis was conducted on thirty representative springs in the Anantnag District, and water samples were collected and analyzed for various physicochemical parameters. Various analytical methods were used to determine the concentrations of different parameters, including spectrophotometric methods for nitrogen, phosphorus, sulphate, and iron, and titrimetric methods for dissolved oxygen, free CO_2, and alkalinity. The analyzed parameters were interpreted using cross-plots, spatial distribution analysis, cluster analysis, and Principal Component Analysis (PCA).

Another study used potentiometric, conductometric, and titrimetric methods to test water samples from springs, and integral toxicity was determined using a luminometer [15]. Water samples from six springs in different districts of Vladimir were collected and tested using standard potentiometric, conductometric, and titrimetric methods. Integral toxicity of the spring water samples was determined using a Biotox-10M luminometer. Data on 31 biochemical and microbiological parameters, as well as integral toxicity, were analyzed for spring water in the city of Vladimir from 2017 to 2022.

A study on karst springs assessed water quality using EPA standard methods for pathogens, nutrients, radon, and physicochemical parameters [16]. Karst spring water samples collected from 50 springs were assessed using EPA Standard methods for pathogens, nutrients, radon, and physicochemical parameters. Statistical and spatial analyses were conducted to assess spatial patterns in the water quality of roadside springs in northeast Tennessee. Local Moran's I and pseudo p-values were calculated to identify spatial clustering of E. coli and radon concentrations. Cokriging was performed to evaluate the relationship between E. coli and land use, as well as radon and distance to mapped fault. Interpolation models were developed to assess the distribution of E. coli and radon concentrations in the study area. Other parameters, such as nitrate, pH, and total dissolved solids, were measured and compared to recommended ranges for drinking water. On-site analysis was conducted in various studies to determine the water quality characteristics of spring water areas. These methodologies provide insights into the safety, integral toxicity, and spatial patterns of spring water quality, including the presence of contaminants and the need for monitoring and regulation.

2.1.Physical, chemical, and biological parameters

Water quality is assessed based on physical, chemical, and biological parameters. Physical parameters include temperature, turbidity, and total dissolved solids (TDS)[17] [18]. Chemical parameters include pH, conductivity, hardness, chloride, alkalinity, and the presence of various elements such as iron, fluoride, nitrite, nitrate, phosphate, and sulphate [19] [20]. Biological parameters involve the presence of microorganisms such as Escherichia coli and coliform bacteria, which indicate pollution. These parameters are crucial in determining the quality of water and its suitability for various purposes, including drinking. Monitoring and analyzing these parameters help in identifying potential health risks and developing strategies to improve water quality (Figure 2).

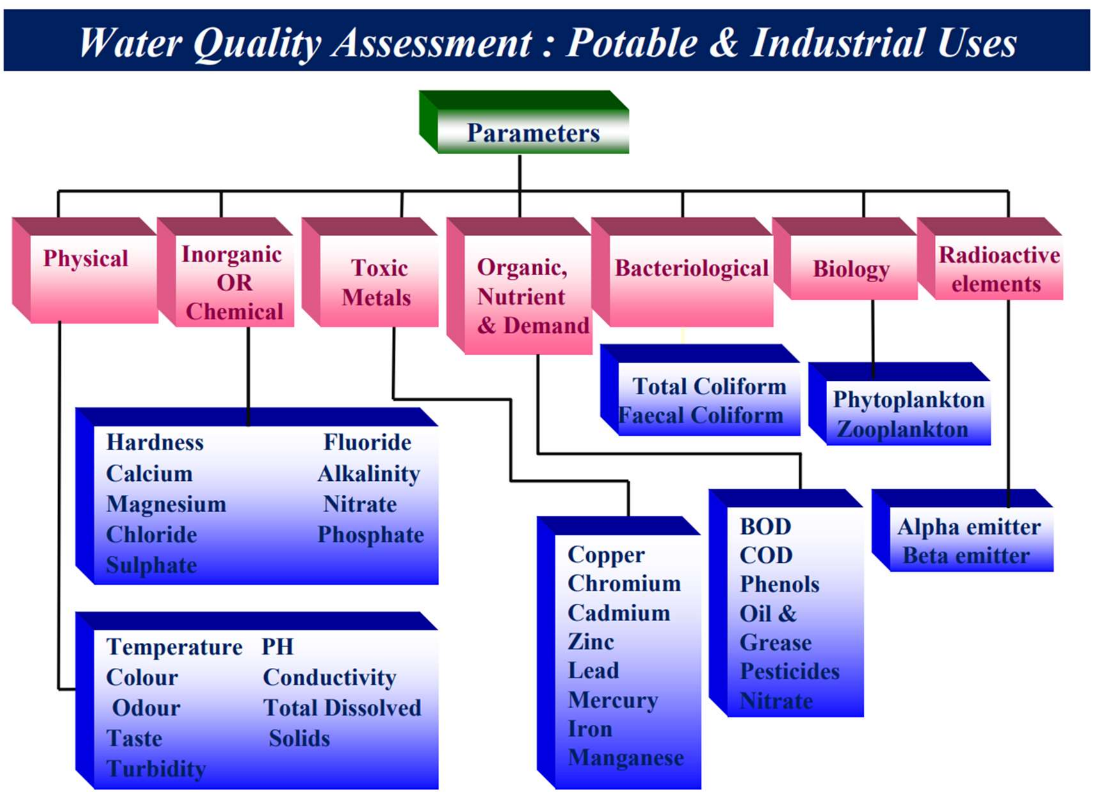

Figure 2 Water Quality Parameters[21]

2.2. Analytical and monitoring techniques

Traditional analytical and monitoring techniques for the assessment of physical, chemical, and biological parameters of water quality involve manual collection of water samples from different locations for laboratory testing and analysis [22]. These techniques are time-consuming, costly, and require highly-skilled professionals [23]. Parameters such as turbidity, conductivity, temperature, total dissolved solids (TDS), oxidation reduction potential (ORP), pH level, and bacteria and viruses are commonly measured[24] [25] . Laboratory tests include the analysis of physiochemical, inorganic, organic, and biological parameters. The use of sensors and microcontrollers, such as Arduino models, in conjunction with wireless communication technologies, like Wi-Fi and GSM modules, has been proposed as a cost-effective and real-time monitoring solution. These advancements enable continuous monitoring of water quality parameters, providing safe water for various purposes.

Modern analytical and monitoring techniques for the assessment of physical, chemical, and biological parameters of water quality include the use of IoT devices [26] and artificial intelligence (AI) models [27]. These techniques involve the use of sensors to measure parameters such as turbidity, conductivity, temperature, total dissolved solids (TDS), oxidation reduction potential (ORP), and pH [28]. Remote sensing (RS) systems and techniques are also used for monitoring ocean water quality (OWQ), including parameters such as chlorophyll-a, colored dissolved organic matter, turbidity, dissolved organic carbon, and sea surface temperature [28]. Additionally, water quality indices, geochemical modeling, multivariate statistical analysis, and adaptive neuro-fuzzy inference systems (ANFIS) are employed for evaluating and predicting groundwater quality (GWQ) [29]. These techniques provide valuable information for managing water resources, ensuring safety for human use, and making decisions in water quality management.

2.3.Comparative analysis of traditional and modern methods

1. Traditional methods
   - Advantages:
     Well-established and proven methods
     Provide accurate and reliable results
     Allow for detailed analysis of water samples
   - Disadvantages:
     Time-consuming and labor-intensive
     Costly
     Require highly-skilled professionals
     Not suitable for real-time monitoring
2. Modern methods
   - Advantages:
     Real-time monitoring
     Cost-effective
     Do not require highly-skilled professionals

Can be used for remote monitoring

- Disadvantages:
  May not be as accurate as traditional methods
  May require calibration and maintenance
  May not be suitable for all water quality parameters

Both traditional and modern methods have their own advantages and disadvantages. The best method for a particular application will depend on the specific needs of the user. For example, if accurate results are required, traditional methods may be the best option. However, if real-time monitoring is needed, modern methods may be a better choice.

3. CHALLENGES IN ASSESSING SPRING WATER QUALITY

3.1. Variability in source and composition

Spring water originates from a variety of sources, such as groundwater, surface water, and a combination of both. This can lead to significant variability in the physical, chemical, and biological properties of spring water.

The composition of spring water can also vary depending on the geology of the area, the time of year, and weather conditions. For example, spring water from areas with high levels of natural minerals may contain elevated concentrations of certain metals.

This variability can make it difficult to assess the overall quality of spring water and to determine whether it is safe for drinking.

3.2. Environmental and anthropogenic factors

Spring water quality can be impacted by a variety of environmental factors, such as:

- Changes in land use
- Agricultural runoff
- Urban development
- Climate change

These factors can introduce contaminants into spring water, such as:

- Sediment
- Nutrients
- Pesticides
- Heavy metals

Anthropogenic activities can also impact spring water quality. For example, poorly maintained septic systems can leach wastewater into groundwater, which can then contaminate spring water.

3.3. Methodological limitations and areas for improvement

1. Traditional methods for assessing spring water quality are often time-consuming and labour-intensive. This can limit the number of samples that can be collected and analysed.

2. Traditional methods also typically only measure a limited number of water quality parameters. This can make it difficult to get a complete picture of the overall quality of spring water.
3. New methods are being developed for assessing spring water quality. These methods are often more rapid and cost-effective than traditional methods. However, these methods are still under development and need to be further validated.

Areas for improvement

- Develop more rapid and cost-effective methods for assessing spring water quality.
- Develop methods for measuring a wider range of water quality parameters.
- Conduct more research on the impact of environmental and anthropogenic factors on spring water quality.
- Develop better methods for communicating the risks associated with drinking spring water to the public.

4. Spring Water Purification Techniques

1. Filtration: Filtration is a physical process that removes suspended solids from water by passing it through a porous medium. Common filtration methods for spring water purification include:
2. Sand filtration: Sand filters are used to remove large particles, such as sediment, from water.
3. Carbon filtration: Carbon filters are used to remove organic contaminants, such as taste and odor compounds, from water.
4. Microfiltration: Microfiltration filters are used to remove bacteria and other microorganisms from water.
5. Sedimentation: Sedimentation is a physical process that removes suspended solids from water by allowing them to settle to the bottom of a container. Sedimentation is often used in conjunction with filtration to remove larger particles from water.
6. Disinfection: Disinfection is a chemical or physical process that kills or inactivates microorganisms in water. Common disinfection methods for spring water purification include:
7. Chlorination: Chlorination is a chemical disinfection method that uses chlorine to kill microorganisms.
8. Ultraviolet (UV) light disinfection: UV light disinfection is a physical disinfection method that uses UV light to kill microorganisms.
9. Ozonation: Ozonation is a chemical disinfection method that uses ozone to kill microorganisms.

A number of advances in technology and innovation have been made in the field of spring water purification. These advances include:

- The development of new filtration media that are more effective at removing contaminants from water.

- The development of new disinfection methods that are more effective at killing microorganisms.
- The development of more energy-efficient and cost-effective water purification systems.

Comparative Analysis of Efficiency, Cost, and Sustainability

The following table provides a comparative analysis of the efficiency, cost, and sustainability of different spring water purification techniques:

Technique	Efficiency	Cost	Sustainability
Sand filtration	High	Low	High
Carbon filtration	High	Moderate	Moderate
Microfiltration	High	High	Moderate
Sedimentation	Moderate	Low	High
Chlorination	High	Low	Moderate
UV light disinfection	High	Moderate	High
Ozonation	High	High	Moderate

Real-World Applications

Spring water purification techniques are used in a variety of real-world applications, such as:

- Providing drinking water to communities in rural areas
- Purifying water for use in food and beverage production
- Removing contaminants from wastewater

A number of success stories have been documented in the use of spring water purification techniques. For example, in the village of Gando in Burkina Faso, a sand filtration system was installed to provide clean drinking water to the community. The system has been successful in reducing the incidence of waterborne diseases in the village.

In another example, a UV light disinfection system was installed at a bottling plant in the United States. The system has been successful in preventing the growth of microorganisms in the bottled water.

Spring water purification techniques are an important tool for ensuring the safety of drinking water. Several advances in technology and innovation have been made in the field of spring water purification. These advances have led to the development of more effective, efficient, and cost-effective water purification systems.

Natural Coagulant Treatment: In wastewater treatment, the coagulation-flocculation process can be used as a preliminary or intermediary step between other treatment processes like filtration and sedimentation. This process is a straightforward method to clarify wastewater. Coagulation is a chemical process that involves the neutralisation of charges. On the other hand, flocculation is a physical process that does not involve the neutralisation of charge. Natural coagulants have the

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2733-2749

ability to clarify turbid water. Natural coagulants that are to be taken are: Arachis hypogea seeds that are used for 50% Pb removal, 40% Cr removal, and 25% Zn removal. Moringa olifera leaves and seeds and Strychnos potatorum (Nirmali seeds) act as bio-coagulants that are used for reducing turbidity, organic matter, and COD. Absorptive coagulation techniques can be used to lower the pH, turbidity, organic matter, COD, Pb, Cr, Zn, As, etc. in the wastewater. Natural coagulants are cost-effective, abundantly available, require a lesser dosage, do not lead to the formation of dissolved particles, settle heavy metals, produce a lesser amount of sludge that is biodegradable, and do not alter pH while being added.

Synthesis of Graphene Oxide:

Firstly, material was obtained from graphite powder using an improved Hummer technique (Li et al. 2017). Add 2.5 g of NaNO3 to 5 g of graphite powder and mix it. Now, transfer this into 140 ml of 1.0M H2SO4 solution by slowly and continuously stirring in an ice-cold bath. The agitation of the above-obtained solution is done while keeping the temperature below 278 °C. After this add 15gm KMnO4 into it, by keeping the temperature less than 278 K for 6h. Now, increasing the temperature to 393K and further agitating the solution for a duration of another 30 minutes Subsequently, 50ml of H2O2 is transfer into the suspension. After centrifuging, the suspension is rinsed with a 5% HCl solution and deionized water until the solution becomes neutralised (pH = 7.0). The final product is collected and dried in an oven (Figure 3).

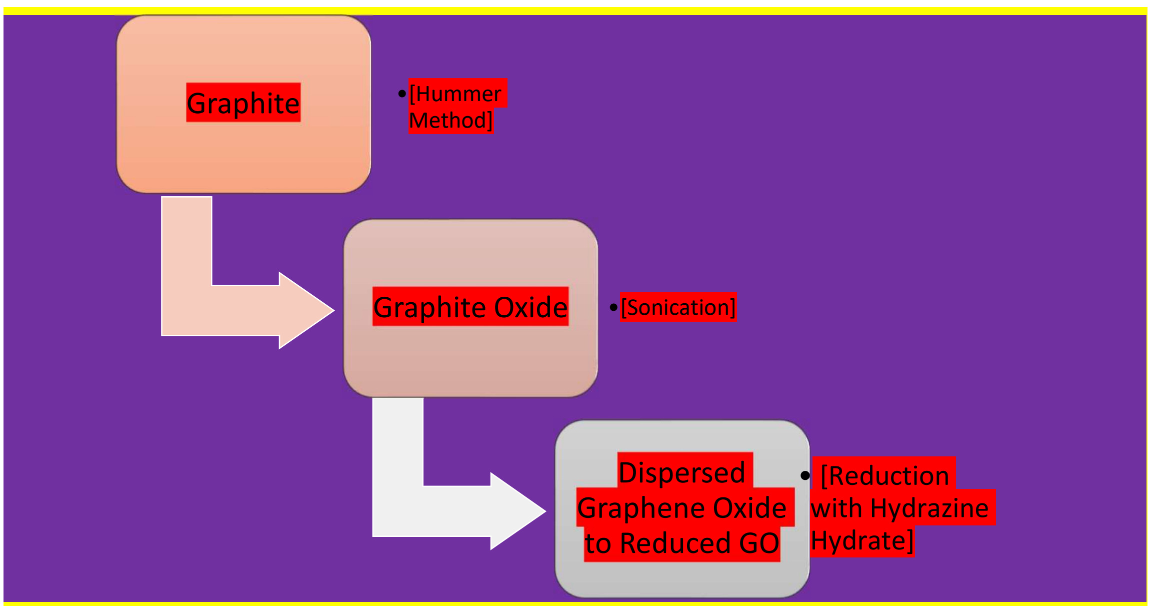

Figure 3 Show the synthesis of Graphene Oxide by Modified Hummer Method

Conversion of dispersed graphene oxide (dGO) into Reduced graphene oxide (rGO):

To convert dGO into rGO, treat dGO in 1% hydrazine hydrate solution. So that grapheme oxide becomes highly conductive in nature (Figure 3).

Catalyst Research Volume 23, Issue 2, October 2023 Pp. 2733-2749

Synthesis of TiO_2 by Sol-Gel Method: Following are the steps that are involved in the synthesis of TiO_2 nanoparticles by sol-gel method (Figure 4).

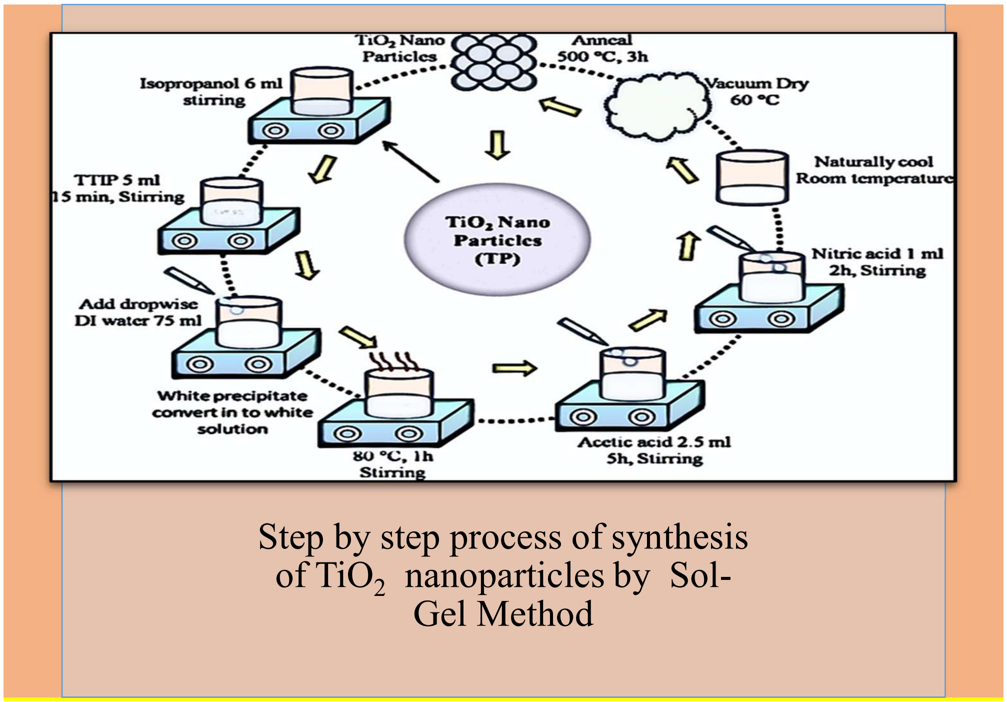

Figure 4: Schematic process of synthesis of TiO_2 nanoparticles by the Sol-Gel method

Synthesis of TiO2-rGO composite: Each GO and TiO2 composite can be made by mixing 2 g of the TiO2 with a predetermined amount of the GO at a concentration of 7.24 ppm. To this GO solution, add 200 ml of deionized water and place it in an ultrasonic dispenser for 1 hour before adding 2 g of TiO2 to each composite. After this, stir for 30 minutes under ultrasonic dispersion, and it can be dried at 293 K for 4 hours. Finally, it can be centrifuged at 6000 rpm for 20 minutes. The suspension can be discarded, and the solids can be dried in an oven at 323K overnight.

Mechanism of TiO_2-rGO composite for the removal of organic dye from water

Under UV-VIS irradiation, TiO_2 produces hydroxyl radicals (·OH) instantaneously. These radicals possess high oxidative potential, facilitating the breakdown of pollutants into smaller by-products. As a result, water pollutants are mitigated, producing harmless CO_2 and H_2O as end-products. Owing to its stability and affordability, TiO2 is a favored photocatalyst in water treatment. The efficacy of TiO_2 is attributed to its electron-hole pairs. When excited by UV radiation, these pairs possess an energy higher than the band gap of TiO_2. Here, UV light promotes charge carriers for the oxidative reaction between target pollutants and TiO_2. When the photocatalyst is irradiated with UV-VIS light of wavelengths below 385 nm (Serpoue et al., 2020), electrons in the valence band of TiO_2 are excited to its conduction band, leaving a hole, referred to as hvb^+ (reaction 1). This hole interacts with OH− or adsorbed H_2O on the TiO_2 surface, producing ·OH. In the following reactions (2-4), the hvb^+:

- Oxidizes target pollutants via an electrophilic attack.

- Oxidizes existing species after forming a hydroxylated TiO_2 surface species.
- TiO_2 possesses a band gap energy (E°) of 3.1 eV, sufficient for pollutant degradation under UV illumination.

However, Marsmanu et al. (2019) reported certain limitations of TiO_2. These include poor visible-light utilization, low quantum yield, rapid recombination of photo-excited electron-hole pairs, and a wide band gap energy of 3.1 eV. These limitations restrict the broad application of UV/TiO_2 in wastewater treatments.

To overcome these issues, TiO_2 is functionalized with rGO. rGO offers a myriad of benefits, including stable thermal conductivity, mechanical strength, and a vast surface area. Moreover, it boasts efficient electron transfer, impressive conductivity, and excellent adsorptive properties (Bal et al., 2017). It is anticipated that the TiO2-rGO composite would exhibit enhanced performance in targeting pollutants, either in terms of selectivity or capacity (Zhu et al., 2020).

5. Regulations and Standards

5.1. Existing policies governing spring water quality: A number of policies and regulations exist at the national, regional, and international levels governing spring water quality (Figure 5). These policies and regulations typically set standards for various physical, chemical, and biological parameters in spring water. For example, the United States Environmental Protection Agency (EPA) has established National Primary Drinking Water Regulations (NPDWRs) for a number of contaminants in drinking water, including spring water. The European Union (EU) has also established Directive 2009/54/EC on the exploitation and marketing of natural mineral waters, which sets standards for the composition and labelling of natural mineral waters. The latest Bureau of Indian Standards (BIS) water quality standards are specified in the following Indian Standards:

- IS 10500:2012: Drinking water specification
- IS 13485:2016: Packaged drinking water (other than packaged natural mineral water) specification
- IS 13486:2016: Packaged natural mineral water specification

Drinking Water Quality Standards

WATER QUALITY PARAMETERS AND BIS STANDARDS FOR VARIOUS CHEMICAL AND BIOLOGICAL CONSTITUENTS

S.No.	Parameters	Drinking water IS 10500 : 2012	
		Permissible Limit	Maximum Limit
1	Odor	Agreeable	Agreeable
2	Taste	Agreeable	Agreeable
3	pH	6.5 to 8.5	No relaxation
4	TDS (mg/l)	500	2000
5	Hardness (as CaCO3) (mg/l)	200	600
6	Alkalinity (as CaCO3) (mg/l)	200	600
7	Nitrate (mg/l)	45	No relaxation
8	Sulfate (mg/l)	200	400
9	Fluoride (mg/l)	1	1.5
10	Chloride (mg/l)	250	1000
11	Turbidity (NTU)	5	10
12	Arsenic (mg/l)	0.01	0.05
13	Copper (mg/l)	0.05	1.5
14	Cadmium (mg/l)	0.003	No relaxation
15	Chromium (mg/l)	0.05	No relaxation
16	Lead (mg/l)	0.01	No relaxation
17	Iron (mg/l)	0.3	No relaxation
18	Zinc (mg/l)	5	15
19	Fecal Coliform (cfu)	0	0
20	E. Coli (cfu)	0	0

Figure 5 BIS water quality standards[30]

The BIS water quality standards are based on the World Health Organization (WHO) Guidelines for Drinking Water Quality. These standards are regularly updated to reflect the latest scientific knowledge on water quality and health.

In addition to the BIS water quality standards, there are also a number of other standards and regulations that apply to drinking water in India. These include the following:

- The Prevention of Food Adulteration Act, 1954: This Act prohibits the adulteration of food, including drinking water.
- The Water (Prevention and Control of Pollution) Act, 1974: This Act aims to prevent and control pollution of water, including drinking water.
- The Environment (Protection) Act, 1986: This Act provides for the protection and improvement of the environment, including the protection of drinking water quality.

The Government of India is also working on a number of initiatives to improve drinking water quality in the country. These initiatives include the following:

- The Jal Jeevan Mission: This mission aims to provide piped drinking water to every rural household in India by 2024.
- The National Water Quality Sub-Mission: This sub-mission aims to improve the quality of water in rivers, lakes, and other water bodies in India.

These initiatives are helping to improve drinking water quality and access to safe drinking water for millions of people in India.

5.2.International and regional perspectives: There is a growing recognition of the importance of spring water resources and the need for effective management of these resources. A number of international and regional initiatives have been developed to promote the sustainable management of spring water. For example, the Food and Agriculture Organization of the United Nations (FAO) has developed a number of guidelines for the assessment and management of spring water resources. The World Health Organization (WHO) has also developed a number of guidelines for drinking-water quality, which include recommendations for spring water.

5.3. **Gaps, challenges, and opportunities for policy enhancement:** While a number of policies and regulations exist governing spring water quality, there are a number of gaps and challenges that need to be addressed. For example, in many cases, existing policies and regulations do not adequately address the potential impacts of climate change and other environmental stressors on spring water quality. Additionally, there is a need for greater harmonization of spring water quality standards across different regions.

6. Future Trends and Recommendations

6.1. **Integration of technology and innovation in assessment and purification:** Emerging technologies such as remote sensing, sensors, and data analytics can be leveraged to enhance the efficiency and accuracy of spring water quality assessment. Additionally, advancements in purification technologies such as membrane filtration, nanotechnology, and photocatalysis offer promising solutions for addressing emerging contaminants.

6.2. **Enhancing policy frameworks and regulations:** Existing policies and regulations governing spring water quality may need to be reviewed and updated to reflect the latest scientific understanding of spring water systems and the potential impacts of climate change, land use change, and other environmental stressors. Additionally, there is a need for greater harmonization of spring water quality standards across different regions.

6.3. **Collaborative approaches for sustainable management:** The sustainable management of spring water resources requires collaboration among stakeholders from various sectors, including government, academia, industry, and communities. Collaborative efforts can focus on developing and implementing integrated management plans, promoting water conservation and protection measures, and raising awareness about the importance of spring water.

7. Recommendations for stakeholders, policymakers, and practitioners

Stakeholders, policymakers, and practitioners can play a role in enhancing spring water quality policies and regulations. Stakeholders can support research and monitoring initiatives to improve understanding of spring water quality. Policymakers can enact and enforce effective policies and regulations governing spring water quality. Practitioners can use best practices for spring water assessment and purification.

7.1. **Stakeholders:** Stakeholders can play a vital role in protecting spring water resources by engaging in watershed management activities, supporting research and monitoring initiatives, and promoting responsible water use practices.

7.2. **Policymakers:** Policymakers can support the sustainable management of spring water resources by enacting and enforcing effective policies and regulations, investing in research and monitoring programs, and promoting education and awareness about the importance of spring water.

7.3. **Practitioners:** Practitioners can contribute to the sustainable management of spring water resources by using best practices for spring water assessment and purification, developing and implementing effective water management plans, and sharing knowledge and expertise with other stakeholders.

8. Conclusion

8.1. **Summary of key findings:** The review highlights the importance of spring water as a vital resource, the challenges associated with assessing and purifying spring water, and the need for integrated approaches to spring water management. Key findings include:

- Spring water quality is influenced by a range of natural and anthropogenic factors.
- Traditional and modern methods for spring water quality assessment have their own strengths and limitations.
- A variety of purification techniques are available for spring water, but the most appropriate method will depend on the specific water quality concerns.
- Existing policies and regulations governing spring water quality may need to be reviewed and updated.
- Collaborative approaches are essential for the sustainable management of spring water resources.

8.2. **Implications for practice and policy:** The findings of this review have implications for the practice of spring water assessment and purification, as well as for the development of policies and regulations governing spring water quality. In particular, the review highlights the need for:

- Greater use of emerging technologies for spring water assessment and purification.
- Enhanced collaboration among stakeholders in spring water management.
- Development and implementation of integrated spring water management plans.

8.3. **Opportunities for future research and development:** Future research and development efforts should focus on:

- Developing more effective methods for assessing and monitoring spring water quality.
- Improving the efficiency and cost-effectiveness of spring water purification technologies.
- Investigating the impacts of climate change and other environmental stressors on spring water quality.
- Developing and implementing effective spring water management strategies.

REFERENCES

[1] V. Glazova, I. Gaponenkov, O. Fiodorova, Z. Vasiljeva, and Y. Glukhikh, “Assessment of Spring Water on Geological Characteristics (Springs in Murmansk Are Taken As an Example),” *KnE Life Sciences*, Jan. 2020, doi: 10.18502/kls.v5i1.6111.

[2] O. A. Lipatnikova, T. N. Lubkova, D. A. Yablonskaya, and O. R. Filatova, “Geochemical assessment of the spring’s waters in the Pushkinsky district, Moscow region,” *Moscow University Bulletin. Series 4. Geology*, no. 6, pp. 129–140, Feb. 2023, doi: 10.33623/0579-9406-2022-6-129-140.

[3] P. Ranjan, P. K. Pandey, V. Pandey, and P. T. Lepcha, “Spring Water Management to Ensure Long Term Sustainability in North-Eastern Regions of India,” *IOP Conf Ser Earth Environ Sci*, vol. 1084, no. 1, p. 012062, Oct. 2022, doi: 10.1088/1755-1315/1084/1/012062.

[4] M. A. Colín Carreño *et al.*, “Human Health Risk and Quality Assessment of Spring Water Associated with Nitrates, Potentially Toxic Elements, and Fecal Coliforms: A Case from Southern Mexico,” *Water (Basel)*, vol. 15, no. 10, p. 1863, May 2023, doi: 10.3390/w15101863.

[5] H. Çadraku, “Monitoring of Water Flow in the Springs of the Golesh Massif, Kosovo,” *Ecological Engineering & Environmental Technology*, vol. 23, no. 5, pp. 109–123, Sep. 2022, doi: 10.12912/27197050/151760.

[6] S. A. Lone, S. U. Bhat, A. Hamid, F. A. Bhat, and A. Kumar, “Quality assessment of springs for drinking water in the Himalaya of South Kashmir, India,” *Environmental Science and Pollution Research*, vol. 28, no. 2, pp. 2279–2300, Jan. 2021, doi: 10.1007/s11356-020-10513-9.

[7] S. U. Bhat and A. K. Pandit, “Water quality assessment and monitoring of Kashmir Himalayan freshwater springs-A case study,” *Aquat Ecosyst Health Manag*, vol. 23, no. 3, pp. 274–287, Jul. 2020, doi: 10.1080/14634988.2020.1816771.

[8] B. Chalise *et al.*, “Water quality and hydrochemical assessments of thermal springs, Gandaki Province, Nepal,” *Heliyon*, vol. 9, no. 6, p. e17353, Jun. 2023, doi: 10.1016/j.heliyon.2023.e17353.

[9] N. A. Mofor, E. B. T. Njoyim, and A. D. Mvondo-Zé, “Quality Assessment of Some Springs in the Awing Community, Northwest Cameroon, and Their Health Implications,” *J Chem*, vol. 2017, pp. 1–11, 2017, doi: 10.1155/2017/3546163.

[10] A. Batool, “Spring Water Quality and Human Health: An Assessment of Natural Springs of Margalla Hills Islamabad Zone-III,” *International Journal of Hydrology*, vol. 2, no. 1, Feb. 2018, doi: 10.15406/ijh.2018.02.00049.

[11] M. Rani, H. Joshi, K. Kumar, D. K. Bhatt, and P. Kumar, “Climate change scenario of hydro-chemical analysis and mapping spatio-temporal changes in water chemistry of water springs in Kumaun Himalaya,” *Environ Dev Sustain*, vol. 23, no. 3, pp. 4659–4674, Mar. 2021, doi: 10.1007/s10668-020-00793-z.

[12] C. A. Vishwakarma *et al.*, “Geochemical Characterization and Controlling Factors of Chemical Composition of Spring Water in a Part of Eastern Himalaya,” *Journal of the Geological Society of India*, vol. 92, no. 6, pp. 753–763, Dec. 2018, doi: 10.1007/s12594-018-1098-0.

[13] R. N. P. A. S. J. D. R. M. Belekar, “Water Pollution Sources and Purification: Challenges and Scope”.

[14] S. U. Bhat, A. U. Nisa, I. Sabha, and N. C. Mondal, "Spring water quality assessment of Anantnag district of Kashmir Himalaya: towards understanding the looming threats to spring ecosystem services," *Appl Water Sci*, vol. 12, no. 8, p. 180, Aug. 2022, doi: 10.1007/s13201-022-01691-7.

[15] T. A. Trifonova, O. V. Saveliev, A. A. Martsev, O. G. Selivanov, Y. N. Kurbatov, and L. N. Romanova, "Assessment of Spring Water Quality in the City of Vladimir," *ЗДОРОВЬЕ НАСЕЛЕНИЯ И СРЕДА ОБИТАНИЯ - ЗНиСО / PUBLIC HEALTH AND LIFE ENVIRONMENT*, pp. 23–31, Jun. 2022, doi: 10.35627/2219-5238/2022-30-6-23-31.

[16] L. Fashina, I. Luffman, T. A. Joyner, and A. Nandi, "Geospatial Assessment of Karst Spring Water Quality in Northeast Tennessee, USA," *Geosciences (Basel)*, vol. 12, no. 8, p. 303, Aug. 2022, doi: 10.3390/geosciences12080303.

[17] I. KATILI, D. W. K. BADERAN, and S. S. KUMAJI, "Analysis of drinking water quality based on biological, physical and chemical parameters in Lekobalo Village, Gorontalo City, Indonesia," *International Journal of Bonorowo Wetlands*, vol. 13, no. 1, Mar. 2023, doi: 10.13057/bonorowo/w130104.

[18] T. Menen Tigga and V. K. Pandey, "A Review on Physico-Chemical Parameters of the Quality of Water." [Online]. Available: www.ijfmr.com

[19] R. Radhika, S. Mathew, and S. Prasad, "Physico - Chemical and Biological Water Quality Analyses of Meenachil River, Kottayam, Kerala, South India," *UTTAR PRADESH JOURNAL OF ZOOLOGY*, pp. 79–94, Mar. 2023, doi: 10.56557/upjoz/2023/v44i23408.

[20] F. H. R. Braga *et al.*, "Study of the Influence of Physicochemical Parameters on the Water Quality Index (WQI) in the Maranhão Amazon, Brazil," *Water (Basel)*, vol. 14, no. 10, p. 1546, May 2022, doi: 10.3390/w14101546.

[21] J. S. Chauhan, T. Badwal, and N. Badola, 'Assessment of potability of spring water and its health implication in a hilly village of Uttarakhand, India', Appl Water Sci, vol. 10, no. 2, p. 73, Feb. 2020, doi: 10.1007/s13201-020-1159-6.

[22] J. Jeyashanthi, J. Barsana banu, M. Pandi Maharajan, and M. Ramuvel, "Assessment of physical and chemical water quality parameters using naive bayes control algorithm," *Mater Today Proc*, vol. 80, pp. 851–859, 2023, doi: 10.1016/j.matpr.2022.11.319.

[23] S. Salehin, T. A. Meem, A. J. Islam, and N. Al Islam, "Design and Development of a Low-cost IoT-Based Water Quality Monitoring System," 2023, pp. 709–721. doi: 10.1007/978-981-19-8032-9_51.

[24] E. GUMUS, "A Case Study on the Relationship between Water Quality Parameters: Bursa," *Sakarya University Journal of Science*, vol. 26, no. 5, pp. 867–878, Oct. 2022, doi: 10.16984/saufenbilder.1083427.

[25] J. Treacy and S. Eslamian, "Sampling and Analytical Techniques for Floodwater Quality Monitoring," in *Flood Handbook*, Boca Raton: CRC Press, 2022, pp. 541–568. doi: 10.1201/9781003262640-32.

[26] J. Jeyashanthi, J. Barsana banu, M. Pandi Maharajan, and M. Ramuvel, "Assessment of physical and chemical water quality parameters using naive bayes control algorithm," *Mater Today Proc*, vol. 80, pp. 851–859, 2023, doi: 10.1016/j.matpr.2022.11.319.

[27] D. P. M. A. Omar, G. Hayder, and Y. T. Hung, “Monitoring and modelling of water quality parameters using artificial intelligence,” *Int J Environ Waste Manag*, vol. 31, no. 4, pp. 525–533, 2023, doi: 10.1504/IJEWM.2023.131153.

[28] F. Mohseni *et al.*, “Ocean water quality monitoring using remote sensing techniques: A review,” *Mar Environ Res*, vol. 180, p. 105701, Sep. 2022, doi: 10.1016/j.marenvres.2022.105701.

[29] M. H. Al-Mashreki *et al.*, “Integration of Geochemical Modeling, Multivariate Analysis, and Irrigation Indices for Assessing Groundwater Quality in the Al-Jawf Basin, Yemen,” *Water (Basel)*, vol. 15, no. 8, p. 1496, Apr. 2023, doi: 10.3390/w15081496.

[30] M. Bhavan, B. Shah, and Z. Marg, “B U R E A U O F I N D I A N S T A N D A R D S,” 2012.