# Application Of Artificial Intelligence and Machine Learning for Evaluating and Predicting Physicochemical Qualities of Drinking Water in Villages of Nashik, Maharashtra

Surekha Bajirao Muthal[1], Sadhana Sajan Gade[2], Gayatri Babaji Handge[3]
[1,2]*Department of Chemistry, MVP Samaj's S.V.K.T. Arts, Science and Commerce College Deolali Camp Nashik*
[3]*Department of Chemistry, MVP Samaj's K.G.D.M. Arts, Commerce and Science College Niphad*
doi.org/10.64643/IJIRT211385

***Abstract*—The present study aims to assess, classify, and predict the quality and potability of groundwater used by the rural population in selected villages of Nashik District, Maharashtra, using Artificial Intelligence (AI) and Machine Learning (ML) techniques. Various physicochemical parameters, including Total Dissolved Solids (TDS), pH, Total Hardness (TH), turbidity, iron, magnesium, potassium, sulphate, nitrate, calcium, fluoride, chloride, and sodium, are analysed using standard analytical methods.**

**The obtained water quality dataset is evaluated using Machine Learning algorithms such as Random Forest, Decision Tree, Support Vector Machine (SVM), and Boost to identify patterns, classify groundwater quality, and predict potential contamination levels. The experimental results are compared with the permissible limits prescribed by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO) to determine the suitability of groundwater for drinking purposes.**

**The proposed AI/ML-based approach helps identify villages with acceptable water quality and those experiencing physicochemical parameter variations beyond recommended limits. Furthermore, the predictive model provides an intelligent decision-support system for early identification of water quality issues and suggests the need for appropriate primary treatment before consumption. This integrated approach aims to improve groundwater quality monitoring, support sustainable rural water resource management, and promote access to safe drinking water.**

***Index Terms*—Physicochemical parameters, EC, pH, TDS, Fluoride, Chlorides, Calcium, Nitrates, Sodium etc.in Nashik region.**

## I. INTRODUCTION

Water is one of the most essential natural resources for the survival of all living organisms and plays a significant role in human health, agricultural development, industrial activities, and environmental sustainability. Groundwater is a major source of water for drinking and domestic purposes, particularly in rural areas. However, increasing human activities, rapid urbanization, industrialization, and agricultural development have gradually deteriorated groundwater quality. Therefore, the availability of pure, safe, healthy, and odourless drinking water has become a major concern worldwide. Groundwater contamination occurs due to various natural and anthropogenic sources, including the seepage of organic and inorganic pollutants, heavy metals, pesticides, fluorides, and other hazardous substances. The quality of water is generally identified through its physical, chemical, and biological parameters [1]. Water plays a vital role in human life and environmental development. However, the consequences of rapid urbanization and industrialization have significantly contributed to water pollution. In rural areas, groundwater is extensively explored for agricultural, domestic, and drinking purposes. During the last decade, groundwater contamination has increased considerably due to expanding human activities and improper waste disposal practices [2, 3]. Water is an integral component of the hydrological cycle, and surface water and groundwater are interconnected

through natural processes. Surface water infiltrates through soil layers and contributes to groundwater recharge, whereas groundwater can also feed rivers and other surface water bodies. Both surface water and groundwater may contain different contaminants that make them unsafe for drinking or aesthetically unacceptable due to unpleasant taste, odour, and appearance. Such contaminants include suspended particles, microbiological pollutants, naturally occurring chemical substances, and pollutants generated through human activities. Therefore, regular monitoring and assessment of groundwater quality are essential for protecting human health and maintaining environmental sustainability. To identify safe drinking water, it is necessary to analyse various physicochemical parameters and compare their measured values with the permissible limits prescribed by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO) [4]. Consumption of contaminated drinking water may result in several waterborne diseases and serious health hazards [5–7]. Water is considered a universal solvent because of its unique physical and chemical properties, which also increase its tendency to dissolve and transport different pollutants.

Water is regarded as polluted when its natural composition or quality changes due to natural processes or human activities, making it unsuitable for drinking, domestic, agricultural, industrial, recreational, wildlife, and other purposes [8]. During the last few decades, groundwater pollution has increased considerably due to rapid industrialization, improper disposal of solid and toxic wastes, and inadequate wastewater management systems [9, 10]. Various hazardous physicochemical substances enter groundwater through the application of agrochemicals, organic residues, irrigation return flows, septic tanks, sewage treatment plants, and infiltration from wastewater storage ponds and lagoons. According to public health estimates, a considerable proportion of diseases worldwide are associated with unsafe drinking water and inadequate sanitation. One of the major difficulties associated with groundwater pollution is that once groundwater becomes contaminated, restoring its original quality is extremely difficult and expensive. Hence, appropriate groundwater quality monitoring, protection, and management strategies are necessary [11]. Water pollution has increased rapidly after industrialization due to population growth, urban expansion, and the excessive use of fertilizers and pesticides in agricultural activities [12–15]. Drinking water safety is affected by several contaminants, including physicochemical and microbiological substances, which may cause serious health problems [16–18]. Globally, increasing awareness regarding water scarcity and the growing demand for freshwater resources have made water quality assessment an important research area. Water resources are under increasing pressure due to the growing requirements of domestic, agricultural, industrial, and hydropower sectors. Therefore, regular monitoring of drinking water quality is necessary to identify contamination and minimize the risks associated with waterborne diseases [19]. Groundwater is a major source of water for domestic, agricultural, and industrial purposes in many countries. India accounts for approximately 2.2% of the global land area, 4% of the world's water resources, and 16% of the world's population (Ramesh and Elango, 2011) [20].

Groundwater quality is influenced by several natural and anthropogenic factors, including local climatic conditions, geological formations, irrigation practices, industrial pollution, and excessive groundwater extraction. Variations in groundwater withdrawal and insufficient rainfall may change the concentration of dissolved salts and other chemical constituents, thereby affecting water quality. Soil and water are two indispensable natural resources, and their proper utilization, conservation, and management are essential for sustainable development (Gagandeep et al., 2017). The indiscriminate use of poor-quality groundwater for agricultural irrigation may deteriorate soil productivity through salinity, solidity, and toxic effects (Chaudhary and Kharche, 2018) [21]. Crop sustainability largely depends on the proper assessment and monitoring of soil and irrigation water quality. Salinity and alkalinity are among the major factors responsible for agricultural land degradation in India, affecting approximately 6.73 million hectares of land (Singh et al., 2009) [22]. The quality of irrigation water is mainly influenced by its mineral composition, soluble solids, and salt concentrations. Excessive concentrations of dissolved salts may adversely affect plant growth and agricultural productivity (Arya et al., 2021) [23]. Therefore, systematic assessment of

groundwater quality is necessary for both drinking and agricultural purposes. The complexity of groundwater quality assessment mainly arises from the large number of physicochemical parameters and their interactions, which significantly influence the overall quality of water resources [24]. Groundwater is the primary source of drinking water in many rural regions of India. However, in several areas, groundwater becomes unsuitable for drinking due to excessive concentrations of fluoride and other chemical constituents. Long-term consumption of fluoride-contaminated water may cause dental and skeletal fluorosis, resulting in serious health complications [25]. Conventional water quality monitoring methods involve the analysis of numerous physicochemical variables, which makes the assessment process time-consuming and complex, particularly when multiple sampling locations are involved [26]. In recent years, Artificial Intelligence (AI) and Machine Learning (ML) techniques have emerged as advanced computational approaches for the assessment, prediction, and classification of groundwater quality. Traditional groundwater quality assessment primarily depends on laboratory-based physicochemical analysis and comparison with standard permissible limits.

Although these methods provide reliable experimental results, analysing large numbers of water quality parameters and identifying complex relationships among them can be challenging. AI and ML techniques provide an effective approach for analysing multidimensional datasets, recognizing hidden patterns, identifying important water quality indicators, and predicting groundwater quality based on experimental observations. Machine Learning algorithms such as Random Forest (RF), Decision Tree (DT), Support Vector Machine (SVM), and Extreme Gradient Boosting (Boost) can be utilized to analyse groundwater quality datasets. These algorithms can establish relationships between physicochemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), calcium, magnesium, sodium, chloride, sulphate, nitrate, and fluoride. Based on these relationships, ML models can be developed to classify groundwater samples according to their drinking water suitability and predict potential variations in water quality. The application of AI/ML techniques also provides opportunities for developing intelligent groundwater quality monitoring systems. Predictive models can help identify locations with potentially poor water quality, recognize the parameters contributing to contamination, and support decision-making regarding appropriate water treatment requirements. Furthermore, integrating laboratory analysis with AI/ML-based computational models can improve the interpretation of experimental results and provide a scientific approach to groundwater resource management. It is estimated that approximately one-third of the world's population uses groundwater for drinking purposes, highlighting the importance of groundwater protection and sustainable management [27]. In India, groundwater quality has become a significant public health concern due to the discharge of untreated or partially treated industrial wastewater, domestic sewage, and agricultural runoff containing fertilizers and pesticides. Inadequate sewage treatment facilities, particularly in rural areas, further increase the possibility of groundwater contamination [28]. Considering the above issues, the present investigation focuses on the physicochemical assessment, AI/ML-based prediction, and classification of groundwater quality in selected villages of Nashik District, Maharashtra. A total of 14 groundwater samples were collected from different villages located adjacent to the river. Fourteen physicochemical water quality parameters were analysed using standard analytical methods, and the Water Quality Index (WQI) was calculated to determine the overall groundwater quality status of each sampling location.

## II. MATERIALS AND METHODS

Fourteen sampling stations were selected from different villages of Nashik District, Maharashtra. The study was undertaken by randomly collecting 14 groundwater samples from dug wells and borewells for physicochemical analysis during November 2025. The samples were collected using pre-cleaned polyethylene plastic bottles. Prior to sample collection, all containers were thoroughly washed and rinsed with the respective groundwater to avoid contamination. The collected samples were immediately transported to the laboratory for further analysis. During the analysis, the temperature was maintained at approximately 27°C. The physicochemical analysis of groundwater samples was carried out using standard analytical procedures. Water quality parameters such

as pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS) were analysed immediately, while other parameters were subsequently analysed in the laboratory. Calcium (Ca) and Magnesium (Mg) were determined titrimetrically using standard EDTA solution. Chloride (Cl) was determined by standard $AgNO_3$ titration, whereas Sodium (Na) concentration was estimated using a flame photometer. All parameters were expressed in milligrams per litre (mg/L), except pH, which was expressed in pH units, and Electrical Conductivity, which was expressed in micro siemens per centimetre (µS/cm) at 25°C. Groundwater samples collected from different locations in the Nashik region were investigated to evaluate their drinking water quality. Total alkalinity was measured by titration with standard 0.1 M HCl using methyl orange and phenolphthalein as indicators [29]. Standard procedures [30–33] involving a conductivity meter, flame photometer, and volumetric analysis were followed for the determination of water quality parameters. All chemicals used for the analysis were of Analytical Reagent (AR) grade. For AI and Machine Learning-based analysis, the experimentally obtained physicochemical data were considered as input parameters for computational analysis. Machine Learning algorithms, including Random Forest, Decision Tree, Support Vector Machine (SVM), and XGBoost, can be employed to analyse the collected dataset, identify relationships among water quality parameters, and classify groundwater quality.

The AI/ML approach can further be used to predict groundwater quality and identify variations in physicochemical characteristics across the selected sampling stations. The model-based assessment can be compared with conventional laboratory results and permissible drinking water standards to evaluate groundwater suitability.

Table 1. Details of Sampling Stations.

| Sampling Code | Sampling Point | Sampling Code | Sampling Point |
|---|---|---|---|
| S-1 | Lahavit | S-8 | Deolaligaon |
| S-2 | Bhagur | S-9 | Samangaon |
| S-3 | Sansari | S-10 | Lohshingve |
| S-4 | Shigvebahula | S-11 | Pathardi |
| S-5 | Shevgedarna | S-12 | Pimpalgaonkhamb |
| S-6 | Belatgawhan | S-13 | Vadner |
| S-7 | Vihitgaon | S-14 | Vanjarwadi |

Table 2. All parameters are in mg/L except pH and Turbidity and EC in µS/cm

| Villages | EC | Tur. | pH | TDS | Total Hardness | Ca | Mg | Cl | Na | K | Fe | F | $SO_4$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lahavit (S1) | 70 | 0.2 | 7.5 | 540 | 420 | 136 | 38 | 18 | 20 | 2 | 0.21 | 0.36 | 45 | 22 |
| Bhagur(S2) | 60 | 0.3 | 7.8 | 367 | 274 | 79 | 24 | 24 | 13 | 1 | 0.17 | 0.12 | 29 | 18 |
| Sansari(S3) | 120 | 0.2 | 8.0 | 392 | 274 | 69 | 79 | 34 | 25 | 2 | 0.17 | 0.38 | 48 | 21 |
| Shigvebahula(S4) | 240 | 0.2 | 8.1 | 413 | 680 | 47 | 39 | 76 | 46 | 3 | 0.15 | 0.25 | 11 | 15 |
| Shevgedarna(S5) | 130 | 0.5 | 7.9 | 588 | 408 | 260 | 34 | 94 | 50 | 4 | 0.15 | 0.21 | 63 | 20 |
| Belatgawan(S6) | 160 | 0.4 | 7.2 | 721 | 392 | 220 | 55 | 80 | 77 | 9 | 0.31 | 0.25 | 26 | 32 |
| Vihitgaon(S7) | 240 | 0.3 | 8.5 | 1120 | 229 | 130 | 63 | 26 | 20 | 6 | 0.62 | 0.25 | 24 | 42 |
| Deolaligaon(S8) | 400 | 0.1 | 8.7 | 1050 | 720 | 168 | 62 | 142 | 49 | 110 | 0.48 | 0.31 | 45 | 31 |
| Samangaon(S9) | 320 | 0.3 | 8 | 867 | 564 | 91 | 81 | 128 | 219 | 60 | 0.13 | 0.47 | 54 | 32 |
| Lohshingve (S10) | 720 | 0.4 | 7.3 | 876 | 880 | 290 | 112 | 290 | 99 | 11 | 0.14 | 0.35 | 59 | 46 |
| Pathrdi(S11) | 310 | 0.2 | 8.2 | 727 | 392 | 310 | 57 | 81 | 79 | 9 | 0.33 | 0.27 | 28 | 33 |
| Pimpalgaonkhamb (S-12) | 180 | 0.3 | 7.2 | 620 | 240 | 146 | 66 | 136 | 44 | 6 | 0.16 | 0.23 | 26 | 32 |
| Vadner(S-13) | 290 | 0.5 | 6.1 | 460 | 310 | 280 | 29 | 340 | 78 | 4 | 0.24 | 0.16 | 42 | 28 |
| Vanjarwadi(S-14) | 90 | 0.4 | 8.2 | 546 | 449 | 59 | 48 | 90 | 56 | 2 | 0.32 | 0.21 | 38 | 49 |

## III. RESULTS

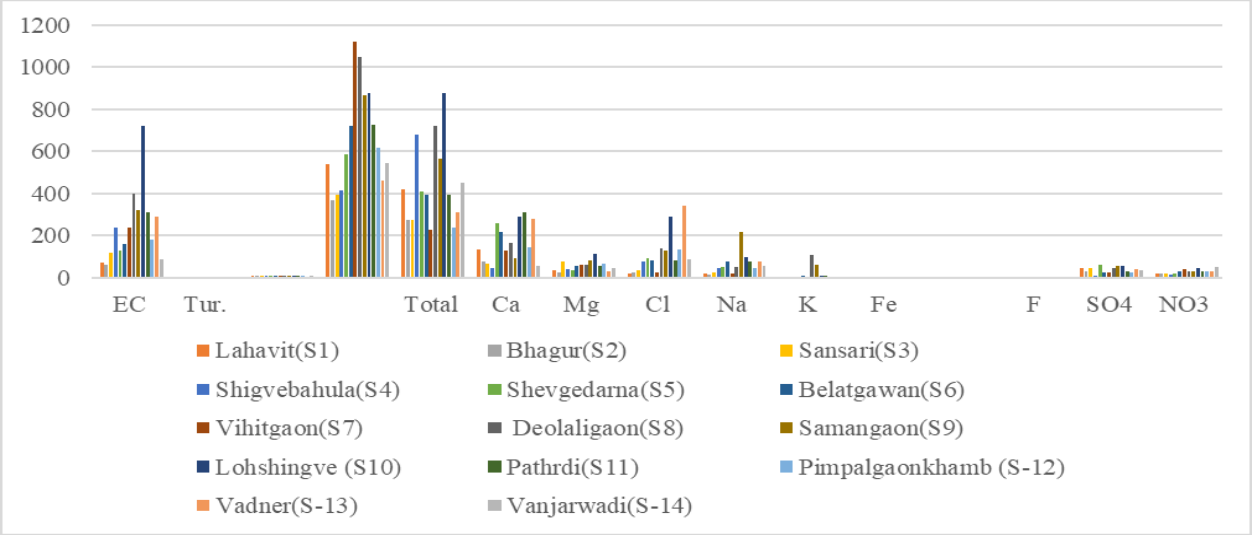
The collected water samples from different sampling stations were colourless and odourless, and the temperature of all water samples was maintained at approximately 27°C. Fourteen groundwater samples were collected from different water sources in Nashik District, including hand pumps, piped water supplies, mini water supply schemes, and open wells. All samples were analysed for various physicochemical parameters. The results of the physicochemical analysis are presented in Table 2, which highlights the critical parameters exceeding the permissible limits prescribed by the Indian Standard Drinking Water Specification (1991) [34]. The obtained experimental results were further considered for AI/ML-based analysis to identify variations in groundwater quality, recognize patterns among physicochemical parameters, and support the prediction and classification of groundwater quality across different sampling stations.

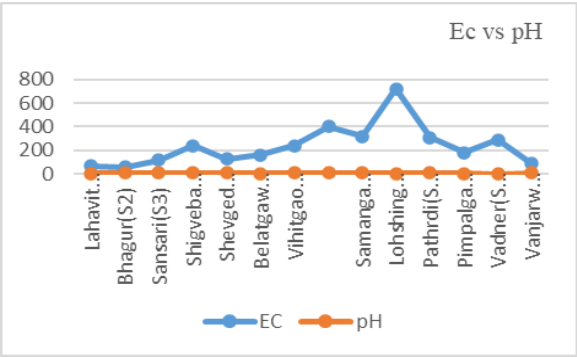
### 3.1. Electrical Conductance

Electrical Conductivity (EC) is an important parameter for evaluating groundwater quality and indicates the concentration of dissolved ionic substances present in water.

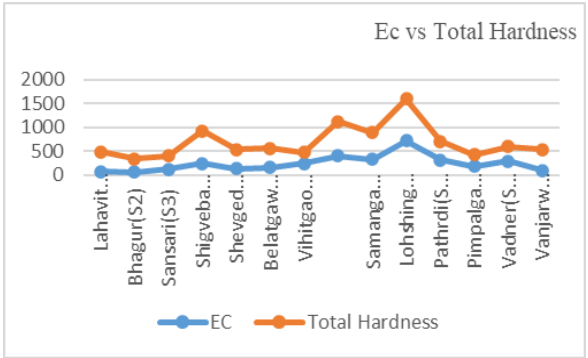
The analysis of groundwater samples collected from different villages in the Nashik region revealed that electrical conductivity values were within or below the permissible limits prescribed by the World Health Organization (WHO), indicating no exceedance of the standard values. The experimentally obtained EC values were also considered as input data for AI/ML-based analysis to examine their relationship with other physicochemical parameters and assess their contribution to groundwater quality prediction and classification.

A graph of various water quality parameters of different villages in Nashik Taluka.

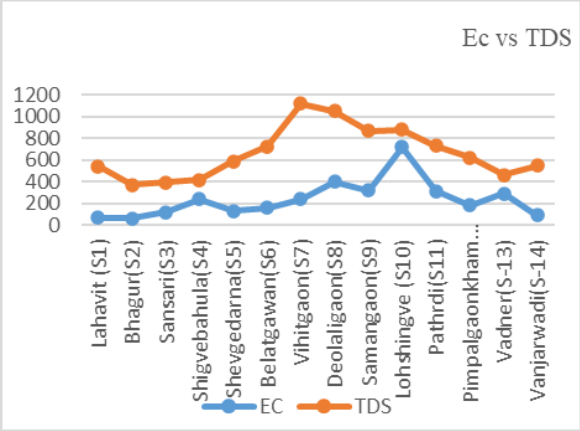


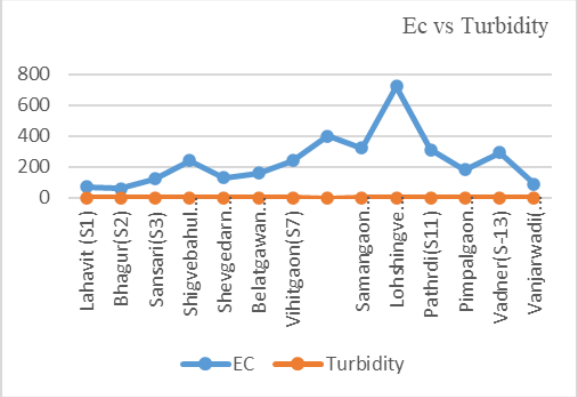

A graph of electrical conductance vs. pH




A graph of electrical conductance vs. Total Hardness




A graph of electrical conductance vs. TDS




A graph of electrical conductance vs. Turbidity

3.2. Turbidity

Turbidity is an important physicochemical parameter that represents the relative clarity of water and plays a significant role in evaluating drinking water quality. High turbidity levels can reduce the aesthetic quality of water and interfere with water treatment processes. Suspended turbidity particles may provide favourable conditions for the survival and growth of pathogenic microorganisms by offering food and shelter, potentially increasing the risk of waterborne diseases. In the present study, turbidity values recorded at all sampling stations were found to be below the permissible limits prescribed by the Indian Standards Institution (ISI) and the World Health Organization (WHO), indicating satisfactory clarity of the groundwater samples. Artificial Intelligence (AI) and Machine Learning (ML) techniques can be utilized to analyse the turbidity data along with other physicochemical parameters to identify hidden patterns, establish relationships, and evaluate their influence on groundwater quality. ML algorithms such as Random Forest, Decision Tree, Support Vector Machine (SVM), and Boost can help assess the contribution of turbidity to groundwater quality prediction and classification. The integration of AI-based analysis with conventional laboratory results provides an intelligent approach for evaluating water quality variations and identifying potential contamination risks across different sampling stations.

3.3. pH

pH is an important physicochemical parameter that indicates the acidic or alkaline nature of water. It is measured on a scale ranging from 0 to 14, where a value of 7 represents neutrality. Values below 7 indicate acidic conditions, while values above pH 7 indicate alkaline conditions. The pH of water reflects the relative concentration of hydrogen ($H^+$) and hydroxyl ($OH^-$) ions present. According to the standards prescribed by the Indian Standards Institution (ISI) and the World Health Organization (WHO), the acceptable pH range for drinking water lies between 6.5 and 8.5. In the present study, the pH values of water samples collected from Vihitgaon and Deolaligaon were found to be 8.5 and 8.7, respectively, indicating alkaline conditions at these locations, with the Deolaligaon sample exceeding the upper recommended limit. These experimentally obtained pH values were further considered as input parameters for AI/ML-based analysis to examine their influence on groundwater quality classification and prediction.

3.4. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is an important parameter that reflects the overall purity of water and represents the combined content of inorganic salts and small quantities of organic matter dissolved in water. The major constituents of TDS typically include cations such as calcium, magnesium, sodium, and potassium, and anions such as carbonate, bicarbonate, chloride, sulphate, and nitrate. The analysis of groundwater samples revealed that TDS concentrations at Vihitgaon (1120 mg/L) and Deolaligaon (1050 mg/L) exceeded the recommended limits, indicating increased dissolved salt concentrations and potentially reduced suitability for drinking purposes. The measured TDS values were also incorporated into the proposed AI/ML-based analytical framework to identify patterns among

dissolved constituents and support groundwater quality prediction and classification.

3.5. Total Hardness

Total hardness of groundwater is primarily attributed to the presence of dissolved calcium and magnesium salts, mainly in the form of carbonates, bicarbonates, sulphates, and chlorides. Analysis of the groundwater samples revealed that the total hardness at Lohshingve (880 mg/L), Deolaligaon (720 mg/L), and Shigvebahula (680 mg/L) exceeded the permissible limits prescribed by the World Health Organization (WHO). These elevated hardness levels indicate significant mineral dissolution and may affect the suitability of groundwater for domestic and drinking purposes. The total hardness values were additionally considered in the AI/ML-based analysis to investigate their relationship with calcium, magnesium, and other physicochemical parameters and to support the prediction and classification of groundwater quality.

3.6. Calcium

Calcium ($Ca^{2+}$) is an essential mineral required for the development and maintenance of bones and teeth, and it plays a vital role in cardiac function, nerve transmission, and blood coagulation. However, excessive concentrations of calcium in drinking water may contribute to increased water hardness and affect its suitability for domestic and drinking purposes. The analysis of groundwater samples from various villages in the Nashik region revealed calcium concentrations exceeding the permissible limits recommended by the World Health Organization (WHO).

Elevated calcium levels were recorded in Shevgedarna (260 mg/L), Belatgavhan (220 mg/L), Lohshingve (290 mg/L), Pathardi (310 mg/L), and Vadner (280 mg/L), indicating potential concerns regarding groundwater quality in these areas. Artificial Intelligence (AI) and Machine Learning (ML) techniques can be applied to analyse calcium concentrations along with other physicochemical parameters to identify their contribution to groundwater hardness and overall water quality. Algorithms such as Random Forest, Decision Tree, Support Vector Machine (SVM), and XGBoost can help identify patterns and predict groundwater quality variations based on calcium concentration and its relationship with other parameters.

3.7. Magnesium

Magnesium ($Mg^{2+}$) is an important mineral constituent of groundwater and a major contributor to water hardness. It plays an essential role in several biological functions; however, its concentration influences the chemical characteristics and suitability of groundwater for drinking purposes. The analysis of groundwater samples from different villages in the Nashik region revealed that magnesium concentrations were within or below the permissible limits prescribed by the World Health Organization (WHO), indicating no exceedance of the recommended standard values. The experimentally obtained magnesium values can also be analysed using AI/ML techniques to examine their relationship with calcium, total hardness, and other physicochemical parameters. Machine Learning models can help identify the contribution of magnesium to groundwater quality variations and improve the classification and prediction of drinking water suitability.

3.8. Chloride

Chloride ($Cl^-$) is an important chemical constituent of groundwater and generally occurs due to the dissolution of chloride-containing minerals, sewage infiltration, agricultural activities, and other anthropogenic sources. Excessive chloride concentrations may affect the taste of drinking water and indicate possible groundwater contamination. The analysis of the investigated water samples revealed that chloride concentrations at Lohshingve (290 mg/L) and Vadner (340 mg/L) exceeded the permissible limits prescribed by the Indian Standards Institution (ISI) and the World Health Organization (WHO), indicating increased chloride content in these locations. AI and ML-based analysis can be utilized to evaluate chloride concentration patterns and identify their relationships with TDS, sodium, and electrical conductivity. Predictive algorithms such as Random Forest and XGBoost can further assist in identifying the influence of chloride on groundwater quality classification and detecting locations with potentially elevated chloride concentrations.

3.9. Sodium

Sodium ($Na^+$) is a naturally occurring cation in groundwater and contributes to its overall chemical composition and dissolved salt concentration. Its concentration may be influenced by geological

formations, mineral dissolution, agricultural activities, and wastewater infiltration. Excessive sodium concentrations may affect drinking water suitability and agricultural irrigation quality. The sodium concentrations in all groundwater samples collected from the Nashik region were found to be below the permissible limits prescribed by the World Health Organization (WHO) and the Indian Standards Institution (ISI), indicating compliance with the recommended standard guidelines. The sodium concentration data can also be incorporated into AI/ML-based computational models to investigate relationships with chloride, electrical conductivity, and total dissolved solids. Machine Learning algorithms can help identify sodium-related variations and evaluate the contribution of sodium to groundwater quality prediction and classification.

3.10. Potassium

Potassium ($K^+$) is an essential mineral that occurs naturally in groundwater due to the weathering of potassium-bearing rocks and minerals. Its concentration may also be influenced by agricultural fertilizers, domestic wastewater, and other environmental sources. The analysis of groundwater samples indicated elevated potassium concentrations at certain locations, with Deolaligaon recording 110 mg/L and Samangaon recording 60 mg/L. These values indicate higher potassium content in these samples compared to other sampling locations, which may influence the overall chemical composition of groundwater. The obtained potassium concentration data can be further examined using AI/ML techniques to identify variations across sampling stations and investigate relationships with other dissolved chemical constituents. Random Forest, Decision Tree, SVM, and XGBoost algorithms can be utilized to determine the contribution of potassium to groundwater quality prediction and classification.

3.11. Iron

Iron (Fe) is a naturally occurring element in groundwater and generally enters water through the weathering and dissolution of iron-bearing minerals. Elevated iron concentrations may cause undesirable taste, colour, and staining of clothes and domestic utensils. The analysis of groundwater samples revealed that iron concentrations in Vihitgaon (0.62 mg/L) and Deolaligaon (0.48 mg/L) exceeded the permissible limits recommended by the World Health Organization (WHO) and the Indian Standards Institution (ISI), indicating elevated iron levels in these locations. AI and ML techniques can be incorporated to analyse iron concentrations in combination with pH, TDS, turbidity, and other physicochemical parameters. These computational models can help identify patterns associated with elevated iron levels, determine the influence of iron on groundwater quality, and support the prediction and classification of groundwater samples according to their drinking water suitability.

3.12. Fluoride

Fluoride ($F^-$) occurs naturally in groundwater through the dissolution of fluoride-bearing minerals and geological formations. At concentrations exceeding recommended limits, prolonged consumption of fluoride-rich water may lead to adverse health effects such as dental fluorosis, skeletal fluorosis, and weakened bones. The World Health Organization (WHO) has established a guideline value of 1.5 mg/L for fluoride in drinking water. Analysis of the groundwater samples in the present study indicated that fluoride concentrations were below the permissible limits, suggesting a lower potential risk of fluoride-related health problems in the sampled areas. The fluoride concentration data can also be incorporated into AI/ML-based models to evaluate its relationship with other physicochemical parameters and identify variations in fluoride distribution across different sampling stations. Machine Learning algorithms can help assess the contribution of fluoride to overall groundwater quality classification and predict potential changes in its concentration.

3.13. Sulphate

Sulphate ($SO_4^{2-}$) is an important chemical constituent of groundwater and contributes to the total dissolved solids (TDS) content. It may occur naturally through the dissolution of sulphate-bearing minerals and can form salts with cations such as sodium, potassium, calcium, and magnesium. Sulphate concentrations in groundwater may range from a few milligrams per litre to several hundred milligrams per litre, depending on geological formations and hydrochemical conditions. Its concentration is an important factor in evaluating groundwater quality and drinking water suitability. AI and ML-based techniques can be applied to analyse

sulphate concentrations along with TDS, calcium, magnesium, and other chemical parameters to identify their interrelationships. Machine Learning models can assist in recognizing sulphate distribution patterns, evaluating its contribution to groundwater quality variations, and supporting predictive classification of groundwater samples.

3.14. Nitrate

Nitrate ($NO_3^-$) is an important groundwater quality parameter that generally enters groundwater through agricultural fertilizers, animal waste, sewage infiltration, and other anthropogenic activities. Excessive nitrate concentrations in drinking water may cause adverse health effects, particularly in infants. The analysis of groundwater samples revealed that nitrate concentrations in Vihitgaon (42 mg/L), Lohshingve (46 mg/L), and Vanjarwadi (49 mg/L) exceeded the permissible limits prescribed by the Indian Standards Institution (ISI), indicating potential groundwater contamination and associated health concerns. AI and ML techniques can be utilized to analyse nitrate concentrations in combination with other physicochemical parameters to identify possible contamination patterns and relationships. Random Forest, Decision Tree, SVM, and XGBoost algorithms can help determine the contribution of nitrate to groundwater quality variations, identify sampling stations with elevated nitrate concentrations, and support AI-based prediction and classification of groundwater drinking suitability.

## IV. CONCLUSION

The physicochemical analysis of groundwater samples in and around the Nashik region reveals that water from all villages is generally suitable for drinking purposes but requires some primary treatment, particularly in the case of S7 and S8, which show high TDS values, and S7, S8, and S10, which exhibit elevated total hardness. From the present study, it can be concluded that groundwater quality in Nashik District is generally satisfactory for drinking purposes; however, proper attention should be given to certain physicochemical parameters to prevent further deterioration of groundwater quality in the future. The integration of Artificial Intelligence (AI) and Machine Learning (ML) techniques, such as Random Forest, Decision Tree, Support Vector Machine (SVM), and Boost, can help analyse the obtained physicochemical dataset, identify relationships among different water quality parameters, and predict groundwater quality variations across the selected villages. This study emphasizes the need for regular groundwater quality monitoring to assess pollution activities and implement appropriate management measures to minimize the intensity of groundwater contamination.

The analysis showed evident variations among the villages, with certain physicochemical parameters exceeding the recommended permissible limits. These differences may be attributed to local geological conditions, agricultural activities, domestic waste discharge, and excessive groundwater exploitation. AI/ML-based analytical approaches can be used to identify these variations, determine important parameters responsible for groundwater quality deterioration, and classify water samples according to their drinking water suitability.

Overall, while some villages showed water quality within acceptable standards, others require immediate attention and regular monitoring. The application of AI-based predictive models can further support early identification of potentially contaminated groundwater sources and assist in developing effective water management strategies. Proper water management practices and community awareness programmes are recommended to ensure safe and sustainable water utilization.

The measures to be taken include:

i) Promoting Rainwater Harvesting:

Rainwater harvesting practices should be encouraged. Excess rainwater should be properly managed through drainage systems and directed into scientifically designed recharge wells. AI/ML-based analysis can help identify groundwater quality variations and support the monitoring of recharge locations.

ii) Promoting Biofertilizers and Biopesticides:

Farmers should be motivated to utilize biofertilizers and biopesticides to prevent contamination of soil, surface water, and groundwater. AI/ML techniques can further help analyse changes in groundwater parameters and identify possible contamination patterns associated with agricultural activities.

ACKNOWLEDGMENT

The author is thankful to Principal, Head of Department of Chemistry S.V.K.T. College Deolali Camp, Nashik for providing all necessary research facilities.

REFERENCES

[1] A. Sargaonkar and V. Deshpande, “Development of an Overall Index of Pollution for Surface Water Based on a General Classification Scheme in Indian Context,” *Environmental Monitoring and Assessment*, vol. 89, no. 1.

[2] A. Abdul Jameel, *Pollution Research*, vol. 17, no. 2, pp. 111–114, 1998.

[3] A. G. Sirkar et al., *Journal of the Indian Water Works Association*, pp. 215–220, Oct.–Dec. 1996.

[4] I. Ustada and G. F. Mustafa, “Assessment of Ground Water Quality in Different Villages of Naldurg, Dist. Osmanabad (M.S.),” Department of Zoology, Sir Sayyed College, Aurangabad, Maharashtra, India, and Department of Chemistry, Sir Sayyed College, Aurangabad, Maharashtra, India.

[5] P. V. Desai, *Pollution Research*, vol. 14, no. 4, pp. 377–382, 1995.

[6] E. E. Muller, M. M. Ehlers, and W. O. K. Grabow, *Water Research*, vol. 35, pp. 3085–3088, 2001.

[7] World Health Organization, *Guidelines for Drinking-Water Quality*, 2nd ed. Geneva, Switzerland: WHO, 1999, pp. 97–100.

[8] J. Sirajudeen, S. Arulmanikandan, and V. Manivel, “Phenomenal influence of effluents released from Uyyakondan channel on groundwater quality in and around Palakarai area, Tiruchirappalli, Tamil Nadu, India,” *Journal of Environmental Research and Development*, vol. 8, no. 2, pp. 299–308, 2013.

[9] K. Ramesh and V. Soorya, “Hydrochemical analysis and evaluation of groundwater quality in and around Hosur, Krishnagiri District, Tamil Nadu, India,” *International Journal of Research in Chemistry and Environment*, pp. 113–122, 2012.

[10] S. Satish Kumar and S. Ravichandran, “Groundwater quality assessment in Cheyyar region,” *International Journal of ChemTech Research*, vol. 3, pp. 1060–1063, 2011.

[11] V. V. Sasane and V. M. Patil, “Assessment of groundwater quality status using NSFWQI,” *International Journal of Advanced Technology in Civil Engineering*, vol. 2, no. 1, 2013.

[12] B. L. Borade et al., “Agricultural land use pattern of Ashti Tahsil in Beed District,” *Shodhankan International Journal*, pp. 41–45, 2012.

[13] D. J. Gadekar, “Level of human resources development in the Akole Tahsil District, Ahmednagar, Maharashtra,” Ph.D. dissertation, Savitribai Phule Pune University, Pune, India, 2018.

[14] D. J. Gadekar, “Regional disparities of agricultural development in Ahmednagar District, Maharashtra, India,” *International Journal of Research in Social Sciences*, vol. 6, no. 8, pp. 389–403, 2016.

[15] D. J. Gadekar, “A study of chemical characteristic of Pravara River in different sites, Ahmednagar District, Maharashtra, India,” *Our Heritage*, vol. 68, no. 1, pp. 4977–4988, 2020.

[16] C. V. Wagh, “Physico-chemical analysis of groundwater in Pravara area, District Ahmednagar, Maharashtra,” *Rasayan Journal of Chemistry*, vol. 2, no. 1, pp. 234–242, 2009.

[17] D. J. Gadekar, “A study of chemical characteristic of Pravara River in different sites, Ahmednagar District, Maharashtra, India,” *Our Heritage*, vol. 68, no. 1, pp. 4977–4988, 2020.

[18] S. Karthick et al., “A study on assessment of physicochemical properties of water and wastewater,” *International Journal of Engineering Science and Innovative Technology*, vol. 4, no. 2, pp. 173–177, 2015.

[19] P. M. Makode, “Physico-chemical parameters of Charghad Dam, District Amravati, Maharashtra,” *International Journal of Science Innovations and Discoveries*, vol. 2, no. 1, pp. 164–169, 2012.

[20] K. Ramesh and L. Elango, “Groundwater quality and its suitability for domestic and agricultural use in Tondiar River basin, Tamil Nadu, India,” *Environmental Monitoring and Assessment*, 2011, doi: 10.1007/s10661-011-2231-3.

[21] O. Choudhary and V. Kharche, “Soil salinity and sodicity,” in *Soil Science: An Introduction*, 2018, pp. 353–384.

[22] A. K. Singh, A. Qadar, and N. P. S. Yaduvansh, *Mineral Nutrition of Crop Plants in Salt-Affected*

*Areas in India*. Karnal, India: CSSRI, ICAR, 2009.

[23] S. Arya, T. Subramani, G. Vennila, and D. Karunanidhi, “Health risks associated with fluoride intake from rural drinking water supply and inverse mass balance modeling to decipher hydrogeochemical processes in Vattamalaikarai River basin, South India,” *Environmental Geochemistry and Health*, vol. 43, pp. 705–716, 2021, doi: 10.1007/s10653-019-00489-y.

[24] “The chlorides, alkalinity, hardness, TDS and electrical conductivity are found to exceed the limits.”

[25] H. S. Horowitz and S. B. Heifetz, “Effects of prenatal exposure to fluoridation on dental caries,” *Public Health Reports*, vol. 82, pp. 297–304, 1967.

[26] K. Saffran, “Canadian water quality guidelines for the protection of aquatic life,” *CCME Water Quality Index 1.0: User’s Manual*, excerpt from Publication No. 1299, 2001.

[27] A. Mohrir, D. S. Ramteke, C. A. Moghe, S. R. Wate, and R. Sarin, “Surface and groundwater quality assessment in Bina region,” *Indian Journal of Environmental Protection*, vol. 22, no. 9, pp. 961–969, 2002.

[28] A. Hamoudi, M. Jeuland, S. Lombardo, S. Patil, S. K. Pattanayak, and S. Rai, “The effect of water quality testing on household behavior: Evidence from an experiment in rural India,” *The American Journal of Tropical Medicine and Hygiene*, vol. 87, no. 1, pp. 18–22, 2012.

[29] *IS 10500: Indian Standard for Drinking Water*, pp. 1–9, 1991.

[30] S. Nagarajan, M. Swaminathan, and P. L. Sabarathinam, *Pollution Research*, vol. 12, no. 4, p. 245, 1993.

[31] M. Hussain, T. V. D. P. Rao, H. A. Khan, and M. Satyanarayan, *Oriental Journal of Chemistry*, vol. 27, no. 4, pp. 1679–1684, 2011.

[32] A. Malviya, S. K. Diwakar, and S. O. N. Choubey, *Oriental Journal of Chemistry*, vol. 26, no. 1, pp. 319–323, 2010.

[33] V. Magarde, S. A. Iqbal, S. Pani, and N. Iqbal, *Oriental Journal of Chemistry*, vol. 26, no. 4, pp. 1473–1477, 2010.

[34] APHA, *Standard Methods for the Examination of Water and Wastewater*, 19th ed., 1996.