Machine Learning Based Prediction of Groundwater Quality for Sustainable Organic Farming in Palnadu District Andhra Pradesh

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Abstract

Water is the main source to any livelihood on this Earth and plays vital role in our daily routine for hygiene and sustainability of any living organism. Due to the increase of global warming every part of the globe has been facing the water scarcity in the layers of Earth. Our main aim is to predict the quality of ground water for sustainable organic farming using GIS Mapping and Machine Learning models in Palnadu region of Andhra Pradesh. The main research has been focused initially on 3 mandals named as Achampeta, Sattenapalle and Rentachinthala ground water, using the concentration of levels of pH , Chloride, Fluoride , Sulphate ,Nitrate, Sodium, Magnesium , Potassium, Calcium , total hardness of CaCo3, particles presents in the ground water in Palnadu region using machine leaning models whether it is useful for sustainable organic farming , drinking water need not be used for irrigation and farming always similarly , irrigation water is not suitable as drinking water, in this regard this research mainly focus on prediction of ground water , especially the quality of groundwater in the 3 mandals initially can be taken from bores, wells, rivers suitable for long and sustainable organic farming used for future generations.

Keywords: ground water, pH, nitrate, machine learning, GIS mapping, geology, drinking water, organic farming, livelihood, Potassium, Fertiliser.

1.Introduction:

Ground Water is the primary source of livelihood of any living being on this Earth Kumar et al., 2024. That plays a vital role for our day-to-day activities. It takes the major part in our daily activities of human, and being an Indian we need more water for not only our activities but also for the surveillance since our country mostly depend on farming Scanlon et al., 2023. In this regard the estimation and prediction of ground water quality, especially in some regions of Andhra Pradesh. Water is crucial not only for both domestic surveillance and hygiene but also for sustaining agricultural productivity, which forms the economic backbone of the nation.

Since it is a semi-arid tropical region , we have low source of water due to low rainfall Pappaka et al., 2025. Study has been focusing on the Palnadu region of

Andhra Pradesh suitable for long and sustainable organic farming which is chemical free that maintains the good quality and health of living beings. Over-exploitation, natural mineral weathering, and agrochemical runoff often lead to high electrical conductivity, elevated total dissolved solids (TDS), and localized contamination such as nitrate leaching and sodicity hazards Pavan et al., 2023, Sanad et al., 2025.

Therefore, evaluating and predicting groundwater quality is essential for sustainable water management. Recent studies have combined GIS with machine learning to predict irrigation water quality: KNN, RF, SVR and GPR models were used to predict SAR, Na%, PI and PS, with SVR performing best Mohammed et al., 2023, and RF, SVM and XGBoost models were used to predict the irrigation water quality index (IWQI) in Haryana, with XGBoost performing best Raheja et al., 2024. This study focuses on the Palnadu region of Andhra Pradesh to assess whether local groundwater is suitable for long-term organic farming.

1.1 Background of Groundwater Resources

Sattenapalle, Achampet and Rentachintala are three mandals in Palnadu district, where most people depend on groundwater for drinking and farming. Across the district the water table is usually shallow: before the monsoon it lies between less than 1 m and 17 m below the ground, with an average of about 4.73 m. Of the 28 mandals, only Veldurthi is over-exploited and Bollapalle is critical, while the remaining 26 are considered safe. Water quality is the bigger concern, as Palnadu ranks 8th in India for high nitrate, with 36% of 70 tested samples above the safe level. In Sattenapalle mandal, one study found fluoride ranging from 1.3 to 12.9 mg/L, with 75% of the sampling points above the safe drinking limit of 1.5 mg/L. In Achampet mandal, groundwater is moderately to highly mineralised: between 2015 and 2023, TDS ranged from about 154 to 3,500 mg/L, and nearly all samples were above the 500 mg/L desirable limit. Rentachintala mandal is generally less saline than Achampet, with TDS ranging from about 317 to 1,258 mg/L and none of the samples exceeding 2,000 mg/L.

1.2 Groundwater Quality Assessment Parameters

The level of groundwater is more important to know for drinking and farming in Andhra Pradesh since it mostly depends on agriculture, similarly the quality of ground water is also more important that particles. Using the parameter of pH, Chloride, Fluoride, Sulphate, Nitrate, Sodium, Magnesium, Potassium, Calcium, total hardness of CaCo3. The study aims to assess the ground water quality in selected mandals of Palnadu district in Andhra Pradesh where agricultural activities predominantly depend on groundwater. Particular emphasis depends on the cultivation of commercial crops due to low rain fall which increases the demand for irrigation. The study evaluates the physio-chemical characteristics of groundwater and examines its suitability for sustainable organic farming from the year 2025 to 2030.

Parameters for Ground Water for farming are Sodium (Na) measured as 22.99 mg/L, Potassium(K) values at 39.10 mg/L, Calcium (Ca) measured as 20.04 mg/L, Magnesium (Mg) measured as 12.15 mg/L, Chloride (Cl) measured as 35.45 mg/L, Sodium (SO4) measured as 48.03 mg/L, HCO3 measured as 61.02(use 50.04 if the value reported as CaCo3), CO3 measured as 30.00 mg/L

Parameters for Drinking water quality used to measure the quality of ground water are pH value ranges from 6.5 to 8.5, TDS Total Depth of Soil ranges from 500/800 mg/L, Total hardness ranges from 200/600 mg/L, Chloride ranges from 250/1000 mg/L, Sulphate ranges from 200/400 mg/L, Fluoride ranges from 1.0/1.5 mg/L and Nitrate levels ranges are 45 mg/L.

1.3 Machine Learning Methods:

Machine Learning is partially the branch of Artificial Intelligence and broadly of Data Science that predicts hidden patterns existed in the data. There are 3 types of machine learning algorithms. Supervised, Unsupervised, Re-enforcement and Semi-Supervised algorithms used for both classification and regression of data. The study has made by using 2 Classification algorithms such as Random Forest Machine Learning and Support Vector Machine Learning algorithm.

1.3.1 Random Forest Machine Learning Algorithm:

Data is the information that describing any physical entity. In the study the ground water samples collected from the 169 villages across 3 mandals namely Achampeta, Sattenapalli and Rentachintala mandals treated as data samples by machine learning algorithm.

Random Forest Algorithm is a classification machine learning algorithm used to classify the data which is a combination of multiple decision trees and works on the basis of majority of voting (outcomes /predictions) comes from the multiple trees.

Representation of Random Forest Algorithm as in the Figure 1 below.

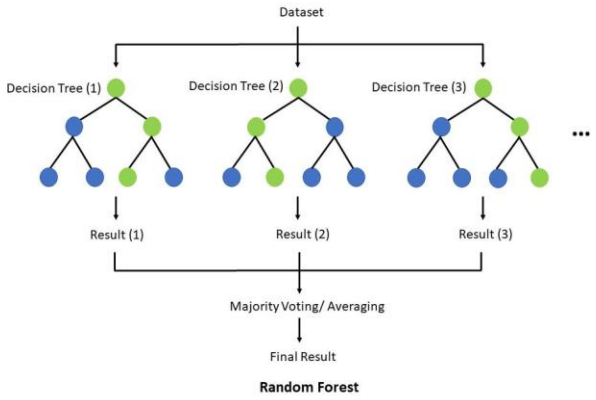


Figure.1 Dataset represents the ground water samples collected from 3 mandals, Decision Tree (1) represents IWQI category (1), Decision Tree (2) represents IWQI category (2) and Decision Tree (3) represents IWQI category (3) mentioned in the dataset. Result (1), Result (2), Result (3) specifies the outcomes of category from those Decision Trees respectively.

Random Forest uses multiple Decision Trees, and a Decision Tree selects the best feature to divide the water samples collected from various sources

represented as data points as a branch of decision tree. The common splitting criterion is Gini Impurity. A pure Gini represents the pure class, means the observations are more clearly belongs to specific class. It uses the mathematical formula Gini Impurity.

Gini Impurity

$$Gini(D) = 1 - \sum_{i=1}^{K} p_i^2$$

D=Dataset at particular tree node
pi =Proportion of observations belong to class,$K = Number\ of classes$

1.3.2 Support Vector Machine Algorithm:

Support Vector Machine is a supervised classification algorithm that uses the best hyper plane that divides the classes using best boundary line also called as maximum margin hyperplane shown in Figure 2, the closest observations called as supporting vectors. The algorithm will work based on

1.1. Decision Function (Hyperplane)

$f(x) = w^T x + b$, where
$x = input\ feature, w = weight\ vector$,
$b = bias\ term$,
Prediction: $\hat{y} = \text{sign}(w^T x + b)$

1.2. Hard-Margin SVM (Linearly Separable Data)

Marginwidth:

$$\text{Margin} = \frac{2}{\|\mathbf{w}\|}$$

Where $\|\mathbf{w}\| = \sqrt{w_1^2 + \cdots + w_p^2}$. A smaller $\|\mathbf{w}\|$ gives a wider margin.

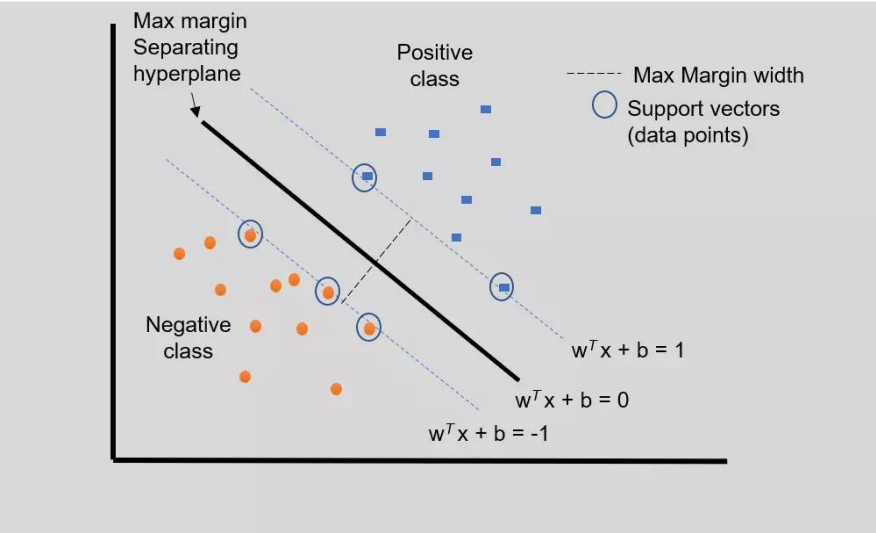


Figure.2 Support Vector Machine algorithm working process, orange dots represents the negative class belongs to IWQI category1 and blue squares represents positive class belongs to IWQI category2, maximum margin is separating the both classes in a clear manner that calculating the distance between maximum separating line and supporting lines (called as vectors) from each class.

1.3.3 Calculation of Water Quality Index (WQI)

This is the weighted arithmetic method (Brown et al., 1972), used with the BIS 10500 or WHO drinking-water limits. considers the relative weight of each parameter quality and quality range of each parameter

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

Where w_i is the weight assigned to parameter i (1 to 5) according to its health importance, and $n$is the number of parameters.

$$q_i = \frac{C_i}{S_i} \times 100$$

where $C_i$is the measured concentration in the sample and S_i is the drinking-water standard (BIS 10500 or WHO) for that parameter.

For pH, the ideal value of 7, use

$$q_{pH} = \frac{C_{pH} - 7.0}{S_{pH} - 7.0} \times 100$$

Sub-index

$$SI_i = W_i \times q_i$$

Calculating Water Quality Index (WQI)

$$\text{WQI} = \sum_{i=1}^{n} S\,I_i = \sum_{i=1}^{n} W_i\ q_i$$

Table 1: Water Quality Index (WQI) for Drinking water using the parameter pH

WQI	Class
Below 50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
Above 300	Unfit for Drinking

1.3.4 Calculating Irrigation Water Quality Index (IWQI) used for Farming

Quality measurement using the parameters

$$q_i = q_{\max} - \frac{(x_{ij} - x_{\inf}) \times q_{amp}}{x_{amp}}$$

Where,
x_{ij} is the measured value of parameter i
$x_{\inf}$is the lower limit of the class the value falls in,
$q_{\max}$ is the highest $q$of that class,
q_{amp} is the range of $q$in that class (for example \$100-85=15\$),
x_{amp} is the range of the parameter in that class. For the open top class, the largest observed value is used as the upper end.

Calculating Weighted Sum using the formula

$$\text{IWQI} = \sum_{i=1}^{5} w_i \; q_i$$

Weights from principal component analysis, they sum to 1)

Table 2: Irrigation sustainability using the parameters with ranges

Parameter	EC	Na+	HCO_3^-	Cl^-	SAR
w_i	0.211	0.204	0.202	0.194	0.189

Sodium Absorption Ration (SAR) concentration is meg/L

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}$$

Table 3: Parameters limit for each q_i class (EC in µS/cm; Na, Cl and HCO_3 in meq/L):

q_i range	EC	Na^+	Cl^-	HCO_3^-	SAR
85-100	200 – 750	2 – 3	1 – 4	1 – 1.5	2 – 3
60-85	750-1000	3 – 6	4 – 7	1.5 – 4.5	3 – 6
35-60	1500 -3000	6 – 9	7 – 10	4.5 – 8.5	6 – 12
0-35	< 200 or ≥ 3000	< 2 or ≥ 9	< 1 or ≥ 10	< 1 or ≥ 8.5	< 2 or ≥ 12

Table 4: Classification for Irrigation

IWQI	Restriction on use
85-100	No restriction
70-85	Low restriction
55-70	Moderate restriction
40-55	High restriction

0-40	Severe restriction

Unit conversions used for the calculation:

$$\text{meq/L} = \frac{\text{mg/L}}{\text{equivalent weight}}, \quad \text{Na: } 22.99,\ \text{Cl: } 35.45,\ \text{Ca: } 20.04,\ \text{Mg: } 12.15$$

2.Study Area

This study has made on the Palnadu District existed in the tropical region of Andhra Pradesh. The southwest monsoon runs from June to September, the northeast monsoon from October to December, and May is the hottest month with an average maximum of about 40°C. The average lowest temperature is about 18.6°C in January[cgwb].The study area has a tropical climate and the nature of rocks and geographical elements in Palnadu area with a strong hot summer up to about 40°C.The geographical representation of my study area in Indian map followed by Andhra Pradesh map. The geographical representation of using latitude and longitude shown in the Table 5.

Table 5: Spatial Extent of the study area

Mandal	Latitude	Longitude
Achampeta	16.6303° N / 16° 37' 49" N	80.1219° E / 80° 07' 19" E
Sattenapalli	16.3946° N / 16° 23' 41" N	80.1491° E / 80° 08' 57" E
Renatchintala	16.5525° N / 16° 33' 09" N	79.5533° E / 79° 33' 12" E

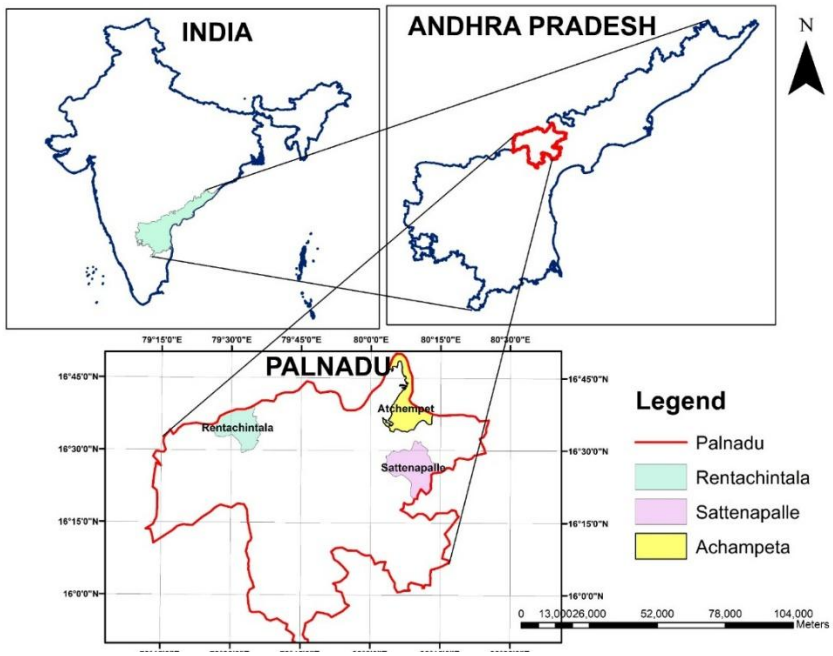


Figure.3 Location map of the study area of Achampeta, Sattenapalli and Rentachintala in Palnadu district in Andhra Pradesh. India Map) Southern part of India, Andhra Pradesh Map) Coastal Region of Andhra Pradesh, Palnadu Map) Semi-arid tropical region

2. 1 Geology and hydrogeology:

Rock units. Archean granitic gneiss and granite cover about 30% of the district and charnockite 8%, overlain by Kurnool and Cuddapah metasediments (58%). cgwb

Mandal-specific. The Narji limestone, which belongs to the Kurnool group, occurs in and around Rentachintala among other mandals. Cumbum shales form a domal structure near Nakrekallu and Achampeta. This agrees with your wells (limestone at Rentachintala, shale at Madipadu). cgwb Aquifers. There are two aquifer units. Aquifer I is the weathered zone, usually 10–20 m thick. Aquifer II is the fractured zone, reaching about 192 m, with most fractures within 100 m. Yields are generally below 1 to 6 lps. cgwb. Water levels. Pre-monsoon depth to water averages 4.73 m and post-monsoon averages 4.24 m. Most monitoring wells show a seasonal rise of up to 6.3 m, and 59% of wells show a falling pre-monsoon trend over 2013–2022. Shallow post-monsoon water levels occur in pockets of Atchampet and Rentachintala. Quality context. High EC (above 3,000 µS/cm) occurs in an extended area in Atchampet and Sattenapalle. Fluoride is highest in areas of banded gneiss, so it is mainly geogenic, and high nitrate is linked to sewage and fertiliser.

3.Model Setup and Statistical Performance Indicators

The machine learning models were developed to assess and predict the quality of ground water across 3 mandals in Palnadu district in Andhra Pradesh for irrigation sustainability from 2025 to 2030 depending upon the historical data from 2013 to 2025.The collected data samples used for preprocessing before training the machine learning model on the data samples including cleaning of missing values , normalization and feature selection using Random Forest and Support Vector Machine (SVM) algorithms to classify more supporting regions for high sustainable organic farming.

3.1 Statistical Performance Indicators

Statistical performance of machine learning models explains the performance and accuracy of algorithms using the parameters Precision, F1-score, Recall, Accuracy and Confusion matrix. Accuracy measures the proportion of correctly classified groundwater samples among the total number of samples evaluated. Mathematical formula of Accuracy is as follows

Precision measures the proportion of correctly predicted positive ground water suitability samples among all samples predicted as positive.

Recall also called as Sensitivity measures the ability of classification model to correctly identify actual positive ground water suitability samples.

F1-Score measures the harmonic mean of precision and recall and provides the balanced evaluation of classification performance of the machine learning model. A confusion matrix is used to evaluate the classification performance

by comparing actual groundwater suitability categories with the predicted categories. It identifies correctly classified and incorrectly classified groundwater samples across different suitability levels.

4.Result and discussion

The groundwater quality assessment across Achampet, Sattenapalli and Rentachintala mandals revealed variations in geographical and physical characteristics. These variations indicate differences in groundwater suitability for agricultural applications. The observations made among the 3 mandals are different from one another. The rocks, aquifers and weather conditions including water levels and monsoons are more differs from one another as mentioned in materials and methods. Testing the parameters of particles present in the collected ground water samples using the resulting the nature of ground water across these 3 mandals in ranges separately and performed the study in the laboratory with the tools.

Digital pH Meter to test the levels of pH, Electrical Conductivity Meter to test EC to identify the dissolved ions. TDS meter to test the dissolved solids in water. Titration Apparatus to determine alkalinity and hardness. To predict the ground water quality of palnadu district using GIS Mapping and Machine Learning models, here I have chosen Random Forest Algorithm and Support Vector Machine (SVM) algorithm from machine learning predicts the quality in several ways.

The results after applying the Random Forest Algorithm classifies the data into 3 major categories as IWQI stated in Table 4 explains the quality of ground water suitable for sustainable organic farming i.e., No restrictions states the ground water is suitable for all types of crops, Moderate restriction states the ground water is useful for non-slaty crops categorizes into IWQI category 1 that are represented in the graphs produced by Random Forest classification algorithm and IWQI category 2 states that area is suitable for commercial crops which needs less rainfall. Support Vector Machine (SVM) algorithm classifies the groundwater samples across 69 villages across 3 mandals classified into 3 major categories as IWQI category1, IWQI category2 and IWQI category3 depending upon the ranges in Table 4. Both algorithms have worked to classify the more suitable region of Andhra Pradesh palnadu region.

Random Forest machine learning algorithm and Support Vector Machine algorithm trained on 169 ground water samples across unique 16 villages across Achampeta, Sattenapalli and Rentachintala mandals. In this regard Achampeta mandal more suitable for sustainable organic farming in future from 2025 to 2030. The study has used the data from 2023 to 2025 , 80% of ground water samples used to training the both machine learning models and 20% of the ground water samples collected from various sources such as naturally formed bore-wells and ponds in used for testing that are not trained by the model at first step. After this step, the same models predict the future sustainability of that ground water resulting says ground water in Rentachintala mandal is more suitable for long and sustainable organic farming in 2025 to 2030. Where as Sattenapalli and Achampeta is less useful depending on particles present in water.

The study has made on 169 ground water samples from 16 villages collected from multiple natural wells, pumping bores, ponds and rivers in Atchampeta, Konduru, Konuru, Madipadu, Taduvoy, Gogulapadu, Karlakunta H/o Dasaripalem, Marrichetlapalem H/O Vipparla, Rompicherla, Santhagudipadu, Subbaiahpalem H/o turumella, Kattamuru, Komerapudi, Panidam, Rentapalla, Sattenapally and Rentachintala. The results produced by Random Forest algorithm shown in Figure 4 and Figure 5.

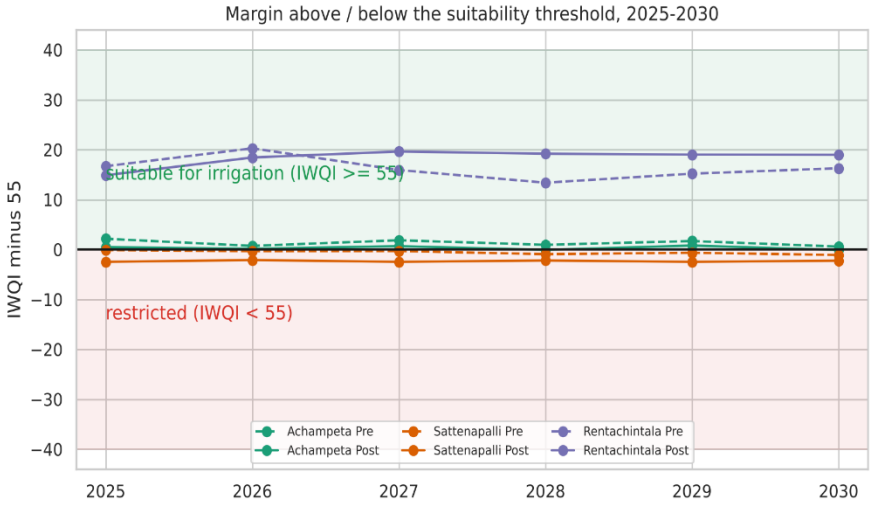


Figure.4 explains the prediction of ground water quality for sustainable organic farming from the year 2025 to 2030. IWQI stated in Table 4 the area under pale red region (negative class) is less suitable for farming and the area under green region (positive class) is more suitable for sustainable organic farming.

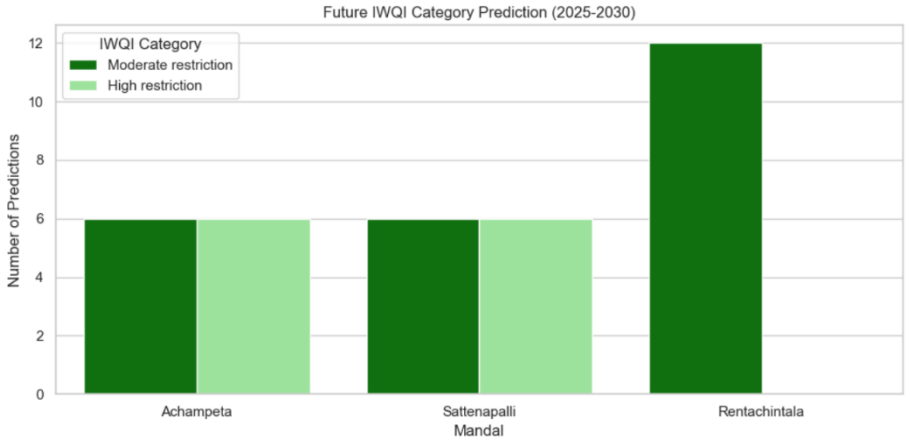


Figure.5 performs the study over the 169 ground water data samples from across 3 mandals and resulting Rentachintala is supporting for sustainable organic farming from 2025 to 2030.

Note: While comparing the results from both algorithms, Random Forest Algorithm in both Historical analysis and Future Forecasting is working more accurately than Support Vector Machine algorithm.

Conclusion

Performed the study on ground water and test the quality of ground water using GIS Mapping and Machine Learning models across Achempeta, Sattenapalle and Rentachintala mandals in Planadu district since it is existed in the semi-arid region of Andhra Pradesh there is a possibility of low rainfall. The study finds that the ground water available in 2025 to 2030 is suitable for non-salty crops based on IQWI classification. After collecting the samples from these areas, trained the machine learning models and by considering the ions and metals (pH, TDS, Sodium, calcium, potassium, SO4, CaCo3, pre-monsoon and post-monsoon) as input features and evaluated the model performance. Random Forest Algorithm predicts the best findings of regions rather than Support Vector Machine algorithm. GIS Mapping helps to locate the actual region of these 3 mandals in Palnadu district in Andhra Pradesh and India map using the latitude and longitudes gathered from the data sources.

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