The Assessment and Predictive Analysis of Factors Influencing EU Countries' Bathing Water Quality

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Abstract. The issue of water quality in the Seine River during the Paris Olympics has again drawn significant attention to the importance of bathing water quality. As bathing water is a critical concern for the health and safety of residents and tourists across the EU, it is essential to understand the factors influencing its condition. In this study, we will explore how bathing water quality in EU countries is affected by six specific factors: CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade. Through the random Forest Regression Analysis, the results show that rainfall is the main factor affecting the quality of both inland and coastal bathing water, wastewater treatment is the least influential factor for coastal bathing water quality, and the average temperature is the least influential factor for inland bathing water quality. By time series forecasting analysis to predict the bathing water quality of nine countries for the next ten years, 2023 to 2032, and compare the data about 2023 bathing water quality, knowing that Poland, Denmark and the Netherlands may have higher predicted water quality than reality.

Keywords: Environmental Quality Assessment; Bathing Water Quality; Random Forest Regression; Time Series Forecasting

1 Introduction

With the conclusion of the 33rd Summer Olympic Games hosted by France, a wave of negative media coverage on the Seine River's water quality and its impact on athletes' health has brought the issue of bathing water quality to the forefront. Based on the geographical environment of Europe, compared to other landmasses, Europe has an abundance of open water bodies and a winding coastline, along with a relatively developed tourism industry. The quality of bathing water is closely related to the environmental quality of open water bodies such as seas and lakes. Low-quality bathing water can lead to ecological imbalance in the region, resulting in environmental degradation, a decline in biomass productivity, and a reduction in biodiversity, with irreversible and severe consequences [1]. For humans, the quality of bathing water is also directly connected to the health of residents and tourists. Prolonged exposure to high levels of E. coli can lead to severe diarrhoea, inflammatory infections, and, in extreme cases, may even result in death [2]. That's why unsafe bathing water should be

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promptly disclosed, with warnings issued to tourists and residents to prohibit entry into the water.

Additionally, efforts should be made to improve its quality to enhance the overall environmental condition and prevent any adverse effects on the health of residents or tourists. Due to the dual impact on the environment and human health, bathing water should be subject to stricter and more standardised monitoring and evaluation criteria [3]. By establishing measurable standards, we can better protect the environment, as well as the health of tourists and residents. However, according to existing literature, we can only observe the changes in bathing water quality within EU countries [4]. Numerous factors influence the quality of bathing water. Although the charts clearly show that an increase in the concentration of E. coli and intestinal enterococci leads to a significant decline in bathing water quality, at its core, the quality of bathing water and the concentration of E. coli and intestinal enterococci are still more heavily influenced by environmental factors and human activities [5].

In this research, we will focus on six specific factors: CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade to study their respective impacts on bathing water quality. CO_2 emissions are closely linked to climate change, which can affect water temperatures and ecosystems, potentially leading to increased bacterial growth or changes in water chemistry. Tourism GDP represents the scale of tourism activities, which can exert pressure on local water resources, leading to higher pollution levels from increased human activity [6]. Average temperature directly influences water quality by affecting microbial growth rates and the overall health of aquatic ecosystems. Rainfall is critical in bathing water quality, as heavy rainfall can increase surface runoff, washing pollutants from urban and agricultural areas into water bodies [7]. The number of tourists can intensify the demand for water resources and lead to increased waste discharge, degrading water quality. Lastly, the grade of wastewater treatment determines the efficiency of pollutant removal from sewage, with higher-grade treatments ensuring better protection of water quality by minimising harmful contaminants from entering natural water bodies [8].

In summary, the purpose of this paper is to analyse the impact of six factors, including CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade, on the quality of bathing water and to assess whether their effects differ between coastal and inland regions in various countries. This study will rely heavily on existing data to provide recommendations and hypotheses that can help national environmental agencies better plan preventive measures for specific water bodies rather than reacting after test results reveal issues that require remediation.

2 Methodology

2.1 Data Source

Bathing water quality is based on the European Economic Area (EEA) database (State of bathing water: fact sheets | European Environment Agency's home page (europa.eu)). EEA classified bathing water into five classes: Excellent, Good, Sufficient, Poor, and Not Classified. All the test samples of bathing water are chosen from the inland and coastal parts of a certain country. This rating standard follows the grading system outlined in the table 1 and table 2 below.

Table 1. Bathing water quality standard (for inland).

	Parameter	Excellent quality	Good quality	Sufficient	Reference methods of analysis
1	Intestinal enterococci (cfu/100 ml)	200	400	330	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	500	1 000	900	ISO 9308-3 or ISO 9308-1

Table 2. Bathing water quality standard (for coastal).

	Parameter	Excellent quality	Good quality	Sufficient	Reference methods of analysis
1	Intestinal enterococci (cfu/100 ml)	100	200	185	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	250	500	500	ISO 9308-3 or ISO 9308-1

[a] Notes: The EEA has also specified the calculation standards for bathing water quality.

[b] Take the $\log_{10}$ value of all bacterial enumerations in the data sequence to be evaluated. (If a zero value is obtained, take the $\log_{10}$ value of the minimum detection limit of the analytical method used instead.)

[c] Calculate the arithmetic mean of the $\log_{10}$ values (μ).

[d] Calculate the standard deviation of the $\log_{10}$ values (σ).

The data of CO_2 emissions is based on GHG emissions of all world countries, 2023 Report. (EDGAR - The Emissions Database for Global Atmospheric Research (europa.eu)). The EU classifies the specific CO_2 emissions accurately to each country, which contain categories such as: power industry, industrial combustion and processes, buildings, transport, fuel exploitation, agriculture and waste.

The data of Tourism GDP is based on Tourism Revenue by Country Comparison. ([Up-to-Date] Denmark Tourism Revenue [Data & Charts], 1995 - 2024| CEIC Data) CEIC classifies the revenue difference from countries, and provides data per year, from 2015 to 2020, using units as million dollars.

The data of tourists is based on Air passenger transport by type of schedule, transport coverage and country. (Statistics | Eurostat (europa.eu)). The EU classifies the number of tourists as total transport per year, calculated as the total passenger carried, and specifies them as each country in the EU.

The data of average temperature is based on Monthly average surface temperatures by year.(Monthly average surface temperatures by year (ourworldindata.org)). Our world in data measures the temperature of the air 2 metres above the ground, encompassing land, sea, and in-land water surfaces, and specific them into different countries in the world per month.

The data of rainfall is based on Average annual precipitation. (Average annual precipitation (ourworldindata.org)). Our world in data measures the rainfall precipitation in millimetres per year. Precipitation is defined as any kind of water that falls from clouds as a liquid or a solid. The data is recorded from 1961 to 2020 and measured as average rainfall in the certain country.

The data of wastewater treatment is based on Wastewater treatment. (Wastewater treatment | Environmental Performance Index (yale.edu)). EPI measured the data as the proportion of wastewater that undergoes at least primary treatment in each country, multiplied by the proportion of the population connected to a wastewater collection system. And it's different from each country in the world.

2.2 Data Analysis

Figure 1 shows the overall bathing water quality in EU countries for 2022, based on the six influencing factors mentioned earlier: CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade. Following the EEA's grading criteria, the four categories of bathing water quality, "Excellent," "Good," "Sufficient," and "Poor" were assigned scores of 10, 7, 4, and 1, respectively. The graph was created by calculating the proportion of each quality category in the bathing water data disclosed by EEA for 2022 and applying the corresponding scores for each EU country. In countries not marked on the graph, the six influencing factors could not be fully identified, meaning that the corresponding data impacts could not be determined.

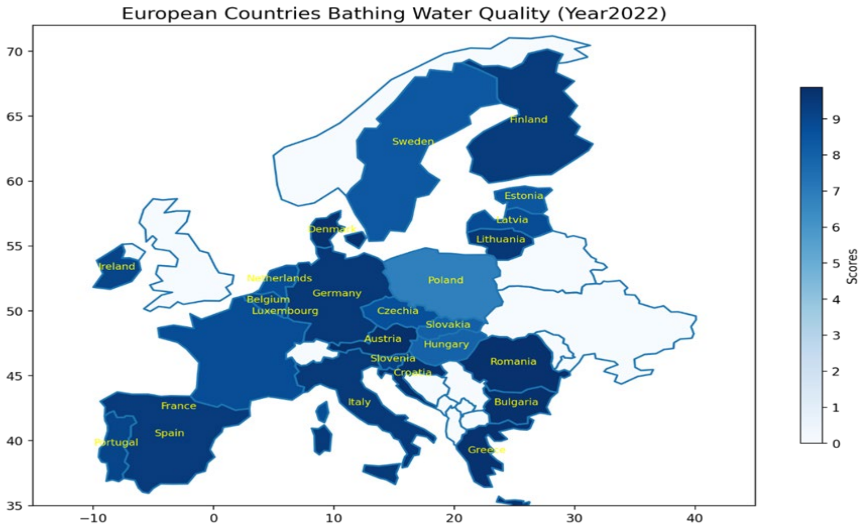

Fig. 1. European Countries Bathing Water Quality (Year 2022).

Figure 2 illustrates the changes in inland bathing water quality across various countries from 2020 to 2022. Based on the relevant data disclosed by the EEA, we can observe significant improvements in water quality management over these three years. This is especially evident in countries like Slovenia and Poland. By 2022, most countries were able to ensure that their bathing water quality remained in the excellent category. Besides, figure 3 shows the changes in coastal bathing water quality across various countries from 2020 to 2022. Based on the relevant data disclosed by the EEA, we can see that, during these three years, the coastal bathing water quality in different countries has also shown a gradual upward trend, although the improvement is not significant.

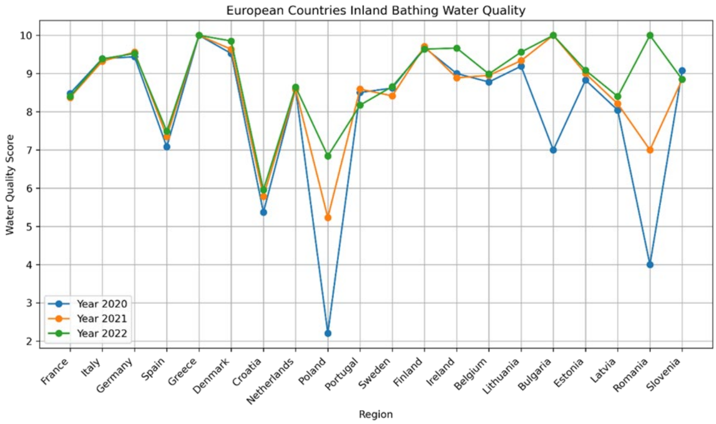

Fig. 2. European Countries Inland Bathing Water Quality.

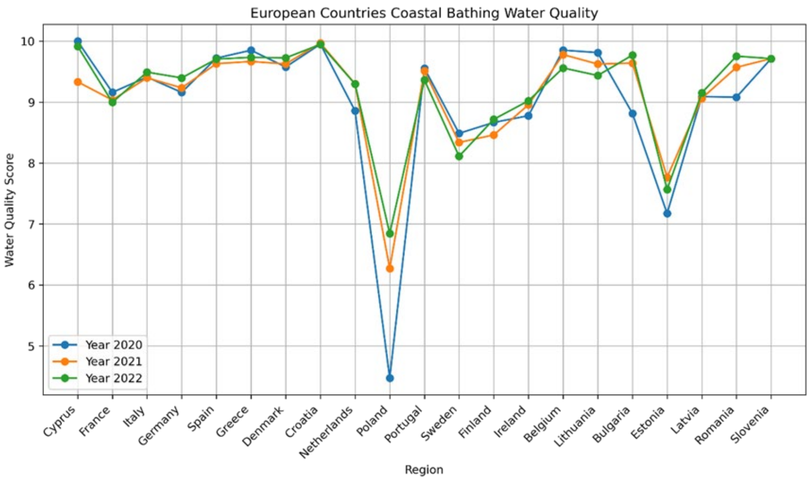

Fig. 3. European Countries Coastal Bathing Water Quality.

The overall bathing water quality score is computed by applying predefined weights to the different bathing water classifications. The independent variables (predictors) and target variables (overall score) are then split into training and testing datasets using a 90/10 train-test ratio. A Random Forest Regressor is trained using the training dataset. Random Forest is an ensemble learning method that builds multiple decision trees and combines them to improve predictive accuracy and control overfitting. After training the model, feature importance scores are computed to determine the relative importance of each independent variable in predicting the overall bathing water quality. These scores help identify the most influential factors affecting the quality of bathing water [9].

An ARIMA model forecasts future bathing water quality scores for each region. ARIMA is well-suited for time series data because it captures the autocorrelations within the data and can model the trend and noise. The parameters (p, d, q) are set to (1, 1, 1), though they can be further tuned to improve model accuracy. For each region, the ARIMA model is trained using the historical data, and predictions are made for the next ten years (2023–2032). The forecasted values are constrained to a range between 0 and 10 to reflect the scoring system's limits [10].

3 Results and Discussion

Using the abovementioned methods, we analysed the relationships between the key factor, CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade—and their impact on inland, coastal, and overall bathing water quality. Additionally, we projected water quality trends for the next ten years.

Figure 4 demonstrates the significance of changes in various influencing factors on inland bathing water quality. It is evident from the chart that environmental factors have a more significant impact on the overall quality changes of inland bathing water across all countries. For example, excessive microorganisms brought about by rainfall can disrupt the ecological balance of inland water systems, while improper discharge of urban sewage can lead to inland water pollution [11]. Additionally, carbon dioxide emissions can accelerate the greenhouse effect, increasing pollution levels in water bodies and affecting human health. In contrast, factors such as tourism GDP, number of tourists, and average temperature do not have a uniform impact on the inland environment, so changes in these three factors do not significantly influence the quality of inland bathing water.

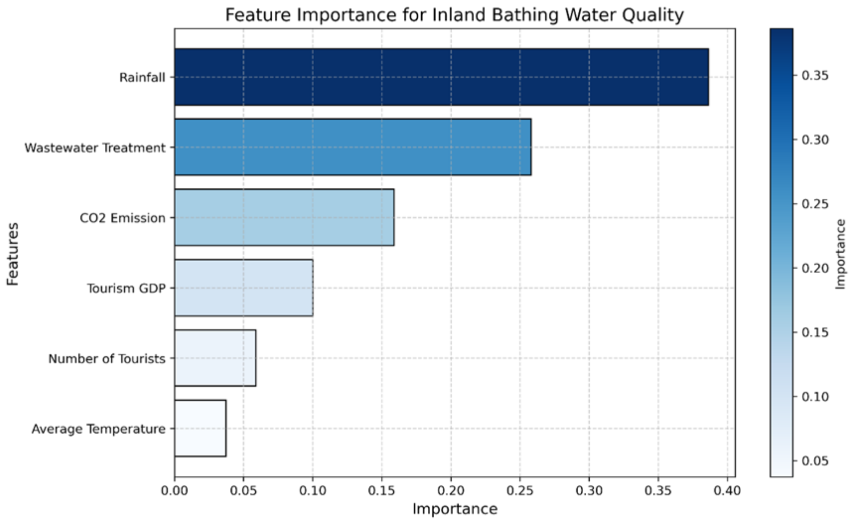

Fig. 4. Feature Importance for Inland Bathing Water Quality.

Figure 5 illustrates the importance of changes in various influencing factors on coastal bathing water quality. It is evident from the chart that, for all countries, variations in rainfall have a far more significant impact on coastal bathing water quality than the other five influencing factors. This is because the quality of coastal bathing water is more dependent on environmental changes. Consequently, fluctuations in rainfall, CO_2 emissions, and average temperature significantly affect the quality of coastal bathing water. In contrast, changes in human activity levels, tourism GDP, number of tourists, and wastewater treatment do not uniformly impact overall coastal bathing water quality, so these three factors have less influence on its quality.

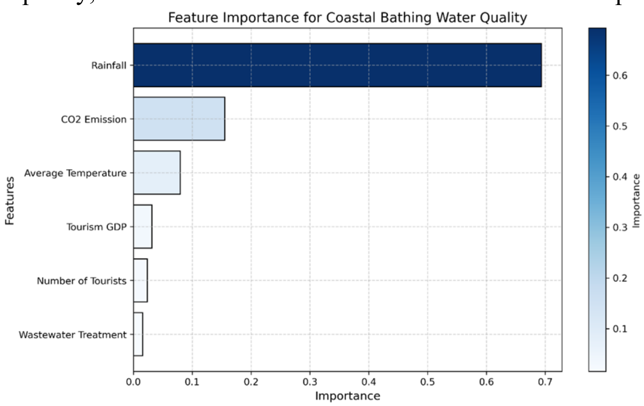

Fig. 5. Feature Importance for Coastal Bathing Water Quality.

Based on the analysis of the six factors that influence the overall bathing water quality in various EU countries, it is evident that rainfall plays a significant role.

Rainfall can uniformly impact both inland and coastal areas and often carries many microorganisms into the water, disrupting the ecological balance and leading to irreversible damage to bathing water quality. Therefore, changes in rainfall can result in substantial variations in bathing water quality. Additionally, human activity levels also influence the quality of bathing water. Factors such as CO_2 emissions, number of tourists, and wastewater treatment grades can almost uniformly affect bathing water quality[12].

On the other hand, tourism GDP reflects the general economic activity of tourists but could be more precise regarding specific economic activities that directly impact bathing water quality. Furthermore, changes in average temperature indicate a rise in national average temperatures, but their effect on the average temperature of bathing water is insignificant. Consequently, these two influencing factors have little impact on overall bathing water quality [13].

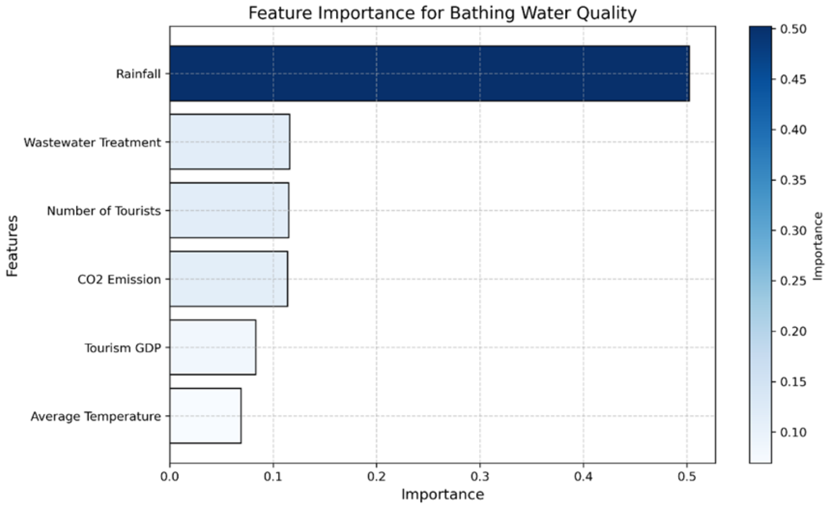

Fig. 6. Feature Importance for Bathing Water Quality.

Figure 6 illustrates the average values of bathing water quality for inland and coastal areas. Overall, the top three influencing factors are rainfall, wastewater, and the number of tourists. Figure 7 presents a forecast of the bathing water quality changes from 2023 to 2032 for nine countries where data for six influencing factors were fully disclosed. The overall quality of bathing water in these nine countries shows an upward trend. Notably, after 2026, all these countries are expected to improve their bathing water quality to the "Excellent" level as rated by the EEA. Among them, the quality of bathing water in the Netherlands, Poland, and Denmark will significantly improve between 2023 and 2032, demonstrating substantial progress. In contrast, the quality of bathing water in other countries will remain broadly stable, with levels similar to those from 2020 to 2022 showing slight fluctuation. This forecast suggests that over the next decade, these countries may achieve favourable results in improving water quality, mainly through advances in technology and policy interventions, gradually reaching higher water quality standards.

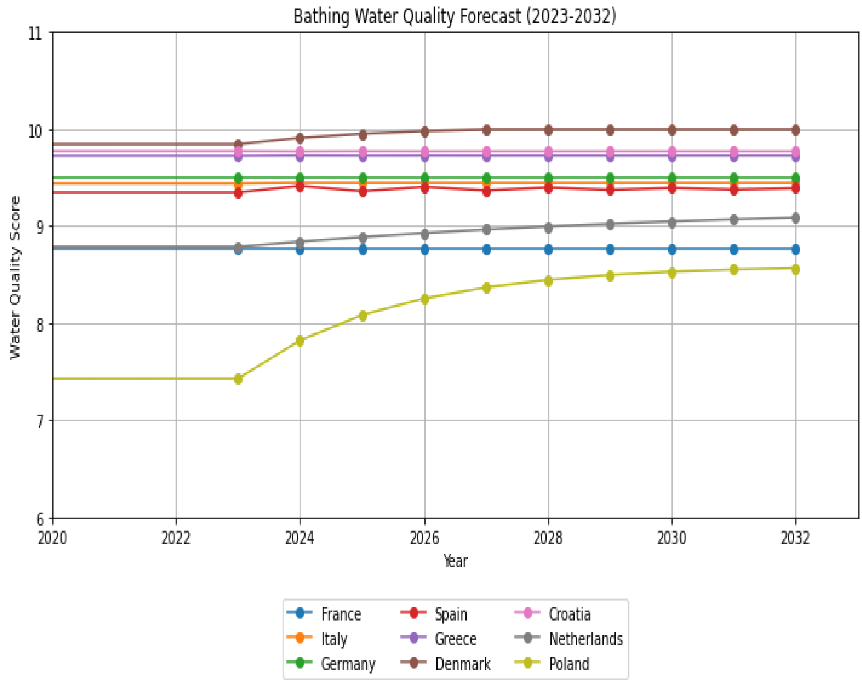

Fig. 7. Bathing Water Quality Forecast (2023-2032).

Figure 8 compares the predicted bathing water quality results for 2023, as projected in this study, and the actual bathing water quality disclosed by the EEA for nine representative countries. By comparing the predicted results with the actual data, we can evaluate the accuracy of our predictions and make more precise adjustments. The error between actual value and predicated value is 0.066 for Mean Squared Error (MSE), 0.256 for Root Mean Squared Error (RMSE), and 0.144 for Mean Absolute Error (MAE). From the results, the forecasts for France, Germany, Spain, Greece, Italy, and Croatia are mainly consistent with their actual results, indicating that the future 10-year bathing water quality predictions for these countries are relatively reliable. However, for Poland, Denmark, and the Netherlands, the predicted results are higher than the actual bathing water quality figures. This discrepancy may arise because the dominant factors influencing the bathing water quality in these three countries are not among the six factors listed in this study, leading to a deviation. Therefore, when considering the future 10-year trends for these three countries, it may be necessary to revise the predictions downward to better align with the actual situation and to inform more effective governance and protection efforts.

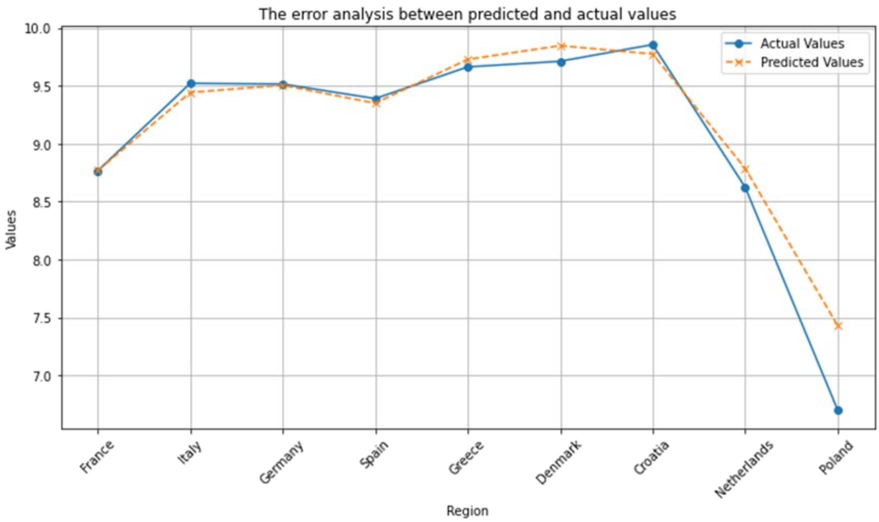

Fig. 8. The Error Analysis Between Predicted and Actual Values.

4 Conclusion

In conclusion, this study highlights the significant impact of six factors, including CO_2 emissions, tourism GDP, average temperature, rainfall, number of tourists, and wastewater treatment grade, on the bathing water quality in EU countries. Among these factors, rainfall emerged as the most influential, especially in both inland and coastal areas, due to its role in carrying pollutants and microorganisms into water bodies. CO_2 emissions also showed considerable influence, reflecting the environmental stress caused by climate change. In contrast, factors like wastewater treatment grade had a relatively minor impact, especially on coastal water quality, where natural environmental changes had more pronounced effects.

The contributions of this research are twofold. First, it provides a comprehensive analysis of how environmental and socio-economic factors interact to influence bathing water quality across different EU regions. Second, the use of time series forecasting offers valuable insights into future trends in water quality, enabling policymakers to anticipate and address potential challenges. The projection models indicate that most countries will see improvements in their bathing water quality over the next decade, with certain regions like the Netherlands and Poland showing significant potential for progress.

However, this study also has limitations. The forecasting model might not fully capture the influence of certain localized factors, such as specific land-use patterns or unmonitored pollutants, that could affect water quality in ways not accounted for by the selected variables. Additionally, the accuracy of the ARIMA model could be enhanced with more precise tuning of its parameters and incorporating other machine learning techniques could further refine predictions. Future research should consider including more granular data on human activities and climate conditions, as well as exploring the integration of real-time monitoring systems to provide more dynamic and responsive water quality management.

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