

RESEARCH ARTICLE

Visualizing water demand and predicting future consumption in Malaysia

Tion Jia Le, Siti Zanariah Satari*, Yip Yoong Eng, Mok Ker Qin, Soh Hong Yang and Chua En Huan

Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhr Persiaran Tun Khalil Yaakob, 26300 Kuantan, Pahang, Malaysia

Abstract - Access to clean water has long been a major issue in Malaysia. Urbanization and flooding have made the need for innovative and sustainable solutions even more pressing. This study aims to analyse the challenges and opportunities of clean water access across states in Malaysia. Datasets from the Department of Statistics Malaysia (DOSM) and MyWater Portal are used to examine accessibility to treated water through data visualization and identify disparities in Kelantan, Sabah, and Sarawak, where coverage remains below 90% despite the abundance of water resources. To explore the underlying factors, the comparison focuses on how dams are built and used in these states versus in Selangor, which, despite its dense population and heavy demand, still manages to provide high access to treated water. Then, time series models (Exponential Smoothing, DES, ARIMA) and machine learning algorithms (XGBoost, Random Forest) are built to forecast state-level water consumption. The result shows that Double Exponential Smoothing (DES) performs the best to capture historical water consumption levels and trends. Water demand is expected to grow rapidly due to population and industrial development in Selangor, while other states are projected to experience steady increases. However, dam capacity or water production alone does not guarantee equitable access. To close these gaps, the study this study proposes two sustainable water treatment technologies; electrocoagulation and photocatalysis. Both eco-friendly recommendations can strengthen Malaysia's long-term water security while supporting Sustainable Development Goal 6: Clean Water and Sanitation.

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1. Introduction

Malaysia is a country rich in water resources, with most of them coming from rivers, dams, and underground water. However, many states are still facing challenges in accessing consistently treated and clean water. These challenges still existed due to gaps in infrastructure between states like poor condition or lack of proper management of water infrastructure, regional disparities, and a mix of environmental factors such as geographical location. Furthermore, the annual occurrence of natural disasters such as floods disrupts the clean water access, resulting in low access to clean water and water outages in certain states of Malaysia. As one of the important basic living necessities, water plays an important role as a foundation of good health, education, and economic development. Access to clean water should be improved to create a more sustainable future, aligning with the sixth sustainable development goal, clean water and sanitation by the United Nations (UN). According to Malaysia Voluntary National Review in 2021 [1], domestic water consumption in Malaysia has reached 245 litres per capita per day which is relatively high compared to the daily water requirement set by the UN organization. This is a concerning matter as Malaysia lost an estimated amount of USD 1.7 billion in wasted water between 2018 and 2022 within a short period of five years [2]. The Malaysian government has made several efforts to encourage citizens to minimise their daily water usage and meet the ideal target set by UN organization such as by promoting water smart products. However, relying only on government initiatives is unlikely to achieve the targeted reduction in water consumption if public participation remains limited. Therefore, Malaysians should actively adopt water-saving practices, such as reducing unnecessary daily water usage and reusing vegetable-washed water for watering plants.

Current water treatment methods like chlorination, membrane technology in ultrafiltration systems, coagulation, flocculation and sedimentation are commonly used in the water treatment process in Malaysia. Water treatment is a very crucial step in providing safe and clean water to the people. This is because water may contain harmful microorganisms, which can spread waterborne diseases throughout the community. Besides, water pollution due to poor management of industrial wastewater further affects the water quality and will bring serious consequences if consumed directly. Hence, adopting an effective and sustainable water treatment method not only ensures safe and clean water for Malaysians but also helps in creating a sustainable future for the next generation. To understand the future water consumption for a better option of water treatment, a study related to the domestic water demand model in Malaysia is done by The Malaysian Water Partnership in 2020 [3]. The study applied several predictive models, including Multiple Linear Regression, Multi-Layer Perceptron and Radial Basis Function Neural Networks. The data acquisition is carried out within the time span between 2000 and 2018 through a collaboration between the Malaysian Water Association, Department of Environment and Department of Statistic Malaysia. Overall, it can be concluded that the Multi-Layer Perceptron yielded the best accuracy in predicting domestic water demand. In particular, raising prices and design capacity are best suits to reduce water consumption among Malaysian.

In addition, a study focusing on forecasting future water demand in Johor, has explored non-linear regression and stochastic frameworks such as geometric Brownian motion to capture the demand variability that is continuously driven

by population growth, consumption trends, and income levels [4]. The study concluded that traditional predictive models may underestimate the real-world uncertainties arising from natural disasters, management failure and infrastructure limitations. In contrast, the stochastic approach provided a more reliable short-term and medium-term demand projections due to its adaptability in population growth changes and water consumption patterns. This study summarizes the importance of choosing the right model that best suits the data to ensure the highest accuracy of prediction that can be used in real-life applications.

1.1 Problem Statement

Natural disasters such as floods happening in Malaysia are causing adverse effects on the water supply and water quality of Malaysians. Other than flood, the rapid development of industry is also a big cause of low water quality due to large disposal of untreated industrial wastewater. These factors contribute to water contamination, which causes more time needed to filter out harmful substances in the water and thus reduces the amount of accessible clean water. To improve access to clean water, the state government has taken actions such as temporarily cutting off water supply to treat water or sending water trucks to affected areas to ensure citizens' daily activities are not significantly affected. However, cutting off the water supply and sending water trucks are not the proper solutions for a long-term basis, other solutions need to be explored. To address this issue, this study aims to investigate the clean water access across Malaysia states and examine the structure of dams in selected states in relation to access to treated water. It also seeks to predict future water consumption trends using appropriate predictive models and identify potential solutions to ensure the long-term sustainability of clean water treatment.

Figure 1 shows the flow of water resources to water consumption. Generally, water flow starts from its respective sources, whether from rivers, underground water, or dams. Next, water demand will be analysed and whether our current clean water access managed to meet the current population's needs. In addition, this study identifies the state with the highest water consumption. Finally, other possible water treatment solutions will be identified to support the long-term sustainability of clean water access for targeted areas. This part will also be linked back to water access as treated water can be reused without reducing the need to extract more water from our natural resources, hence, creating a more sustainable cycle.

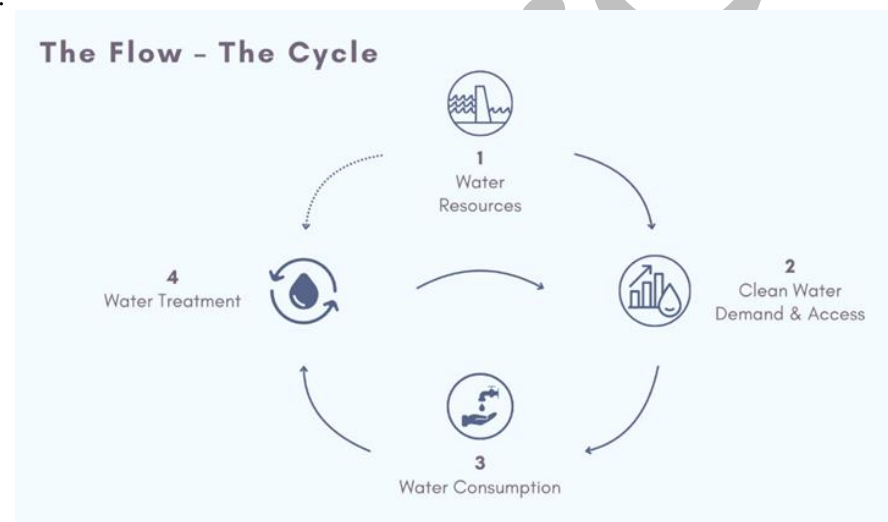


Figure 1. Flow from water resources to water consumption

1.2 Significance of Study

This study contributes to understanding clean water demand and access patterns in Malaysia, particularly in states with low water access. As the nation continues to develop along with rapid growth of the population, industrial activities and urbanization have significantly increased the water demand, putting more pressure on existing water resources and infrastructure. States such as Selangor and Kuala Lumpur, acts as the major economic and residential hubs of Malaysia, are witnessing the growing of water consumption levels, highlighting the importance of providing clean water for national development. Meanwhile, other states are still facing challenges related to access, such as floods and aging infrastructure, which require more attention from the authorities.

This study is crucial in identifying and analysing the disparities in water distribution, growth of population, as well as access and consumption behaviour across multiple regions in Malaysia. By highlighting the regional imbalances, the research aims to raise awareness of authorities and the public to act on supporting a more efficient approach to water resources management. It also brings attention to the environmental, social and economic consequences of water shortages, including the health risks, increased cost of water treatment, potential disruptions in agricultural productivity, and social inequality in terms of access to clean water. Furthermore, this study offers a data-driven foundation for policymakers and stakeholders to design targeted interventions such as infrastructure upgrades, publishing forecasting models, and public education campaigns.

2. Methodology

Generally, the methods used in this study are data acquisition, data cleaning and preparation, data visualization, and predictive models for forecasting and analysis. In this study, several datasets are integrated to gain a more detailed understanding of clean water demand and its access patterns in Malaysia. The software used for visualization and prediction are Tableau and Streamlit.

2.1 Data Acquisition

The datasets used in this study are obtained from various trusted and licensed resources such as OpenDOSM by Department of Statistics Malaysia (DOSM) and MyWater Portal [5-9]. The datasets cover different time periods: Water Consumption data span from 2003 to 2022, Access to Treated Water and Water Production data span from 2000 to 2022, while River Distribution and List of Dams datasets are from 2025. Lastly, Population Malaysia span from 2000 to 2022. The datasets obtained are combined for further and detailed analysis to seek deeper insights and understanding. The names of the datasets and their respective sources are displayed in Table 1.

Table 1. Source of datasets and their range of years

Dataset(s)	Source	Range of Years
Water Consumption by State and Sector	OpenDOSM	2003 – 2022
Access to Treated Water by State and Strata	OpenDOSM	2000 – 2022
Water Production by State	OpenDOSM	2000 – 2022
Population Malaysia	OpenDOSM	2000 – 2022
River Distribution	MyWater Portal	2025
List of Dams	MyWater Portal	2025

2.2 Data Cleaning and Preparation

To ensure the research remains centred on Malaysia, filters were applied across all datasets to exclude unrelated data. Null values were removed using Tableau to improve data cleanliness and reliability. For river data, standardization was done by assigning a primary state to each river. This step was taken to enhance the accuracy and consistency of geographic information, especially for the rivers that cross state boundaries.

2.3 Data Visualization

All datasets were imported into Tableau for visualization purposes. Various visual formats, including graphs, charts, and maps, were generated to help interpret trends and explain key insights to the audience. Interactive dashboards were created to provide a comprehensive overview of the current situation and uncover the relationships between variables. Finally, a data story was developed by sequencing these dashboards to present a clear and cohesive narrative of the findings.

2.4 Predictive Modelling for Forecasting and Analysis

To forecast clean water consumption in Malaysia, five different models were used, including Exponential Smoothing, Double Exponential Smoothing, ARIMA, Extreme Gradient Boosting (XGBoost) and Random Forest Regressor. Exponential Smoothing forecasts value without requiring any obvious trend and seasonality of data while Double Exponential Smoothing, also known as Holt's Linear Exponential Smoothing, was used to forecast data that shows discernible trend over time without seasonal patterns [10]. Machine learning models such as XGBoost and Random Forest Regressor provide predictions based on previous features and are used to investigate the relationship between dependent and independent variables through interpolation phenomenon. Both exponential smoothing methods and ARIMA model allow time series analysis while machine learning methods including XGBoost and Random Forest Regressor predict future water consumption by investigating the non-linear relationship between variables [4]. In between both exponential smoothing methods, exponential smoothing is a simple yet powerful model to forecast future water consumption based on the previous records of water consumption while double exponential smoothing predicts future water consumption by considering the trends of historical data. The predictions were implemented using exponential smoothing in Tableau, as well as in Streamlit using Python. Streamlit library was used to build a simple, interactive application that runs the models, which are ARIMA, Double Exponential Smoothing (DES), Extreme Gradient Boosting (XGBoost) and Random Forest Regressor and displays the forecast in a user-friendly way.

2.4.1 Exponential smoothing

Exponential smoothing was used in this study to predict the future water consumption trend. This method is widely used for time series data without clear seasonal trends by assigning most weightage to the most recent data and exponentially decreasing the weightage for each data point across the time period. In this study, future water consumption is predicted using total water consumption (x), smoothing parameter (α), forecast of total water consumption (s) and year (t). The model is expressed as in Equation (1).

$$s_t = \alpha x_t + (1 - \alpha)s_{t-1} \quad (1)$$

where s_t represents the value forecasted at the year t , x_t actual observations for year t , x_{t-1} for the actual observations of the previous year, as well as $\alpha = 0.5$ as the smoothing parameter. It is assumed that $s_{2003} = s_{2004}$ as there are no actual water consumption data recorded for 2002.

2.4.2 Double exponential smoothing

Double Exponential Smoothing, also known as Holt's Linear Exponential Smoothing, was chosen to forecast clean water consumption in Malaysia. This method is suitable for small size time series data that exhibits a clear trend over time without any seasonal patterns. This model works by smoothing two components: the level (L) and the trend (T). The mathematical formulation is expressed as in Equation (2), Equation (3) and Equation (4).

$$L_t = \alpha Y_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \quad (2)$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \quad (3)$$

$$F_{t+m} = L_t + mT_t \quad (4)$$

where L_t represents the level at time t , T_t the estimated trend, Y_t the actual observation, F_{t+m} the forecast for m periods ahead, and α, β are smoothing parameters ($0 < \alpha, \beta < 1$). The model was implemented in Python and integrated into the Streamlit application for interactive visualization.

2.4.3 Autoregressive integrated moving average (ARIMA)

Autoregressive Integrated Moving Average (ARIMA) was also selected to forecast the clean water consumption in Malaysia. This method is widely used to forecast univariate time series data that does not show any seasonal patterns. This model works by combining the autoregression (AR) model and the moving average (MA) model with differencing. The AR (p) model uses past values to forecast the next value using multiple linear regression, while the MA (q) model uses past forecast errors to improve the prediction accuracy. The model is expressed as in Equation (5).

$$y'_t = c + \phi_1 y'_{t-1} + \dots + \phi_p y'_{t-p} + \theta_1 \varepsilon_{t-1} + \dots + \theta_q \varepsilon_{t-q} + \varepsilon_t \quad (5)$$

where y'_t represents the differenced time series data with differencing order d at time t , c is a constant, $\phi_1 \dots \phi_p$ are the autoregressive parameters, $\theta_1 \dots \theta_q$ are the moving average parameters, and ε_t is the error term.

2.4.4 Extreme gradient boosting

Extreme gradient boosting, also known as XGBoost was used in this study to predict the future clean water consumption in Malaysia. This method is an ensemble learning algorithm that is effective for identifying complex and non-linear growth patterns in water consumption. This model works by building an ensemble of decision trees one after another, where each subsequent tree is trained to correct the residual errors produced by the previous tree using a gradient descent algorithm. The model is expressed as in Equation (6).

$$Obj(\theta) = \sum_i L(y_i, \hat{y}_i) + \sum_k \Omega(f_k) \quad (6)$$

where L represents the differential loss function measuring the error between the actual water consumption y_i and the predicted value $\hat{y}_i$, while Ω is the regularization term that is used to penalize the model to prevent overfitting.

2.4.5 Random forest regressor

Random forest regressor was selected in this study to forecast the clean water consumption in Malaysia. This method is also an ensemble learning method that is less sensitive to outliers and effective for identifying non-linear patterns. This model works by constructing large numbers of independent decision trees during the training phase and combining their results. For regression, the final output is calculated by averaging the predictions of all individual trees to improve accuracy and reduce variance. The model is expressed as in Equation (7).

$$\hat{Y} = \frac{1}{B} \sum_{b=1}^B T_b(X) \quad (7)$$

where $\hat{Y}$ represents the final predicted value for clean water consumption, B is the total number of decision trees, and $T_b(X)$ is the prediction generated by each tree for the input data.

2.4.6 Model evaluation

The model accuracy was assessed using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), ensuring the reliability of the prediction model. The mathematical formulations are expressed as in Equations (8) and (9).

$$MAE = \frac{1}{n} \sum_{t=1}^n |Y_t - \hat{Y}_t| \quad (8)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{t=1}^n (Y_t - \hat{Y}_t)^2} \quad (9)$$

where Y_t represents the actual observation at time t , $\hat{Y}_t$ the forecasted value, and n the total number of observations.

There are several ways of identifying which formulas are most suitable for the model. For MAE, this formula is more suitable to find the overall error of the whole model and provides easier interpretability, but it cannot detect outliers that lie among the model. On the other hand, RMSE can detect outliers, which means that if large mistakes are not acceptable in the situation, RMSE is more suitable for evaluating model accuracy.

3. Results and Discussion

In this section, insights analysed will be discussed in detail based on the addressed objectives. The discussion begins by investigating the proportion of clean water access in every state of Malaysia and discussing the clean water demand and access. Subsequently, the structure of dams and their influence on clean water access are discussed. Finally, the current water consumption trends in Malaysia and the prediction of future water consumption trends using an appropriate predictive model are investigated.

3.1 Water Resources in Malaysia

Water is a critical necessity in all social and economic sectors, and it is the most precious natural resource that is essential for all living things for a sustainable life in Malaysia. Malaysia is naturally blessed with abundant water resources, including rivers, lakes, and groundwater, mainly due to its strategic geographical location near the equator, which results in high and consistent annual rainfall. According to the World-Wide Fund Malaysia in 2023, Malaysia experiences rainfall of more than 3,000 mm annually, which helps to increase an estimated 900 billion cubic metres of annual water resources. The surface water resources, primarily rivers, account for approximately 97% of the raw water supply to agricultural, domestic and industrial uses, for economic growth. In Malaysia, water is mostly sourced from rivers and processed in water treatment plants to become a clean water supply for human beings [11].

Figure 2 shows the latest data on Malaysian water resources in 2025. Malaysia is rich in water resources with an abundance of rivers, dams, and groundwater. There are about 189 rivers, and 27 dams recorded in Malaysia, with each of them taking up 80.8% and 17.9% of total water resources, respectively. The remaining 1.3% of water in Malaysia is sourced from groundwater. Sabah has the highest total number of rivers and dams, while Perlis has the least. Water resources development is also known as a catalyst for stable socio-economic development of the country over the past few decades. The Malaysian Water Partnership revealed that in Malaysia, dams, pipelines and canals, which are responsible for diverting water from rivers to sustain domestic, industrial and agricultural needs, are essential for a country's development [3]. The climate is governed by the yearly alternation of the northeast and southwest monsoons, where the northeast monsoon normally occurs from November to March, whereas the southwest monsoon occurs from May until September [13]. Due to the climate, the highest rainfall was recorded at 5130mm in Sarawak, and the lowest rainfall was recorded at 1350mm in Perlis. There are more than 150 river systems in Malaysia, contributing to the largest percentage of total water used in Malaysia [13]. However, the rapid population growth, ongoing urbanization, fast industrialization, and the expansion of irrigated agriculture are imposing rapidly growing demands and pressures on water resources, besides contributing to the serious issues of water pollution.



Figure 2. Water resources distribution in Malaysia

3.2 Clean Water Demand and Access

Water quality has become an important concern and it has also played a role in accelerating economic development in the past two decades. In Malaysia, there are only about 46% of rivers that are rated as “clean”, with the remaining rivers are rated as slightly polluted or polluted according to the Department of Environment data during 2017 [3]. Rivers such as Klang, Skudai, and Juru, which are located in heavily populated areas, are found to be the most contaminated due to the industrial waste, sewage, faecal matter, and human waste. Figure 3 shows the annual population distribution and water production in each state in Malaysia. Clean water demand is dependent on the population of each state. A higher population indicates higher clean water demand as well as high water production and vice versa. For example, in 2022, Selangor recorded the highest average water production, while Labuan recorded the lowest water production due to differences in water demand. Selangor has the highest population, while Labuan has the lowest population among all the states in Malaysia. However, high water production does not mean having high access to clean water.

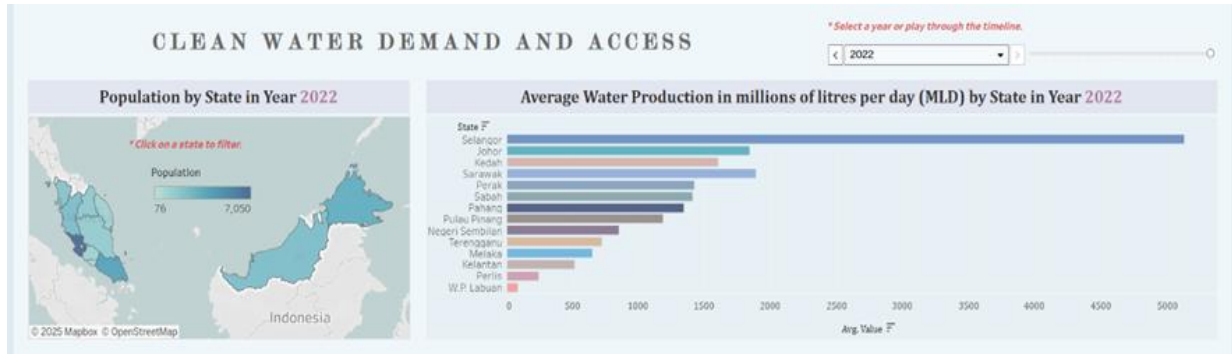


Figure 3. Population distribution and water production in each state

Next, based on Figure 4, Kelantan has significantly low access to treated water, followed by Sabah and Sarawak. Although there are abundant water resources such as rivers and dams located in Sabah and Sarawak, these three states still have less than 90% of the population with access to treated water. The amount of water production is not the main factor that leads to low access to treated water. By applying an additive trend and seasonality exponential model forecasting, access to treated water in Kelantan, Sabah and Sarawak is expected to increase in the future.

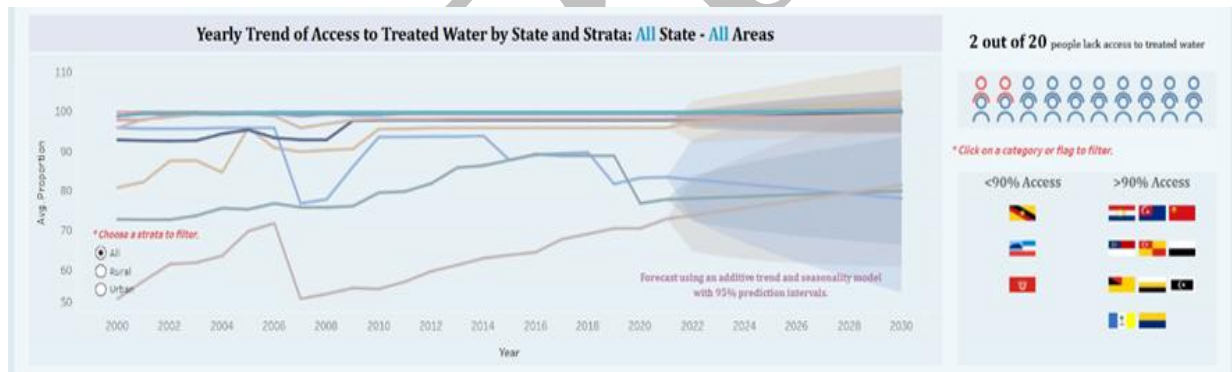


Figure 4. Yearly trend of access to treated water by states

3.3 Comparison of Dams Characteristics

Since water production is not the main cause of low access to treated water, dams in each state are compared for further investigation. Dams built in Kelantan, Sabah and Sarawak will be compared with dams built in Selangor. This is because Selangor has the highest population density among all states in Malaysia and yet Selangor still manages to have high access to treated water. From Table 2, the dam in Sarawak has the highest height and reservoir capacity, while the dam in Sabah has the highest reservoir area but the lowest reservoir capacity. Despite having large and tall dams, Kelantan, Sabah and Sarawak still face low access to treated water, suggesting that physical characteristics of infrastructure do not guarantee high clean water access.

Table 2. Dams' characteristics

States	Dams	Dam Height	Reservoir Area (km ²)	Reservoir Capacity (million m ³)
Sarawak	Batang Ali	110.0	24.0	750.0
Sabah	Tenom Pangi	83.0	152.0	12.9
Kelantan	Pergau	75.0	4.3	62.6
Kelantan	Bukit Kwong	7.6	4.0	36.6
Selangor	Batu	44.0	2.5	25.1
Selangor	Klang Gates	37.0	74.5	14.3

Besides physical characteristics of dams, their functional roles are another aspect to be discussed. As shown in Figure 5, among the six dams in Kelantan, Sabah, Sarawak and Selangor, only three dams are built for water supply, which are Bukit Kwong in Kelantan, Batu and Klang Gates in Selangor. Dams built in Selangor are mainly used in supplying water, which explains that Selangor still has high access to clean water despite having a large population. In terms of flood control, only Batu dam in Selangor helps in managing floods, reflecting the severe floods happening frequently in Kelantan, Sabah and Sarawak. While for irrigation, Bukit Kwong, located in Kelantan, is the only dam that is used for irrigation to supply water for farming. In short, the functions of dams might be the reason contributing to the low access to treated water.

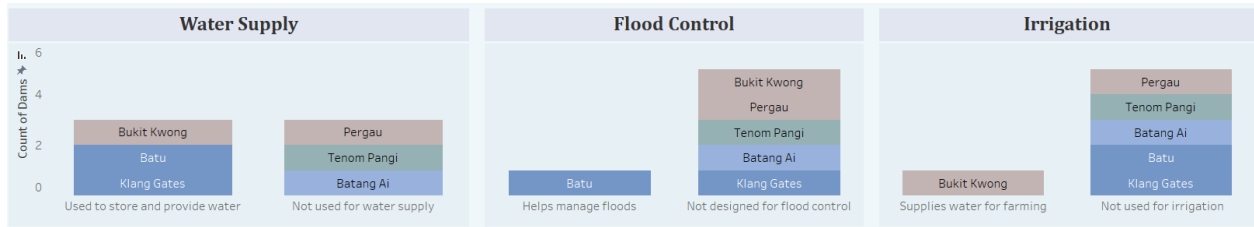


Figure 5. Functional roles of dams in Sabah, Sarawak and Kelantan

3.4 Water Consumption Trend and Future Prediction

The water consumption trend analysis from Tableau and its future prediction are shown in Figure 6. Selangor consistently has high water consumption across the year, which also indicates that larger populations and more developed states consume more water. For example, in 2022, Selangor recorded the highest total water consumption among all states, reflecting its large population and high level of urban and industrial development. In contrast, Labuan recorded the lowest total water consumption due to its small population. In terms of daily water consumption, the average daily water consumption of Malaysia has reached 11,785 million litres per day, with 62.39% used for domestic purposes. This reflects the high demand from households for daily personal use and residential uses like drinking, cooking and cleaning compared to industries. The future water consumption rate is predicted by two software, which are Tableau and Python, using different techniques. Future consumption rate is crucial for utility providers, policymakers, and management authorities to align supply with growing demand. Figure 6 shows the prediction using exponential smoothing from Tableau, where Selangor is forecasted to have the highest total amount of water consumption due to its urbanization and large population. Figure 7 shows the prediction using ARIMA, Single Exponential Smoothing (SES), Double Exponential Smoothing (DES), Extreme Gradient Boosting (XGBoost) and Random Forest Regressor from Python. From both figures, Selangor continues to show rapid growth in water consumption across the years due to increasing population and rapid development. Other states show slow to moderate growth with minor fluctuations, likely due to slower urbanization and almost constant population growth.

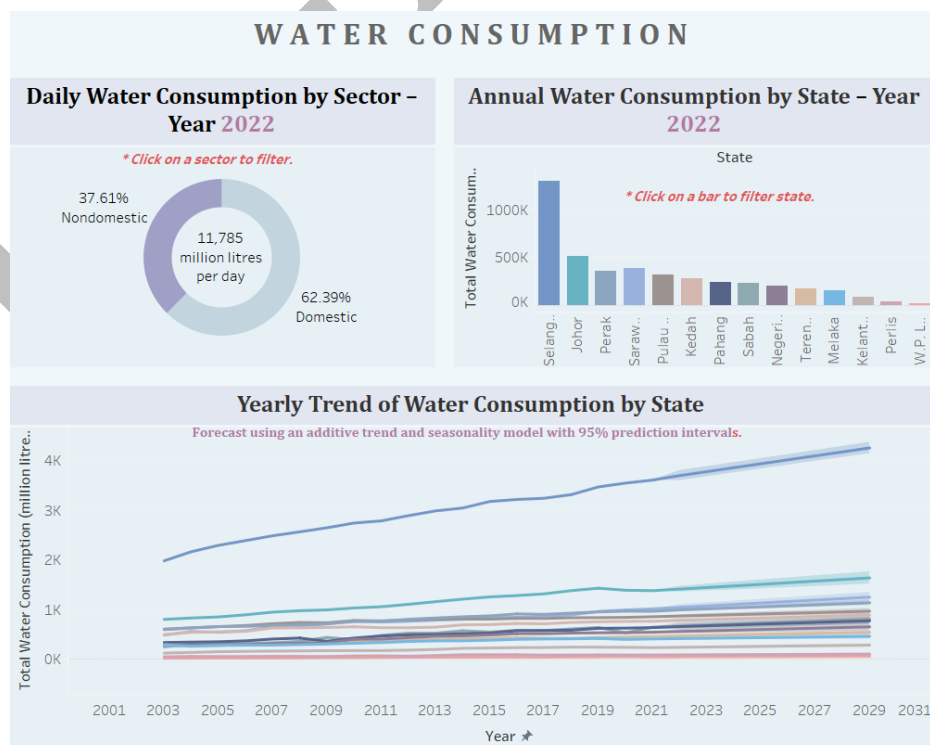


Figure 6. Water consumption trend in 2022

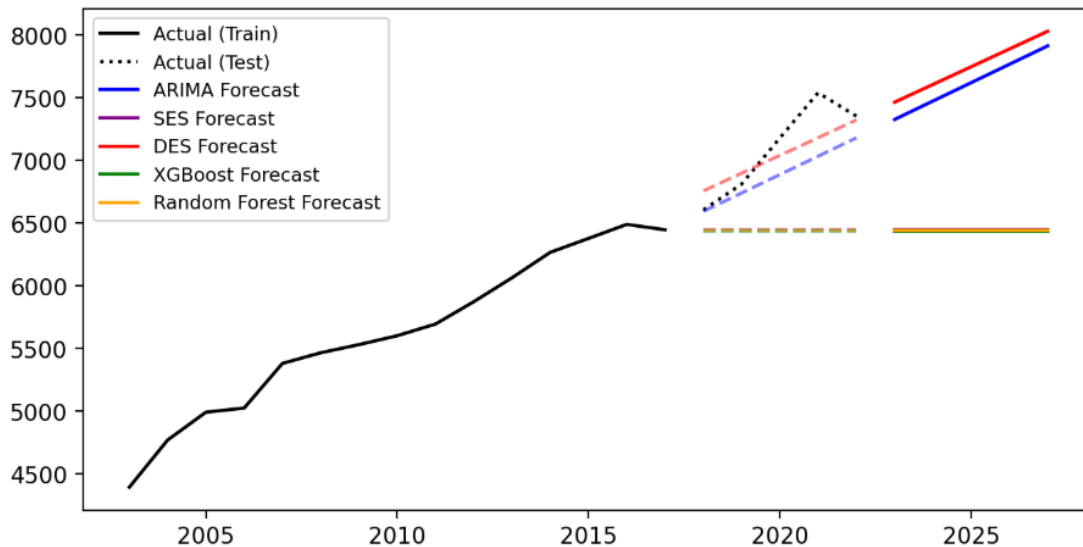


Figure 7. Water consumption prediction of the domestic sector in Selangor

The model accuracy was assessed using MAE and RMSE, given in Table 3. The simplest way of choosing the most accurate model is by choosing a model with low MAE and RMSE. Based on the evaluation of the domestic sector in Selangor, Double Exponential Smoothing (DES) performed slightly better, achieving a MAE of 153.45 and a RMSE of 189.53. In contrast, ARIMA resulted in a MAE of 210.67 and a RMSE of 274.50, making it slightly less optimal than DES. Among the time series models, SES least performed with MAE of 650.60 and RMSE of 736.04. As for the machine learning models, both XGBoost and Random Forest Regressor yielded significantly higher error values. Random Forest Regressor achieved a MAE of 656.69 and a RMSE of 741.43, while XGBoost achieved a MAE of 661.53 and a RMSE of 745.72. This performance is likely due to both machine learning models require a larger amount of training data and informative predictor variables to effectively capture complex relationships. In this study, the forecasting on water consumption was based on historical water consumption without considering other factors, which has exhibited a relatively smooth trend without strong seasonal or nonlinear patterns. This finding indicates that DES is a more accurate and reliable prediction model for visualizing the future water consumption for the domestic sector in Selangor. This performance is likely contributed to by the ability of DES that can effectively capture trends without involving seasonality in forecasting.

Table 3. Model accuracy on prediction test set of the domestic sector in Selangor

Model	MAE	RMSE
Double Exponential Smoothing (DES)	153.45	189.53
ARIMA	210.67	274.50
Single Exponential Smoothing (SES)	650.60	736.04
Random Forest Regressor	656.69	741.43
XGBoost	661.53	745.72

4. Conclusions

This study has provided an overview of the clean water supply in Malaysia. Based on the analysis, the clean water access proportion is above 90% for all states in Malaysia except Sarawak, Sabah, and Kelantan. Although these three states have tall and large dams, it does not guarantee a clean water supply to their people, as the dams built might have other functions, such as supplying water specifically for farming. Besides that, the dams built in Sarawak, Sabah, and Kelantan do not help in managing flood control, which contributes to the lack of access to clean water. Predictive models have been built to predict water consumption of Malaysians by state, which can be a reference for policymakers. Comparing times series method and machine learning approaches, the results show Double Exponential Smoothing performs the best to capture the historical water consumption level and trend. This proved that time series analysis works well to predict future water consumption and it is applicable in real life. Also, several water treatment solutions, such as electrocoagulation and photocatalysis, are suggested to achieve sustainable development in cities by increasing the proportion of people who have access to clean water.

To increase the population's access to treated water, two sustainable water treatment solutions are recommended, which are electrocoagulation and photocatalysis. Electrocoagulation uses electric current to dissolve and coagulate pollutants from water, and it is more suitable for industrial use due to its high-power supply. Based on the analysis, it is found that households have higher water consumption, which brings out the idea of treating water in our homes. Photocatalysis is one of the best water treatment solutions that can be carried out in our home. Although the installation fee is slightly higher, considering the tropical weather in Malaysia that provides abundant sunlight, making photocatalysis a useful long-term solution. The process of photocatalysis uses a semiconductor photocatalyst, such as titanium dioxide,

which is activated by solar energy to generate reactive oxygen species that degrade organic pollutants and inactivate microorganisms. In drinking water treatment, photocatalysis is typically integrated with conventional treatment processes, and catalyst recovery or separation is required for heterogeneous systems to ensure compliance with drinking water quality standards [14]. Hence, additional treatment to separate catalyst particles and disinfection are typically required. Adopting both solutions in Malaysia will not only increase the population that has access to treated water but also achieve sustainable development by using renewable energy. However, there is still a lack of research on the actual possibilities of adopting electrocoagulation and photocatalysis in Malaysia.

While this study produces valuable insights, there are also several limitations faced during the process, including incomplete and outdated data. The data recorded for water consumption is yearly instead of monthly, which hides the seasonality of water consumption among Malaysians and increases the error rate of the predictive model. Also, the latest data can be obtained for water consumption is 2022, which is three years ago from 2025. This lag of time might lead to inadequate decision-making and errors in prediction. Nevertheless, this study contributes to Malaysia's long-term water security strategy and supports the broader national and international commitments. At the national level, this research supports the National Water Resources Policy by the Department of Environmental under the Ministry of Natural Resources and Environmental Sustainability. Globally, it also contributes to the United Nations Sustainable Development Goal (SDG) 6, which aims to ensure clean water and sanitation for all. By raising the understanding of water demand dynamics and consumption trends, this study provides essential knowledge to build adaptive water governance frameworks that can meet both present and future needs.

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Declaration of Competing Interest

The authors declare no conflict of interest.

CRediT Authorship Contribution Statement

Siti Zanariah binti Satari (Conceptualization; Writing – review; Supervision; Project Administration)
Tion Jia Le (Conceptualization; Formal analysis; Writing – original draft; Supervision)
Yip Yoong Eng (Methodology; Data curation; Software; Writing – original draft)
Mok Ker Qin (Formal analysis; Visualization; Writing – review & editing; Resources)
Soh Hong Yang (Formal analysis; Investigation; Writing – review & editing; Resources)
Chua En Huan (Data curation; Visualization; Writing – review & editing; Resources)

Availability of the Data and Materials

The data used to support the findings of this study are included within the article.

Ethical Declarations

No artificial intelligence tools were used in the preparation of this manuscript. All content was developed manually by the authors. This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

References

- [1] Perpustakaan Negara Malaysia Cataloguing-in-Publication Data. Malaysia Voluntary National Review (VNR) 2021. [cited 2026 Jul 10]. Retrieved from https://sustainabledevelopment.un.org/content/documents/285982021_VNR_Report_Malaysia.pdf.
- [2] Eco-Business. Malaysia likely to face water crisis by 2030 amid growing demand: officials [Internet]. Eco-Business. 2024 [cited 2026 July 10]. Retrieved from <https://www.eco-business.com/news/malaysia-likely-to-face-water-crisis-by-2030-amid-growing-demand-officials/>.
- [3] Malaysia's Water Vision: The Way Forward - The Malaysian Water Partnership. [cited 2026 July 10]. Retrieved from <https://www.fao.org/4/AB776E/ab776e02.htm>.
- [4] Al Saleem M, Harrou F, Sun Y. Explainable machine learning methods for predicting water treatment plant features under varying weather conditions. Results Eng. 2024 Mar;21:101930.

- [5] Department of Statistics Malaysia. Access to Treated Water by State & Strata | OpenDOSM [Internet]. Dosm.gov.my. OpenDOSM; 2022 [cited 2026 July 10]. Available from https://open.dosm.gov.my/data-catalogue/water_access.
- [6] Department of Statistics Malaysia. Water Consumption by State and Sector | OpenDOSM [Internet]. Dosm.gov.my. OpenDOSM; 2022 [cited 2026 July 10]. Available from https://open.dosm.gov.my/data-catalogue/water_consumption.
- [7] Department of Statistics Malaysia. Water Production by State | OpenDOSM [Internet]. Dosm.gov.my. OpenDOSM; 2022 [cited 2026 July 10]. Available from https://open.dosm.gov.my/data-catalogue/water_production.
- [8] MyWater Portal [Internet]. mywater.gov.my. [cited 2026 July 10]. Available from <https://mywater.gov.my/portal/Modules/HidroMet/Banjir.aspx?Q=HZ8s5GaAFPM=>.
- [9] MyWater Portal [Internet]. Mywater.gov.my. 2024 [cited 2026 July 10]. Available from <https://mywater.gov.my/portal/Modules/SumberAir/Sungai.aspx?Q=KYVlnrQtFKw=>.
- [10] Cheema MA, Hanif M, Albalawi O, Mahmoud EE, Nabi M. Evaluating water-related health risks in East and Central Asian Islamic Nations using predictive models (2020–2030). *Scientific Reports*. 2024 July 22;14(1).
- [11] Opinion Piece: Much Ado about Malaysia's Water Woes [Internet]. Wwf.org.my. 2023 [cited 2026 July 10]. Available from: <https://www.wwf.org.my/?31346%2fopinion-piece-much-ado-about-malaysias-water-woes>.
- [12] Loi JX, Chua ASM, Rabuni MF, Tan CK, Lai SH, Takemura Y. Water quality assessment and pollution threat to safe water supply for three river basins in Malaysia. *Science of The Total Environment* 2022; 832:155067.
- [13] Attia MS, Abdel-Wahed MS, Algethami FK, El-Kalliny AS. Advanced oxidation processes (AOPs) for drinking water treatment: a state-of-the-art review on applications, efficacy, and implementation challenges. *RSC Advances*. 2026 Jan 1; 16(24):22186–203.
- [14] Sathasivam S, Adebayo SA, Velevan M, Liang JKW. Determine the Parameters for Photoelectric Effect Data using Correlation and Simple Linear Regression. *Journal of Quality Measurement and Analysis*. 2022;18(3):61–70.
- [15] Tan CQ, Bahar A. Uncertainty Quantification in Water Demand Prediction in Johor. In: *Proceedings of Science and Mathematics*. 2024. p. 153–64.
- [16] Home | Sustainable Development [Internet]. Retrieved from: https://sustainabledevelopment.un.org/content/documents/285982021_VNR_Report_Malaysia.pdf; 10 July 2026.
- [1] **Economic Planning Unit, Prime Minister's Department**. Malaysia voluntary national review (VNR) 2021 [Internet]. *Putrajaya: Economic Planning Unit*; 2021 [cited 2026 Jul 10]. Available from: https://sustainabledevelopment.un.org/content/documents/285982021_VNR_Report_Malaysia.pdf
- [2] Eco-Business. Malaysia likely to face water crisis by 2030 amid growing demand: officials [Internet]. *Singapore: Eco-Business*; 2024 **[Mon DD]** [cited 2026 Jul 10]. Available from: <https://www.eco-business.com/news/malaysia-likely-to-face-water-crisis-by-2030-amid-growing-demand-officials/>
- [3] **Malaysian Water Partnership**. Malaysia's water vision: the way forward [Internet]. *Rome: Food and Agriculture Organization of the United Nations*; **[year]** [cited 2026 Jul 10]. Available from: <https://www.fao.org/4/AB776E/ab776e02.htm>
- [4] Al Saleem M, Harrou F, Sun Y. Explainable machine learning methods for predicting water treatment plant features under varying weather conditions. *Results in Engineering*. 2024;21:101930. <https://doi.org/10.1016/j.rineng.2024.101930> ‡
- [5] Department of Statistics Malaysia. Access to treated water by state & strata [Internet]. *Putrajaya: Department of Statistics Malaysia (OpenDOSM)*; 2022 [cited 2026 Jul 10]. Available from: https://open.dosm.gov.my/data-catalogue/water_access
- [6] Department of Statistics Malaysia. Water consumption by state and sector [Internet]. *Putrajaya: Department of Statistics Malaysia (OpenDOSM)*; 2022 [cited 2026 Jul 10]. Available from: https://open.dosm.gov.my/data-catalogue/water_consumption
- [7] Department of Statistics Malaysia. Water production by state [Internet]. *Putrajaya: Department of Statistics Malaysia (OpenDOSM)*; 2022 [cited 2026 Jul 10]. Available from: https://open.dosm.gov.my/data-catalogue/water_production
- [8] **[Portal owner, e.g., responsible ministry]**. MyWater portal: **[page title, flood (banjir) module]** [Internet]. **[Place: Publisher]**; **[year]** [cited 2026 Jul 10]. Available from: <https://mywater.gov.my/portal/Modules/HidroMet/Banjir.aspx?Q=HZ8s5GaAFPM=>
- [9] **[Portal owner, e.g., responsible ministry]**. MyWater portal: **[page title, river (sungai) module]** [Internet]. **[Place: Publisher]**; 2024 [cited 2026 Jul 10]. Available from: <https://mywater.gov.my/portal/Modules/SumberAir/Sungai.aspx?Q=KYVlnrQtFKw=>
- [10] Cheema MA, Hanif M, Albalawi O, Mahmoud EE, Nabi M. Evaluating water-related health risks in East and Central Asian Islamic nations using predictive models (2020–2030). *Scientific Reports*. 2024 Jul 22;14(1):**[article number]**. <https://doi.org/10.1038/s41598-024-67775-3>

- [11] **WWF-Malaysia**. Opinion piece: much ado about Malaysia's water woes [Internet]. *Petaling Jaya: WWF-Malaysia* ‡; 2023 **[Mon DD]** [cited 2026 Jul 10]. Available from: <https://www.wwf.org.my/?31346%2fopinion-piece-much-ado-about-malaysias-water-woes>
- [12] Loi JX, Chua ASM, Rabuni MF, Tan CK, Lai SH, Takemura Y, **et al**. Water quality assessment and pollution threat to safe water supply for three river basins in Malaysia. *Science of the Total Environment*. 2022;832:155067. <https://doi.org/10.1016/j.scitotenv.2022.155067>
- [13] Attia MS, Abdel-Wahed MS, Algethami FK, El-Kalliny AS. Advanced oxidation processes (AOPs) for drinking water treatment: a state-of-the-art review on applications, efficacy, and implementation challenges. *RSC Advances*. 2026;16(24):22186–203. [\[https://doi.org/10.1039/...\]](https://doi.org/10.1039/...)
- [14] Sathasivam S, Adebayo SA, Velavan M, **Kng JWL**. Determine the parameters for photoelectric effect data using correlation and simple linear regression. *Journal of Quality Measurement and Analysis*. 2022;18(3):61–70. **[doi — not located; confirm whether assigned]**
- [15] Tan CQ, Bahar A. Uncertainty quantification in water demand prediction in Johor. *Proceedings of Science and Mathematics*. 2024;**[volume]**:153–64. **[doi]**
- [16] Duplicate of [1] delete and cite [1] instead. Economic Planning Unit, Prime Minister's Department ‡. *Malaysia voluntary national review (VNR) 2021* [Internet]. Putrajaya: Economic Planning Unit; 2021 [cited 2026 Jul 10]. Available from https://sustainabledevelopment.un.org/content/documents/285982021_VNR_Report_Malaysia.pdf