



Climate-driven rainfall forecasting for small-scale hydropower potential in Dhaka using SARIMAX modeling

 Ashif Imdad¹

 Md Osman Ali^{2*}

 Md Sajedul Islam³

 Mohammad Zoynal Abedin⁴

 Hasibul Islam⁵

^{1,2,3,4}Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur, Gazipur-1707, Bangladesh.

¹Email: ashifimdadjpi@gmail.com

²Email: osman@duet.ac.bd

³Email: mdsajedulislam349@gmail.com

⁴Email: abedin.mzoynal@duet.ac.bd

⁵Department of Industrial and Production Engineering, Dhaka University of Engineering and Technology, Gazipur, Gazipur-1707, Bangladesh.

⁵Email: hasibul106083@gmail.com



(+ Corresponding author)

ABSTRACT

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Bangladesh is one of the most populous countries in the world and faces significant challenges in meeting its energy demands due to rapid population growth and economic development. Considering this, even a small amount of power can be significant in fulfilling part of the demands. The purpose of this paper was to investigate the feasibility of forecasting hydropower generation in Dhaka, Bangladesh, using predicted precipitation trends. Daily rainfall readings from 1981 to 2025 were accessed and used to determine monthly and annual forecasts for the period 2026-2045. The forecasting model (SARIMAX), which incorporates 2-meter air temperature and specific humidity as exogenous variables, was used, and its performance was compared with historical data. SARIMAX exhibited reliable data, closely matching the actual situation, especially regarding seasonal changes. This model can be suitable for Dhaka as a data-informed approach to renewable energy planning. The forecasted data indicates that Dhaka receives a substantial amount of rain annually, nearly 2,564 mm. The power generation results suggest that the yearly rainfall in Dhaka could generate approximately 0.117 MW, 0.234 MW, and 0.351 MW of continuous power under 1 m, 2 m, and 3 m head conditions, respectively, with an average runoff coefficient of 0.60 and 80% system efficiency. This highlights the importance of using climate forecasting in sustainable energy strategies, especially in rapidly urbanizing and climate-vulnerable regions like Dhaka.

Contribution/Originality: This study contributes by focusing on the potential of small-scale power generation from rainfall, which can still be significant in addressing the huge energy crisis in a developing country like Bangladesh, whereas existing studies have focused on rainfall forecasting without considering the concept of power generation.

1. INTRODUCTION

With the increasing rate of global urbanization and growing concerns over dependency on fossil fuels, investigations into alternative and renewable energy sources have become major focuses in engineering studies and environmental research (Omar, Khalifa, & Oz, 2025). Among all alternatives, rainwater is an almost unused resource, especially in urban areas, where surface runoff is often poorly managed. In Dhaka, the capital of Bangladesh, the annual average rainfall exceeds 2,000 mm (Bashar, Karim, & Imteaz, 2018), but most of it gets wasted due to poor

catchment systems along with inadequacy in infrastructure for storage or energy conversion (Suberu, Mustafa, & Bashir, 2014). Under such conditions, it becomes feasible to study the potential for generating electricity through micro- or small-scale hydropower systems using processed urban rainwater (Mahsin, Akhter, & Begum, 2012). From the mechanical engineering perspective, the energy potential of rainwater is substantial, yet very little is utilized (Karim, Sakib, Sakib, & Imteaz, 2021).

Shourav, Mohsenipour, Alamgir, Pour, and Ismail (2016) investigated the projected and historical climate information for Dhaka, Bangladesh. Through their investigation, the city's vulnerability has been outlined due to rapid urbanization, poor infrastructure, and high population density. They suggested that the overall climate will experience a minimal temperature increase in the future, with a significant temperature rise in the pre-monsoon and monsoon seasons, without affecting the rainfall. They observed a marginal increase in rainfall, with most of it occurring in June. There will be greater temperature variability, and the class of very intense weather events, which currently have a low probability, will exhibit a higher frequency of occurrence in the future. They did not provide any information as to how this massive rainfall could be converted into a usable form of energy.

Bhuiyan, Mamur, and Begum (2021) provided a comprehensive update of renewable and sustainable energy resources in Bangladesh. They discussed that the country's overdependence on fossil fuels, specifically natural gas, resulted in over 70% of electricity generation in 2019–2020, while renewable sources contributed only 1.23%. After realizing this dependence, they analyzed the importance of alternative energy sources that can meet a part of the country's energy demands. Their article lists solar energy from the sun as the renewable energy source most likely to be practical in Bangladesh due to the country's favorable geographical position. According to them, Solar Home Systems (SHS), introduced by IDCOL, can be one of the projects with high electricity potential. The fact that they were widely deployed in rural areas and contributed significantly to expanding electricity access is very important. Solar irrigation pumps, which helped reduce dependence on diesel in agriculture, also decreased costs and emissions. Although wind energy is only available in coastal areas, its potential is promising, as these are the only locations suitable for wind turbines. Hydro projects are small-scale but more concentrated, benefiting hill areas only to a limited extent. Methods of harnessing biomass and biogas focus on utilizing waste produced through agricultural and organic materials, beyond just being convenient for energy producers' needs at any given time.

This study describes a convenient and feasible method to evaluate the energy potential of rainwater in urban areas, a topic not fully researched in small-scale, city-specific applications of hydropower literature. Although several meteorological studies have been conducted on rainfall distribution and seasonal patterns in Bangladesh, most of these only focused on short-term analyses or overviews without comprehensive long-term forecasting or application in energy generation (Rahman, Afreen, & Hussain, 2011). The purpose of this study is to fill this gap by focusing on long-term predictive modeling of rainfall, approximately 20 years for Dhaka city. This work uses daily historical rainfall data from 1981 to 2025, taken from the NASA POWER database. A time-series forecasting model, Seasonal AutoRegressive Integrated Moving Average with eXogenous variables (SARIMAX), has been applied. This model is an exogenous version of the SARIMA model and the Prophet model by Facebook. This model is specifically suited to handle seasonal non-stationary patterns and external climatic variables characteristic of rainfall data.

This study will serve a dual purpose. Firstly, to assess the effectiveness of using modern forecasting models in predicting long-term precipitation in Dhaka. Secondly, to theoretically estimate the potential hydropower derived from the predicted rainwater under fixed runoff conditions and energy conversion. Although there are many practical problems related to such energy systems, such as infrastructure, efficiency of water collection, and cost of the system, the conceptual framework presented here provides one basic insight into the size and scope of urban rainwater-based energy recovery.

2. METHODOLOGY

This paper outlines a data-driven methodology that exploits rainfall to derive hydroelectric energy in Dhaka over long periods using time-series models and hydropower equations. The process involves data collection, data preprocessing, the use of three statistical models for forecasting, and theoretical energy calculations under perfect runoff conditions.

2.1. Data Source and Preparation

The meteorological data were collected from the NASA POWER database, which covers daily rainfall, surface temperature, and specific humidity from 1981 to 2025. The initial dataset was formatted and reorganized to ensure consistency with the forecasting models. The daily rainfall values were summed to align with the monthly amounts, which were then used for model training and prediction.

2.2. Forecasting Period and Resolution

The rainfall forecast was performed over 20 years, from 2026 to 2045. Monthly rainfall was forecasted for the year; the 12 monthly predictions were summed to determine the annual rainfall. This method balances time granularity with computational efficiency and can conduct both cross-sectional and time-series analysis.

2.3. Study Location

The study focuses on Dhaka, Bangladesh, as shown in Figure 1, due to its urban nature and rainfall potential. This city is also surrounded by rivers such as Buriganga, Turag, Balu, Shitalakhya, and Dhaleshwar, making it ideal for generating small amounts of electric power from rainfall. However, for simplicity in calculation, we proposed a single small power generation unit.

2.4. Time-Series Forecasting Framework

The rainfall data from 1981 to 2025 were used to forecast monthly rainfall from 2026 to 2045, a 20-year projection, using the SARIMAX model.

2.4.1. Seasonal ARIMAX (SARIMAX)

In this study, a Seasonal AutoRegressive Integrated Moving Average with exogenous regressors (SARIMAX) model was used to predict monthly rainfall in Dhaka for the period 2026 to 2045. Figure 2 illustrates the SARIMAX-based forecasting model framework. In this model, the dataset undergoes Min–Max normalization and stationarity testing via the Augmented Dickey–Fuller test. In case of non-stationary data, wavelet decomposition and resampling are utilized to achieve a stationary series, with subsequent ACF and PACF analysis for model identification. After that, the data is processed and then incorporated into SARIMAX and machine learning regression models, with the result being a performance analysis to obtain the final forecasting result.

SARIMAX was the desired model because it could handle both seasonality and the effect of external climate variables on rainfall. This model expands the traditional SARIMA framework by incorporating exogenous factors, thereby improving forecasting accuracy in meteorology.

The rainfall data used for the model were obtained from the NASA POWER database, derived from daily precipitation records for Dhaka from 1981 to 2025.

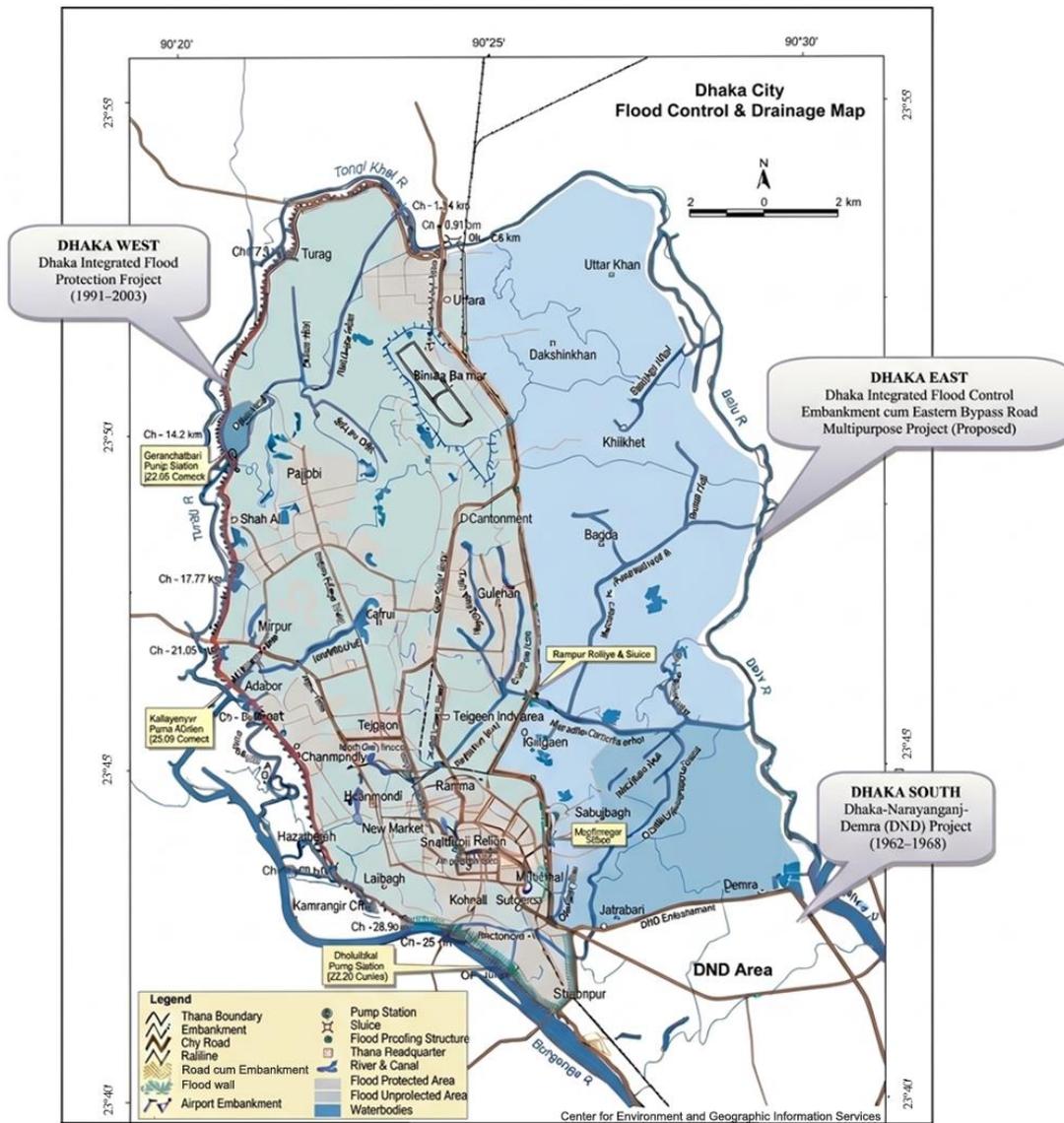


Figure 1. Dhaka city flood control and drainage map.

Source: Barua and van Ast (2011).

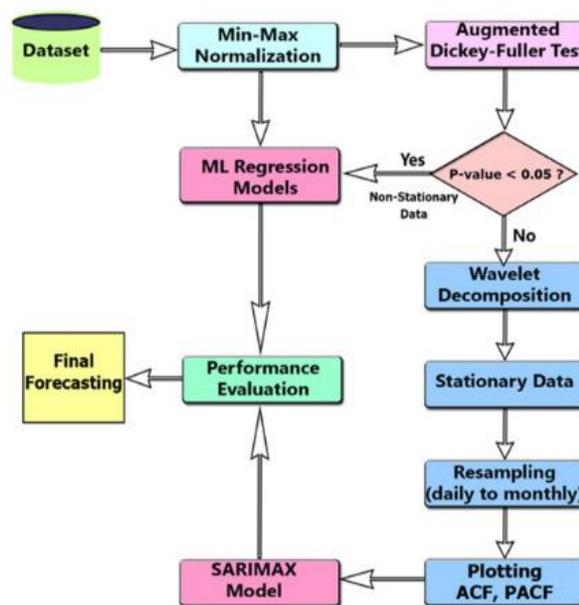


Figure 2. Flow chart of the SARIMAX model.

The day-based data was aggregated into monthly data to fit the seasonal periodicity of rainfall in the region for forecasting purposes (Elshewey et al., 2023).

Base Equation:

$$y(t) = g(t) + s(t) + h(t) + \varepsilon_t \quad (1)$$

Where,

$y(t)$ = Observed value of the time-series at time t .

$g(t)$ = Trend function modeling non-periodic, long-term changes.

$s(t)$ = Seasonality function capturing periodic effects (e.g., weekly, yearly).

$h(t)$ = Holiday effects function (Optional, user-defined).

ε_t = Error term

For the SARIMAX model to be executed, specific humidity and surface temperature were identified as the two exogenous variables with the most significant impact on precipitation. These atmospheric condition features were extracted from the NASA POWER database and manipulated to match the month (Tarsitano & Amerise, 2017).

Base Equation:

$$Y_t = c + \phi_1 Y_{t-1} + \theta_1 \varepsilon_{t-1} + \Phi_1 Y_{t-s} + \Theta_1 \varepsilon_{t-s} + \beta_1 X_{1,t} + \beta_2 X_{2,t} + \varepsilon_t \quad (2)$$

Where:

Y_t = Rainfall at time t .

ϕ_1 = Autoregressive (AR) coefficient.

θ_1 = Moving average (MA) coefficient.

Φ_1, Θ_1 = Seasonal AR and MA components.

s = Seasonal period (12 for monthly data).

β_1, β_2 = Coefficients for exogenous variables.

X_1 = Specific humidity.

X_2 = Temperature.

ε_t = White noise (Error).

The SARIMAX model was implemented in Python using the 'statsmodels' library (Lemenkova, 2019; Seabold & Perktold, 2010), which made it quite easy to perform time-series analysis and allowed the inclusion of exogenous variables. The empirical formula is provided below.

$$\begin{aligned} \text{Rainfall}_t = 31.46 \times \text{Humidity}_t - 27.19 \times \text{Temperature}_t + 0.226 \times \text{Rainfall}_{t-1} + 0.0019 \times \text{Rainfall}_{t-12} - \\ 1.014 \times \varepsilon_{t-1} - 0.817 \times \varepsilon_{t-12} + \varepsilon_t \end{aligned} \quad (3)$$

Python's versatility and capability to handle data are the characteristics that make it an appropriate tool for processing rainfall data and developing long-term forecasts.

3. ANNUAL RAINFALL IN BANGLADESH

A detailed history of historical rainfall data is presented in this section, which highlights noteworthy trends and anomalies. A key objective is to assess how climate variability affects rainfall.

The monthly rainfall recorded at the Dhaka station from 1981 to 2025 is shown in Figure 3. The plot shows a clear seasonal pattern with significant fluctuations in rainfall, and the peaks indicate rainfall during the monsoon months. The data show consistent annual cycles, which indicate a strong seasonal component in Dhaka's rainfall over the 45 years.

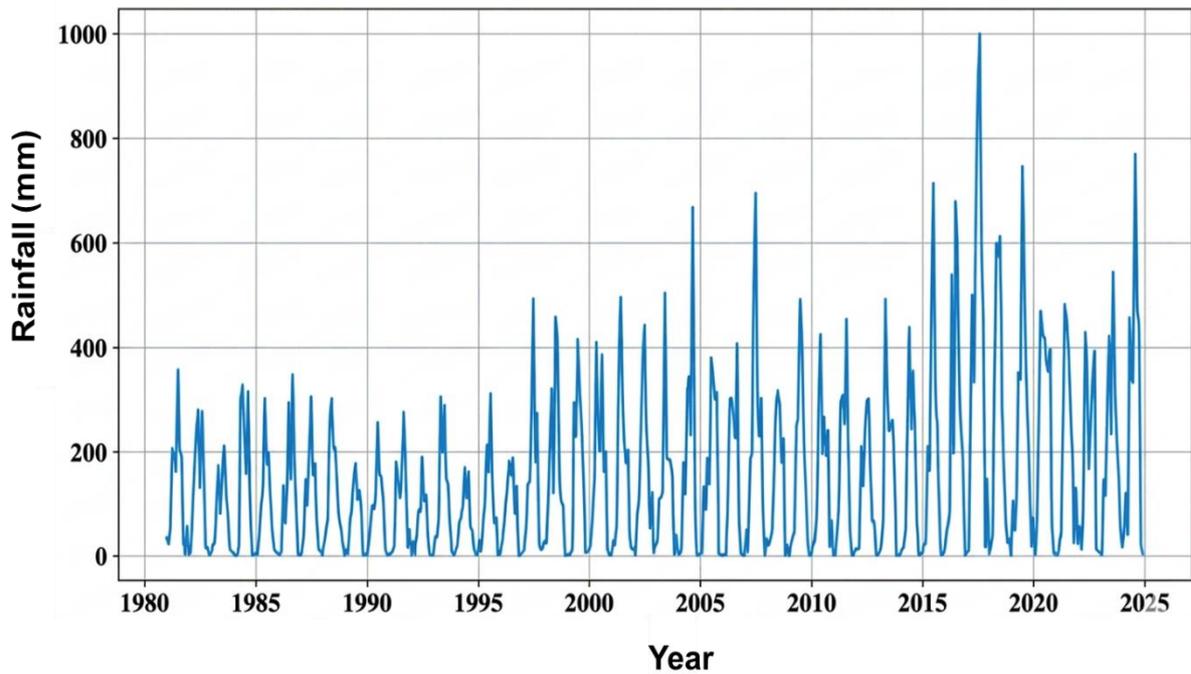


Figure 3. Dhaka Month Rainfall 1981 to 2025.

Source: Islam, Ray, Anannya, Tusher, and Roy (2014) and Khatun, Samad, and Rashid (2017).

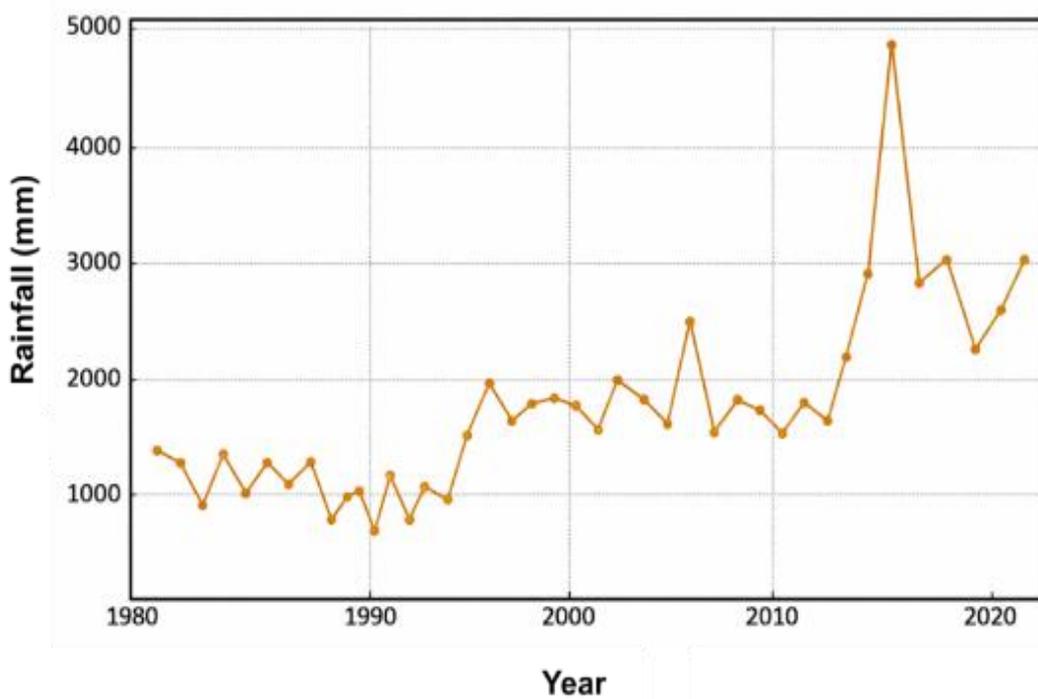


Figure 4. Annual rainfall from 1981 to 2025.

Source: Ahammed, Hewa, and Argue (2014).

Figure 4 shows the variation of total annual rainfall (in millimeters) over 45 years from 1981 to 2025. For a particular year, each dot represents the annual rainfall amount. The data is fitted with a line, which shows a slight upward trend over the period. In general, it appears that rainfall over the observed period has been increasing marginally but consistently over the course of the study period.

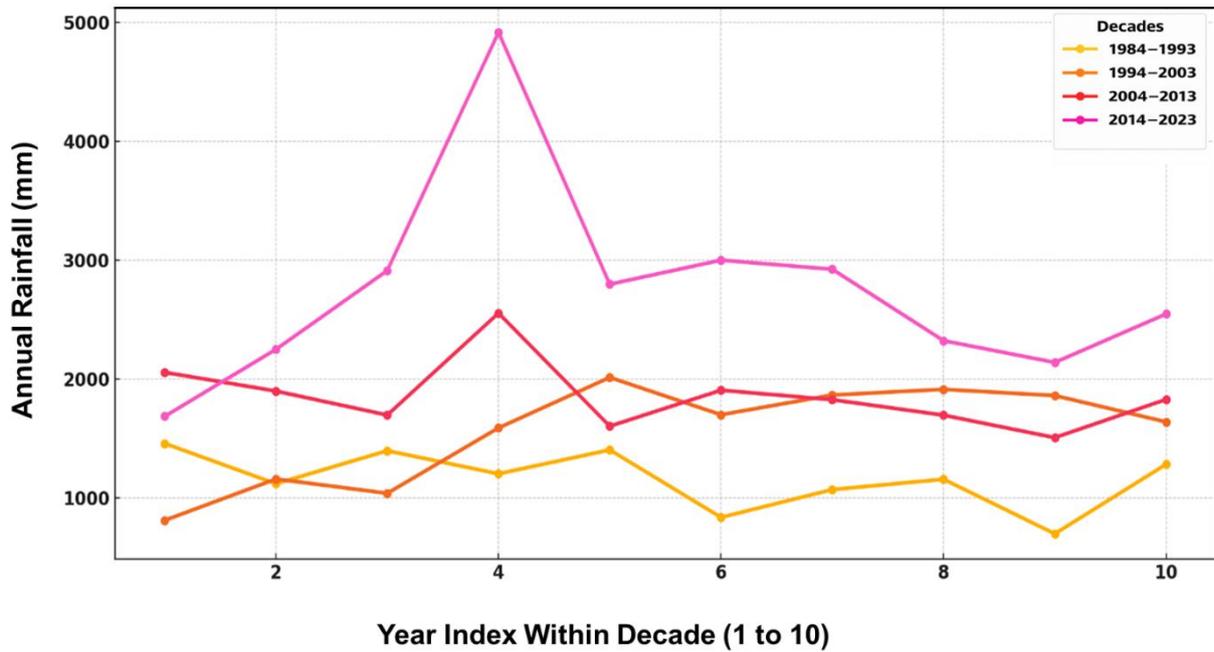


Figure 5. Illustration of rainfall trends in Dhaka from 1984 to 2023.

Source: Alam, Montaz, Bhuiyan, and Baby (2019) and Jihan et al. (2025).

Figure 5 shows the decadal rainfall trends in Dhaka (1984 to 2023). This line chart illustrates the annual rainfall trends in Dhaka across four decades: 1984–1993, 1994–2003, 2004–2013, and 2014–2023. According to the data, from 2014 to 2023, there was an increase in rainfall for the most recent period, with a few years exceeding 3000 mm and a peak near 5000 mm, which is significantly higher than previous decades. On the other hand, earlier decades show relatively stable and lower rainfall patterns, with most of them ranging between 1000 mm and 2500 mm each year. From this trend, rainfall events have increased in recent years, perhaps indicating a shift in local climate patterns soon.

4. RESULTS AND ANALYSIS

This study aimed to forecast long-term rainfall patterns in Dhaka using the SARIMAX model and estimate the hydropower generation potential based on these projections. Historical daily rainfall data from 1981 to 2025 were sourced from the NASA POWER (Duarte & Sentelhas, 2020; Rodrigues & Braga, 2021) database and aggregated into annual totals. The forecasting period extended from 2026 to 2045, yielding a 20-year monthly forecast that was also aggregated for annual comparison.

4.1. Historical Rainfall Overview

The previously recorded rainfall data is shown in Table 1. The experienced historical rainfall was seen to vary significantly from year to year, which indicates irregular monsoon behavior, with the amounts varying from the lowest of approximately 699 mm in 1992 to the highest of over 4914 mm in 2017 (Ahammed & Hewa, 2012). The highest rainfall recorded was in 2017, indicating a wet year, while 1992 saw the lowest rainfall, indicating a significant decline in precipitation.

Over the past 10 years, mean yearly rainfall has ranged from approximately 1700 mm to 2400 mm, reflecting monsoon variability and dry spells. Dhaka has a tropical monsoon climate, with most rainfall occurring between May and September; thus, the rainfall pattern is distinctly seasonal. These extreme variations in rainfall over time demonstrate alternating wet and dry cycles that may affect the predicted rainfall amount.

Table 1. Historical yearly rainfall data.

Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)
1981	1506	1996	1040	2011	1697
1982	1401	1997	1589	2012	1508
1983	997	1998	2014	2013	1829
1984	1459	1999	1700	2014	1686
1985	1120	2000	1866	2015	2250
1986	1398	2001	1914	2016	2912
1987	1204	2002	1861	2017	4914
1988	1405	2003	1640	2018	2797
1989	837	2004	2056	2019	3000
1990	1071	2005	1899	2020	2923
1991	1158	2006	1697	2021	2323
1992	699	2007	2554	2022	2140
1993	1283	2008	1604	2023	2547
1994	812	2009	1906	2024	3053
1995	1160	2010	1827	2025	2318

4.2. Forecasted Rainfall Using SARIMAX

Historical rainfall data in Dhaka show significant seasonal variation, with recorded totals ranging from approximately 998 mm in 1983 to about 2044 mm in 1996. The annual average rainfall over the past decade fluctuated between roughly 1700 mm and 2400 mm, influenced by changes in the monsoon and intermittent dry periods. Rainfall predominantly occurs from May to September, leaving the remainder of the year largely rain-free.

The SARIMAX model (Alharbi & Csala, 2022; Ampountolas, 2021) was configured using specific humidity and surface temperature as exogenous regressors. The new predictions for 2026-2045 ranged from 2346 mm to 2806 mm, with a clear monsoon pattern remaining. The model also estimates a moderate increase in annual precipitation compared to the historical norm, likely related to higher temperatures and increased vapor content in the air.

The model predicts a strong and consistent future monsoon pattern, suggesting that these weather systems will be more stable or slightly more powerful; thus, they will not only increase the city's risk of water resource mismanagement but also point to unused energy resources.

Now, the forecasted rainfall values in Table 2 show a gradual upward trend over 20 years, indicating a potential shift toward wetter climatic conditions. The predicted rainfall fluctuates slightly from year to year, highlighting interannual variability, but the overall rise from approximately 2346 mm in 2026 to around 2807 mm in 2045 suggests a long-term upward pattern.

Table 2. Forecasted rainfall data from 2026 to 2045.

Year	Forecasted rainfall (mm)	Year	Forecasted rainfall (mm)
2026	2346	2036	2589
2027	2371	2037	2613
2028	2395	2038	2637
2029	2419	2039	2661
2030	2443	2040	2686
2031	2467	2041	2710
2032	2492	2042	2734
2033	2516	2043	2758
2034	2540	2044	2783
2035	2564	2045	2807

4.3. Comparative Analysis

The comparison between the two years shows that the anticipated numbers surpass the long-run averages quite significantly, particularly in the first few years of the forecast horizon. A case in point is that in 2025, the forecast

exceeds 2300 mm, a value higher than the median in historical data. This situation is maintained over the period of 2018-2023, which underscores the power of the SARIMAX model in capturing signals from atmospheric variables responsible for long-term climatic changes.

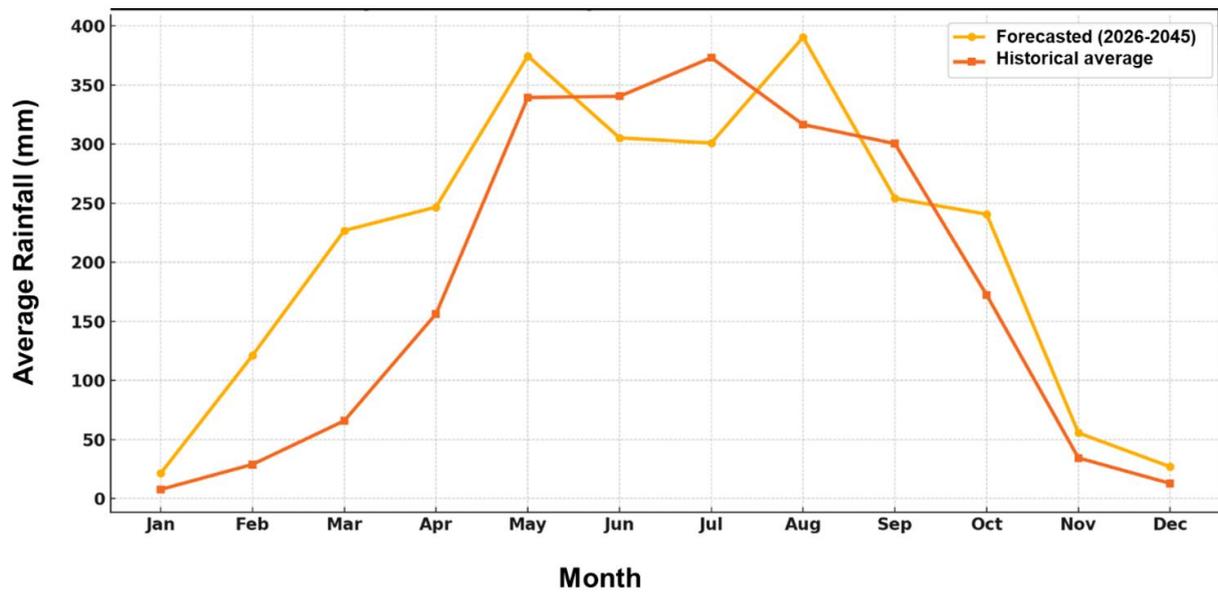


Figure 6. Comparison of monthly rainfall between historical and forecasted data.

Figure 6 shows a comparative analysis of monthly average rainfall between historical data and forecasted data for the period 2026 – 2045. The historical data show a gradual increase in rainfall from January, reaching a peak in July, and then a steady decline until December. The forecasted data also follow a similar pattern with some significant differences. It is interesting to note that the rainfall is considerably higher from January to May compared to historical values. Forecasted values peak in June, while historical data peak in July; therefore, the peak shifts slightly earlier, with forecasted values peaking in June. After July, the forecasted rainfall drops faster and remains somewhat lower than historical values from August to October. Both datasets, however, display minimal rainfall in November and December, though the forecasted values are slightly higher than historical values in December.

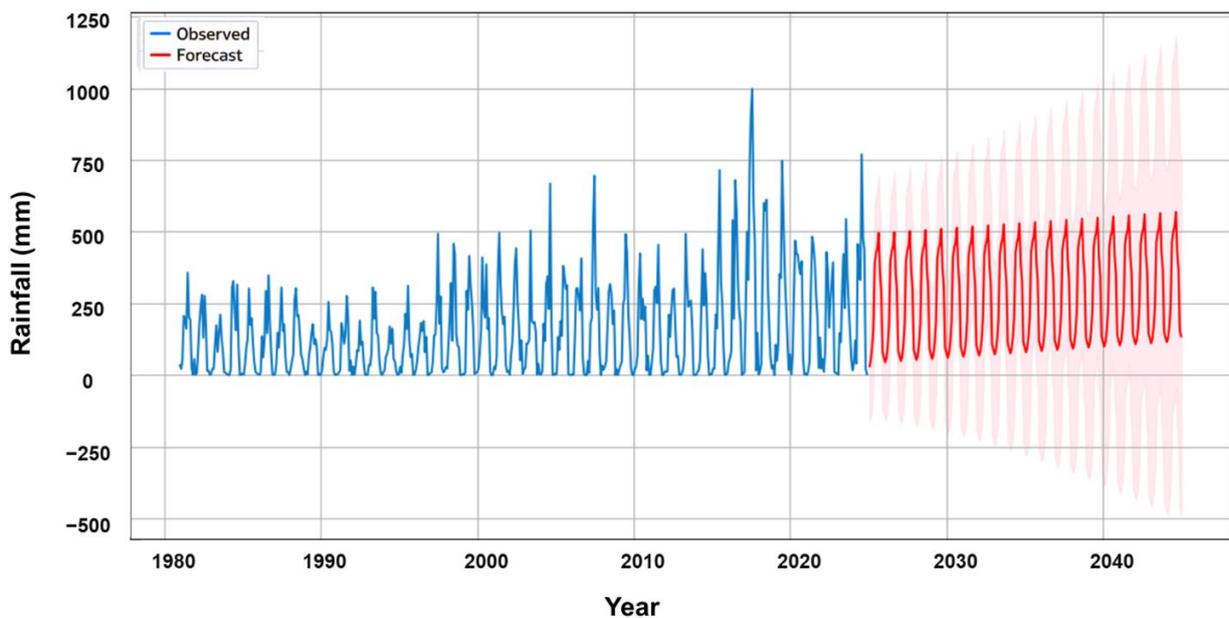


Figure 7. Forecasted monthly rainfall using the SARIMAX model.

The observed and forecasted monthly rainfall data by the SARIMAX model are shown in Figure 7. The historically observed rainfall data, indicated by the blue line, displays clear seasonal variation with recurring peaks and troughs over the years. The red line indicates the forecasted rainfall values between 2026 and 2045. The comparison between historical rainfall and forecasted rainfall (2026 to 2045) shows a clear transition from high interannual variability in the recent past to a gradually decreasing trend in future projections. The forecasted data follows a seasonal pattern but reveals a smoother tendency compared to the historical data. It is important to note that the red shaded area around the forecasted line indicates the uncertainty surrounding the forecast. Also, the forecast results indicate a steady increase in rainfall amounts, whereas the historical data shows irregular climatic behavior with quick rises and falls.

4.4. Validation

To ensure rainfall forecasts serve as reliable input for hydropower potential estimation, a validation step was conducted by comparing SARIMAX-predicted data (for 2035-2045) with observed rainfall data from the most recent decade (2014-2025). The total observed rainfall during this 12-year reference period was 30,551.75 mm, while the forecasted rainfall was 29,541.75 mm. This results in an absolute error of 1,010 mm and a percentage error of only 3.31%, calculated using the formula.

$$\text{Percentage of error} = \left(\frac{|\text{Actual Total} - \text{Forecasted Total}|}{\text{Actual Total}} \right) \times 100$$

$$\text{Percentage of error} = \left(\frac{|30551.75 - 29541.75|}{30551.75} \right) \times 100 = \left(\frac{1010.00}{30551.75} \right) \times 100 = 3.31\%$$

Because of the low error margin, even upon long-term feasibility analysis, the predictions given by the SARIMAX model can still be regarded as accurate enough to serve as a benchmark. In other words, this enables the goal of the study, which is the approximate calculation of the theoretical amount of rainwater wasted annually in Dhaka, and how renewable energy production can be obtained in ideal runoff conditions, to be achieved. Despite some obstacles in real reproduction, the mentioned approach to forecasting remains a powerful one concerning concept energy planning with the help of historical and future precipitation conditions.

4.4.1. Rainfall Forecast Summary

The SARIMAX model, validated through historical comparison, projected a yearly rainfall range of 2,346 mm to 2,807 mm for 2026 to 2045. The average forecasted annual rainfall over these 20 years was calculated to be approximately 2,564.24 mm/year.

This value represents the mean expected precipitation across the city for each year during the forecast horizon.

4.4.2. Catchment Area

For this study, the total land area of the Dhaka City Corporation, comprising both Dhaka North and South, was considered (Kabir & Parolin, 2012; Pramanik & Stathakis, 2016; Uddin, Khan, Islam, Kamruzzaman, & Shahid, 2022). The official combined land area is: $305.47 \text{ km}^2 = 305,470,000 \text{ m}^2$

4.4.3. Power Generation

Figure 8 illustrates the schematic of the proposed small power conversion unit. To convert the volume of water into a continuous power estimate, the following standard hydropower formula is used (Karim et al., 2021; Sritram & Suntivarakorn, 2017).

$$P = C \cdot \eta \cdot \rho \cdot g \cdot Q \cdot H \quad (4)$$

Where,

C = Runoff coefficient.

$\eta = 0.80$ (Assumed system efficiency, or 80%).

$\rho = 1000 \text{ kg/m}^3$ (Density of water).

$g = 9.81 \text{ m/s}^2$ (Gravitational acceleration).

$H = \text{Head}$.

The flow rate is derived from annual rainfall.

$$Q = \frac{\text{Volume}}{\text{time}} = \frac{\text{Catchment Area} * \text{Annual rainfall depth}}{\text{time}}$$

$$= \frac{305,470,000 * 2.56424}{31,536,000 \text{ s}} \approx 24.83 \text{ m}^3/\text{s}$$

$$= \frac{783,298,393 \text{ m}^3}{31,536,000 \text{ s}} \approx 24.83 \text{ m}^3/\text{s}$$

And the power generation

$$P = C \times 0.80 \times 1000 \times 9.81 \times 24.83 \times H = 194,930.4HC \text{ Watt} = 0.195HC \text{ MW}$$

Under an average runoff coefficient of 0.60 (Matin, Moniruzzaman, Rowsan, & Toushif, 2016; Sifa, Nila, Hossain, & Hayat, 2024) and different heads, the power generation could be as follows:

For $H = 1.0 \text{ m}$, $P = 0.117 \text{ MW}$.

For $H = 2.0 \text{ m}$, $P = 0.234 \text{ MW}$.

For $H = 3.0 \text{ m}$, $P = 0.351 \text{ MW}$.

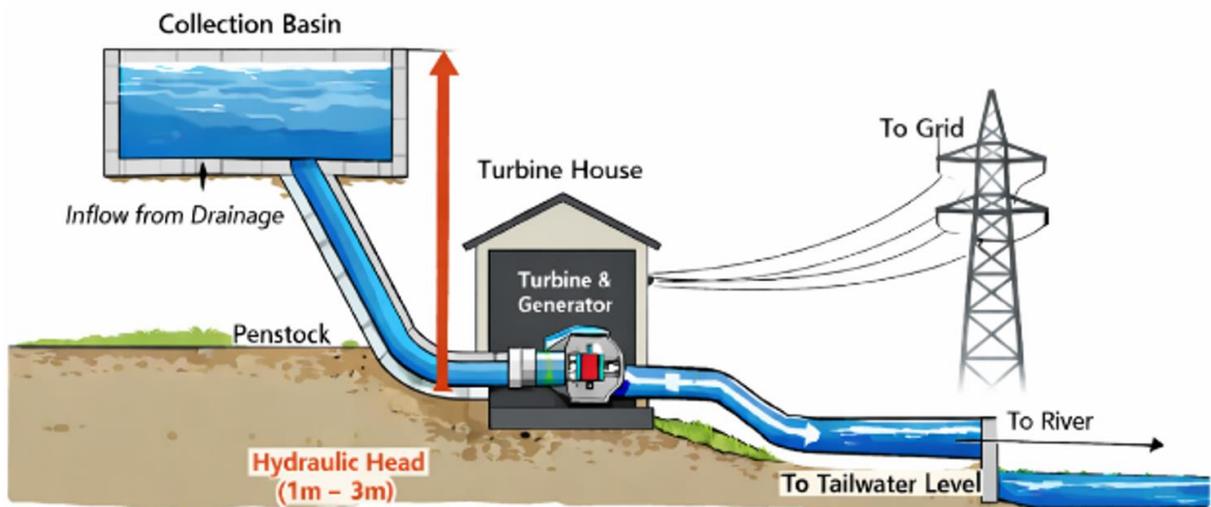


Figure 8. Proposed small hydropower system.

5. DISCUSSION

The scope of this study involved an analysis of the case study of the city of Dhaka to determine whether it is possible to generate hydropower from collected rainfall in an urban area where a significant waterlogging problem occurs, along with poor management of the sewage system. The study shows that the large amount of precipitation during the monsoon season, as experienced by Dhaka, and the building of stormwater management systems, contain good potential for small-scale hydropower. This would address flooding and provide an elaborate network of rainwater turbines used to generate clean energy from runoff.

Likewise, the sewer systems of Dhaka, which carry a large quantity of sewage water in one trip, present an opportunity for generating energy using low-head hydropower systems, despite difficulties in flow characteristics and wastewater sizes.

At the same time, several constraints came to light: systems that did not consider seasonal patterns in rainfall or were never maintained, water supply infrastructure, and very high levels of pollution. Another problem is that the

business climate in Dhaka remains unfavorable for developing new urban hydropower solutions. To overcome these limitations, it will be necessary to develop infrastructure for upgraded methods concurrently with a policy approach designed to encourage investment in renewable energy technologies, as well as an effective water quality management approach.

Dhaka has the potential for hydroelectric power generation from rainwater and sewerage inflows. However, significant investments in infrastructure, policy development, and technical advancements are crucial. Including additional renewable sources, more researchers should consider conducting pilots to verify the system's scalability and efficiency. Strategies suggest this could provide Dhaka with a sustainable, dependable energy source while effectively controlling urban flooding.

6. CONCLUSIONS

This paper presents a systematic evaluation of prospective electricity generation from rainfall in Dhaka using data and fundamental principles. Here, we employed a time-series model for rainfall prediction and probable power generation from this rainfall. The predominant findings demonstrated that:

- a. Dhaka receives a considerable volume of rain annually (~2,564 mm forecasted average).
- b. This rainfall, over its 305.47 km² land area, amounts to ~783 million m³ of theoretical water input per year.
- c. Averaging a runoff coefficient of 0.60 and 80% system efficiency, the results showed that Dhaka's annual rainfall could generate approximately 0.117 MW, 0.234 MW, and 0.351 MW of continuous power under 1 m, 2 m, and 3 m head, respectively.

Even though the model is not practical and the conditions assumed are ideal, urban rainwater is still considered a resource that remains untapped for power. On the contrary, if this water is harvested, at least a small part of it, better urban water management, flood mitigation, and sustainable electricity generation are possible. It is expected that this study will also persuade policymakers, engineers, and urban planners to consider rainwater as another form of renewable energy, rather than simply a drainage problem in a city. Among the many advantages of clean energy, none is more beneficial than securing the future of a densely populated and energy-starved city like Dhaka. The production of a megawatt of clean energy, particularly one that does not depend on rainfall, contributes significantly to building a resilient and environmentally friendly future in Dhaka, a city with high energy demand.

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Institutional Review Board Statement: This study was conducted as part of an undergraduate thesis and did not require formal IRB approval according to our institutional policy.

Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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