

Assessment of Water Availability and Variability under Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.2 of Agos River in Quezon, Philippines

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Abstract

This study assesses the variability of water availability in the Agos Watershed from 2025 to 2044 under Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5, highlighting the potential hydrologic impacts of climate change. Using the Statistical DownScaling Model (SDSM), rainfall projections were statistically downscaled and bias-corrected through its integrated Variance Inflation Method (VIF). The model was calibrated using observed rainfall data from 2003 to 2023, with 70% allocated for calibration, enhancing the reliability of rainfall and river inflow simulations. Results reveal consistent seasonal peaks in October and November, with annual rainfall under RCP 8.5 reaching a projected maximum of 4,470.10 mm by 2032—substantially higher than 3,836.87 mm (RCP 2.6) and 3,720.63 mm (RCP 4.5). These rainfall trends correspond to inflow peaks of 218.69 m³/s, 217.47 m³/s, and 211.53 m³/s, respectively. While increased inflows enhance short-term availability, drier months such as February and May reflect potential periods of scarcity. Findings underscore the importance of climate-informed water management strategies, emphasizing adaptive infrastructure, conservation measures, and integrated planning to bolster the watershed's resilience.

1.0 INTRODUCTION

Water resources are one of the highly stressed natural resources due to growing population and the continuously changing land use and development. It is also severely affected by the increasing pollution and changing weather patterns due to climate change. Climate change affects rainfall and runoff patterns which can have a serious impact on the availability of surface water.

Concentration of greenhouse gases (GHG) in the atmosphere has significantly increased over the years due to different human activities. As a result, global warming has increased notably and is causing an impact and alterations to the precipitation patterns and global temperatures affecting the ecosystems directly and indirectly according to the 2021 report of the Intergovernmental Panel on Climate Change (IPCC). In recent years, this issue of global warming and climate change has gained so much attention from many individuals, scientists, policy makers, and researchers. Groups of scientists and researchers were established worldwide to study the rising concerns about global warming to predict future risks and to create adaptation and mitigation plans.

Climate models, while providing valuable insights into large-scale climate patterns, often lack the spatial resolution necessary to capture localized variations in precipitation and temperature. Downscaling methods bridge this gap by refining coarse-scale climate model outputs to a finer resolution, enabling a more accurate representation of regional climate conditions [1]. In the context of water availability, downscaling becomes a powerful tool to assess the impacts of climate change on local hydrological cycles. Statistical downscaling method correlates variable global climate data and local scenarios using Global Circulation Model (GCM) or Regional Climate Model (RCM) to predict future scenarios [2].

Global warming and climate change are inevitable events as countries in the world move towards development. The huge amount of carbon dioxide (CO₂) emission due to different human activities has always been the major contributor to the continued warming of global temperatures. Studies conducted in country like China have shown that warming and significant increase in precipitation will be experienced all over the country under different Representative Concentration Pathway (RCP) scenarios [3]. RCPs are pathways that are consistent with a set of broad climate outcomes used by the climate modelling community [4]. There are four main RCP scenarios—2.6, 4.5, 6.0, and 8.5, with the higher

value indicating higher CO₂ concentration.

RCP scenarios are widely used in hydrological studies to project future climate impacts on water resources. The study of Monjardin et. al. on water availability and variability in Bauan, Batangas, Philippines applied RCP2.6, RCP4.5, and RCP8.5 scenarios to assess precipitation and inflow changes over a 20-year period. Using HEC-HMS, researchers simulated rainfall-runoff processes and found that RCP8.5 projected the highest average inflow (541.8 m³/s), while RCP2.6 showed the lowest inflow values (406.5 m³/s) [2]. This highlights how different emission scenarios influence water availability, with higher emissions leading to increased hydrological variability. Another study in Santa Cruz Watershed in Laguna, Philippines examined the combined effects of rainfall variability and land cover changes using HEC-HMS and RCP projections. Researchers bias-corrected five General Circulation Models (GCMs) under RCP4.5 and RCP8.5 to assess future hydrological responses. Findings indicated that peak discharge and total runoff volume would increase under high-emission scenarios, with earlier peak flow occurrences due to intensified rainfall patterns. This study underscores the role of climate change in modifying watershed hydrology and increasing flood risks [5].

HEC-HMS has also been extensively used to estimate water potential and runoff dynamics in various river basins. A study on the Punpun River Basin developed a rainfall-runoff model using daily, monthly, and monsoonal rainfall data from 2005 to 2017. The study demonstrated that monthly models performed better in predicting hydrological responses, with R² and Nash-Sutcliffe efficiency (NSE) values exceeding 0.75, indicating strong model reliability [6]. This reinforces the effectiveness of HEC-HMS in simulating hydrological variability under different climatic conditions.

These studies demonstrate the critical role of RCP scenarios and HEC-HMS in assessing water variability under climate change conditions. High-emission scenarios (RCP8.5) consistently project increased runoff and peak discharge, emphasizing the need for adaptive water management strategies. The integration of land cover changes, bias-corrected climate models, and hydrological simulations enhances the accuracy of water variability assessments, aiding in flood risk mitigation and sustainable water resource planning.

In the Philippines, the Agos River provides an essential supply of water for the nearby settlements. Its hydrological behavior is influenced by the varied terrain it flows through, which includes lowland and mountainous areas. There are distinct rainy and dry seasons in the river basin's tropical environment. Throughout the year, the river's flow and water availability are greatly impacted by rainfall patterns, which are mostly caused by typhoons and monsoons.

Seasonal variations as well as outside influences like deforestation and changes in land use have caused the Agos River's water flow to fluctuate. Historically, the rainy season produced the highest discharges, while the dry months produced the lowest discharge. According to studies, the river has seen water level variations that have an impact on local ecosystems, agriculture, and hydropower potential [7]. Furthermore, predictions of climate change indicate that future hydrological patterns might change, which could result in more severe floods or droughts.

Continuous monitoring, advanced modeling techniques, and interdisciplinary collaboration will be essential in ensuring the long-term stability of water resources. Strengthening conservation initiatives and adaptive management approaches will enhance water security, helping mitigate the detrimental effects of climate change on hydrological systems.

Given projected shifts in precipitation due to increased greenhouse gas concentrations, it is hypothesized that rainfall and surface water inflow in the Agos Watershed will significantly vary across RCP scenarios. Compared to low-emissions scenarios (RCP 2.6), excessive emissions pathways (RCP 8.5) are anticipated to result in more severe hydrological responses and seasonal variations.

The aim of this study is to predict the future scenario of Agos river in terms of water availability and variability for the next 20 years with specific objectives as follow: a) Determine the appropriate General Circulation Model (GCM) and predictors for the downscaling process b) Generate downscaled climate data using the Statistical DownScaling Model (SDSM) to predict future precipitation levels under RCP 2.6, RCP 4.5, and RCP 8.5, and c) Simulate hydrologic scenarios using the generated climate data to forecast future water availability and variability conditions of Agos river using HEC-HMS.

2.0 METHODOLOGY

The conceptual framework below outlines the process used to evaluate rainfall activity and water availability within a watershed using statistical downscaling and simulation models. It shows the step-by-step method applied to assess climate scenarios and their impact on water resources.

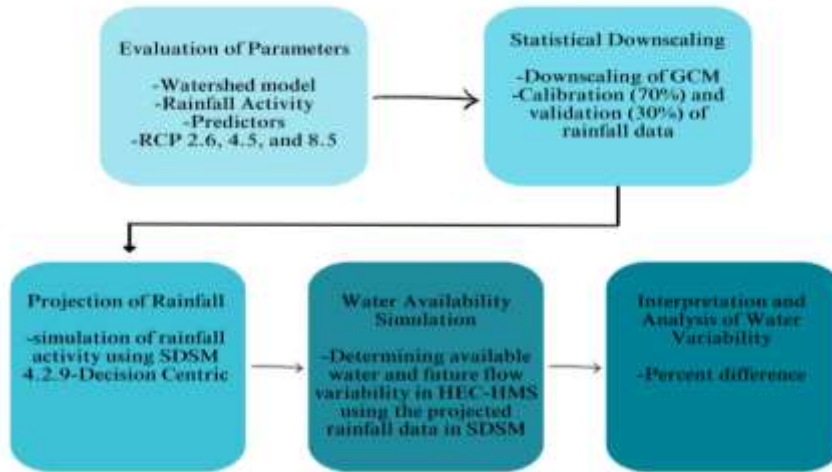


Figure 1: Conceptual framework

2.1 Data Gathering

To assess future water variability in the Agos watershed, this study collects data on both historical climate data and global climate projections. PAGASA provided historical rainfall data, providing realistic local climatic trends for validation and calibration. Large-scale climate scenarios required for statistical downscaling were obtained from the IPCC's global climate model results. To improve precipitation estimates under RCP 2.6, RCP 4.5, and RCP 8.5, these datasets were analyzed using SDSM. Additionally, HEC-HMS hydrological modeling incorporated the downscaled data to simulate future runoff patterns and river flow variations. GIS applications were utilized for spatial analysis, mapping hydrological features and assessing surface water distribution as shown in Figure 2. This integrated approach ensures data reliability and accuracy, allowing for a thorough assessment of the Agos watershed's future water availability conditions.



Figure 2. Basin Model of Agos Watershed

2.1 Downscaling and Simulation

In this research, the coarse global climate model (GCM) outputs from the IPCC CMIP5 dataset are converted into more localized precipitation predictions using the Statistical Downscaling Model (SDSM). Realistic future forecasts under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios were projected by the selection of appropriate predictive parameters, which ensures that the downscaled climatic data correlates with historical rainfall records acquired from PAGASA. In order to bridge the gap between local hydrological estimates and large-scale climatic projections, this step is essential.

Following the projection, the downscaled precipitation data was used into the HEC-HMS hydrological model, which models the rainfall-runoff relationship, changes in streamflow, and total water availability in the Agos river for the next 20 years. To improve accuracy and dependability, historical hydrological records are used throughout the model calibration and validation phases. By using this method, the study makes sure that surface water variability simulations accurately represent how watersheds react to climate change.

Additionally, the methodology incorporates GIS-based spatial analysis, which enables a thorough representation of the watershed's hydrological trends and surface water distribution. A comprehensive understanding of anticipated hydrological responses is ensured by this geospatial analysis, which improves the study's capacity to comprehend the effects of climate variability at both temporal and spatial scales.

In order to assess potential impacts on runoff and streamflow, the study employs concepts from rainfall-runoff theory through HEC-HMS modeling, which is based on the conversion of precipitation into hydrographs via abstraction, infiltration, and routing mechanisms. It uses channel flow routing techniques, lag time equations, and the SCS-CN method to simulate watershed response. Forecasting the cascade of changes in climatic input variables into hydrologic outputs is made easier by these theoretical techniques.

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a conceptual rainfall-runoff model used to simulate surface water inflow based on the downscaled rainfall data. This study applied the Loss Model - SCS Curve Number (CN) Method to estimate direct runoff (Q) from rainfall (P):

$$Q = \frac{(P - Ia)^2}{(P - Ia) + s}$$

Where:

P is the total rainfall depth.

Initial abstraction (Ia) = 0.2S

Potential maximum retention (S) = (1000/ CN) - 10

Curve Number (CN) which is derived from land use, soil type, and antecedent moisture conditions.

2.3 Data calibration and validation

Validating the downscaled climate data is the first step in the analytical process, which makes sure that precipitation estimates from the Statistical DownScaling Model (SDSM) match actual historical rainfall records obtained from PAGASA. Statistical correlation tests, which evaluate how well the downscaled precipitation data matches historical trends, are used to accomplish this validation. Precipitation variability is examined over time using descriptive statistical techniques including mean, variance, and trend analysis to see if anticipated future rainfall deviates significantly from historical data.

After climate estimates have been validated, the hydrological simulation phase is carried out using HEC-HMS. In this phase, downscaled precipitation values are used as input to evaluate changes in surface water availability, runoff patterns, and river flow. Model calibration and sensitivity analysis improve the accuracy of hydrological estimates by fine-tuning model parameters by comparing simulated runoff results with historical hydrological records.

Furthermore, hydrological responses to various climatic trajectories can be compared using scenario-based models under RCP 2.6, RCP 4.5, and RCP 8.5, offering insight into possible long-term trends in water resources.

III. RESULTS & DISCUSSION

This chapter shows the results of the study on rainfall and river inflow in the Agos Watershed from 2025 to 2044. It explains how rainfall and water levels may change under different climate scenarios and what these changes might mean for water use and planning in Quezon Province.

Table 1. Average Monthly Rainfall (2025-2044)

MONTH	RCP 2.6	RCP 4.5	RCP 8.5
January	11.80	11.65	11.57
February	10.05	10.10	9.58
March	3.56	3.55	3.47
April	4.72	4.76	4.62
May	4.02	3.51	3.12
June	4.14	4.29	4.98
July	10.86	10.76	10.03
August	6.36	5.89	6.84
September	13.67	13.44	13.89
October	20.25	19.79	20.46
November	27.01	28.15	27.25
December	18.37	18.62	20.15

Table 1 shows the projection of average monthly rainfall from 2025 to 2044 under various Representative Concentration Pathways (RCPs). Seasonal variations are modest in RCP 2.6, 4.5, and 8.5 scenarios when comparing the average monthly rainfall from 2025 to 2044. Notably, May shows a sharp decline in rainfall under RCP 8.5—roughly 22.4% less than under RCP 2.6 and 11.1% less than under RCP 4.5—indicating increased risks of water scarcity during this crucial dry-to-wet season transition. June, August, and December, on the other hand, exhibit notable increases in rainfall in RCP 8.5, with June rising by more than 20% in comparison to RCP 2.6 and August rising by 16.1% in comparison to RCP 4.5. These findings indicate a potential intensification of off-peak wet periods, which may strain stormwater infrastructure or disrupt agricultural cycles. While peak-rainfall months like October and November remain relatively stable, a notable increase of nearly 10% in December rainfall under RCP 8.5 suggests a subtle shift in seasonal rainfall distribution extending later into the year.

Table 2. Average Monthly Inflow (2025-2044)

MONTH	RCP 2.6	RCP 4.5	RCP 8.5
January	130.12	126.84	127.02
February	108.61	109.18	103.74
March	40.42	40.46	43.11
April	51.14	51.30	49.95
May	43.81	38.56	34.66
June	45.98	46.78	54.05

July	115.19	114.26	106.69
August	69.79	65.32	74.94
September	146.15	143.79	148.46
October	217.47	211.53	218.69
November	289.22	302.86	291.35
December	199.19	202.07	220.54

Table 2 shows the rainfall variability, the analysis of average monthly inflow from 2025 to 2044 shows clear seasonal fluctuations among the three RCP scenarios. RCP 8.5 shows a significant decrease in inflow in May of about 34.66 m³/s, 20.9% less than RCP 2.6 and 10.1% less than RCP 4.5, highlighting the increased susceptibility to water scarcity at the conclusion of the dry season. In contrast, June (54.05 m³/s), August (74.94 m³/s), and December (220.54 m³/s) have significantly larger inflows in RCP 8.5, with December inflow surpassing RCP 2.6 by 10.7% and RCP 4.5 by 9.1%. These changes imply that situations with higher emissions intensify inflows outside of the usual peak months, which could put current flood prevention and storage technologies to challenge. Although October and November continue to be the months with the highest inflows in all scenarios, the slight variations between them suggest that seasonal peaks are comparatively constant.

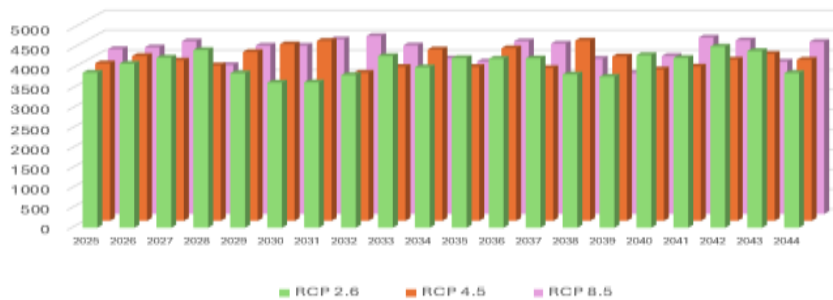


Figure 2. Comparison of Total Annual Rainfall (in mm) Under Different RCP Scenarios (2025-2044)

Significant variability and trends shown in Figure 2 are highlighted by the estimated total annual rainfall for Quezon Province under various Representative Concentration Pathways (RCPs) from 2025 to 2044. In comparison to RCP 2.6 and RCP 4.5, RCP 8.5 typically exhibits increased annual rainfall, especially in years like 2025, 2026, and 2031. This suggests that over time, larger emissions and concentrations of greenhouse gases may result in more rainfall overall.

Average Annual Inflow

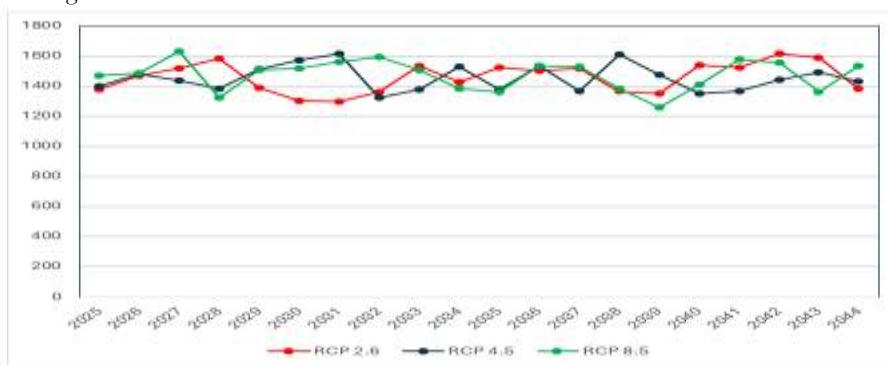


Figure 3. Comparison of Average Annual Inflow (in m³/s) Under Different RCP Scenarios (2025-2044).

Figure 3 shows that under various Representative Concentration Pathways (RCPs), the estimated average annual inflow for the Agos River in Quezon Province from 2025 to 2044 exhibit notable fluctuation, suggesting possible shifts in water availability brought on by climate change. In general, RCP 8.5 indicates a tendency towards larger inflows under higher emission scenarios by projecting higher inflow values in specific years, such as 2025, 2026, and 2027. RCP 8.5, for instance, displays an inflow of 1631.72 m³/s in 2027, as opposed to 1516.94 m³/s and 1438.27 m³/s under RCP 2.6 and 4.5, respectively. With RCP 8.5, inflows are lower in years like 2028 and 2039, which may be a sign of less water available times.

In summary, significant variability and trends under various Representative Concentration Pathways (RCPs) are highlighted by the data sets that are supplied, which include the average annual inflows and anticipated monthly and yearly rainfall for the Agos River in Quezon Province from 2025 to 2044. Higher emission scenarios, especially RCP 8.5, generally forecast higher rainfall and inflow values during specific months, such October and December, as well as years, like 2025 and 2026. These trends imply that increased concentrations of greenhouse gases may result in greater precipitation and river inflow, which would affect agricultural practices, flood hazards, and water resource management.

On the other hand, there are times, like 2028 and 2039, when less rainfall and inflow are anticipated, which suggests possible variations in the amount of water available. These results highlight the necessity of strong, flexible approaches to infrastructure development and water management to lessen the effects of climate change. Considering the changing climate, it is imperative to comprehend these anticipated patterns to ensure sustainable resource management and efficient planning in Quezon Province. This unpredictability emphasizes how crucial it is to use adaptive water resource management techniques to deal with both times of less influx, which could have an impact on agricultural operations and water supply, and greater inflow events, which could cause flooding.

IV. CONCLUSION

This study on the water variability revealed significant variations in rainfall and inflow patterns in the Agos watershed from 2025 to 2044 under various Representative Concentration Pathway (RCP) scenarios—RCP 2.6, RCP 4.5, and RCP 8.5—underscoring the possible effects of climate change on regional hydrology. The monthly rainfall patterns exhibit significant annual fluctuation, albeit being constant across scenarios with October and November peaks. In 2032, for example, annual rainfall peaks at 4,470.10 mm under RCP 8.5, while it peaks at 3,836.87 mm for RCP 2.6 and 3,720.63 mm for RCP 4.5. More strong and frequent rainfall episodes are indicated by this scenario, which also typically shows the highest annual rainfall, such as 4,553.30 mm in 2042. These trends in rainfall are closely followed by the Agos River's inflow patterns. The October inflow, for instance, is 218.69 m³/s under RCP 8.5, but it is 217.47 m³/s under RCP 2.6 and 211.53 m³/s RCP 4.5. The potential for greater water availability is highlighted by the larger inflow during months with more precipitation, but it also presents difficulties during dry times, especially in early months like February and May.

These results highlight how crucial it is to create flexible water management plans to deal with both times of surplus water and possible shortages. To ensure availability during dry spells, this involves improving the infrastructure for storing water to collect and hold extra rainfall during peak months. To reduce the hazards associated with shifting precipitation patterns, investments in resilient infrastructure— such as stronger water delivery systems and better drainage networks—are essential.

To ensure proactive planning, policymakers should incorporate climate projections into their water resource management regulations. For example, strategic planning should incorporate extreme weather events and their effects on water resources, especially considering the considerable unpredictability in rainfall and influx predicted under RCP 8.5. The resilience and sustainability of water resources in the Agos River basin will be further improved by putting into practice effective water use techniques, encouraging water conservation, and involving stakeholders in cooperative initiatives. By incorporating these insights, the area can ensure sustainable management and well-informed decision-making while better preparing for the intricate effects of climate change on its essential water supplies.

V. RECOMMENDATIONS

To enhance the scientific and policy relevance of this study, it is recommended to incorporate a more explicit uncertainty analysis that addresses emissions scenario variability, model structural limitations, and internal climate variability. These three sources of uncertainty are widely recognized in climate-impact research and are essential for robust decision-making [8]. Adaptive water management strategies should be expanded to include both engineered and nature-based solutions. For instance, integrating wetland restoration, riparian buffers, and reforestation can complement traditional infrastructure and improve long-term watershed resilience [9] [10]. Demand-side strategies such as water pricing, seasonal allocation, and leakage reduction should also be considered to balance supply and demand, particularly during dry months [11]. Policymakers are encouraged to adopt scenario-based planning frameworks that incorporate climate projections into land use, disaster risk reduction, and agricultural planning [12]. Strengthening institutional coordination across water, climate, and land management sectors will be vital for implementing these strategies effectively. Furthermore, the study could benefit from examining the socioeconomic implications of hydrological variability, particularly its disproportionate effects on marginalized communities and vulnerable livelihood sectors such as agriculture and hydropower [13]. Future research may explore the integration of machine learning techniques for rainfall-runoff modeling, evaluate alternative bias correction methods beyond SDSM's Variance Inflation Method, and expand the scope to include multi-hazard assessments such as landslide and flood risks associated with inflow extremes [14] [15].

To manage flood and water supply risks in the Agos Watershed, it is recommended to use an approach that incorporates climate-driven inflow estimates into a dynamic decision-making system. Under RCP 2.6, 4.5, and 8.5 scenarios, it is intended to react to long-term changes in hydrologic behavior as well as seasonal variability.

As a result of this study, the following climate-adaptive water management framework is recommended:

1. **Input Layer:** Climate-Informed Inflow Data

- a. Downscaled rainfall from SDSM (HadCM3, RCP 2.6/4.5/8.5)
- b. Simulated inflow from HEC-HMS (daily/monthly hydrographs)
- c. Key metrics: peak inflow, seasonal deficits, interannual variability

2. **Decision Layer:** Adaptive Rule-Based Logic

- a. Dry Season (e.g., May, under RCP 8.5):
 - b. Prioritize domestic and agricultural supply
 - c. Suspend non-essential withdrawals
 - d. Activate conservation campaigns
- e. Wet Season (e.g., December, under RCP 8.5):
 - f. Initiate controlled reservoir pre-releases
 - g. Activate flood warning systems
 - h. Adjust dam gate operations based on inflow thresholds

3. **Optimization Layer**

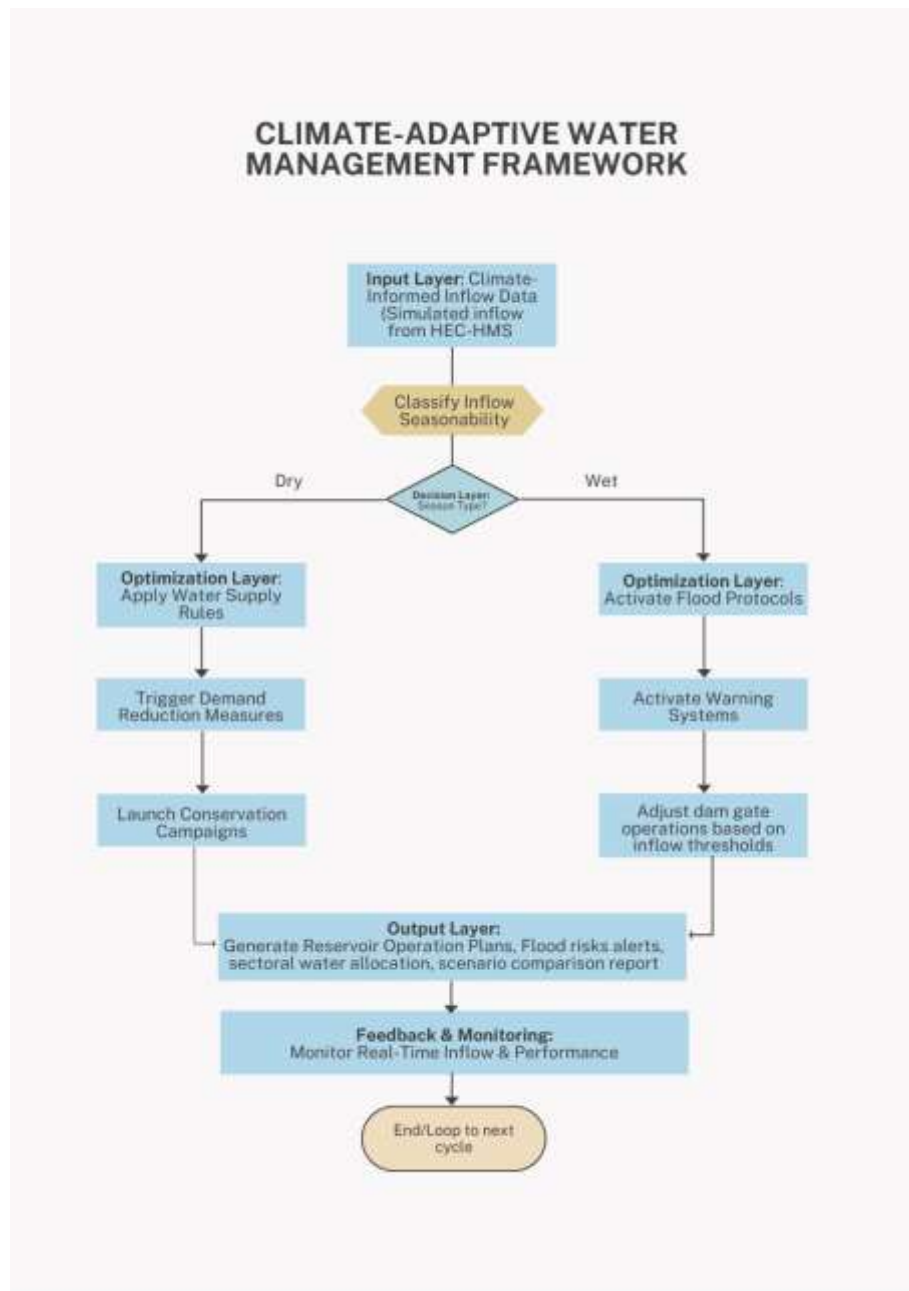
- a. Use multi-objective optimization (e.g., dynamic programming) to: maximize water reliability, minimize flood volume exceedance, and maintain ecological flow thresholds

4. **Output Layer:** Decision Support Tools

- a. Reservoir operation plans (monthly)
- b. Flood risk alerts (threshold-based)
- c. Sectoral water allocation dashboard
- d. Scenario comparison reports (RCP 2.6 vs. 8.5)

5. **Monitoring & Feedback**

- a. Real-time inflow tracking
- b. Seasonal performance review
- c. Adjustment of thresholds and rules based on observed trends



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