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Modeling climate change impact on the inflow of the Magat reservoir using the Soil and Water Assessment Tool (SWAT) model for dam management

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ABSTRACT

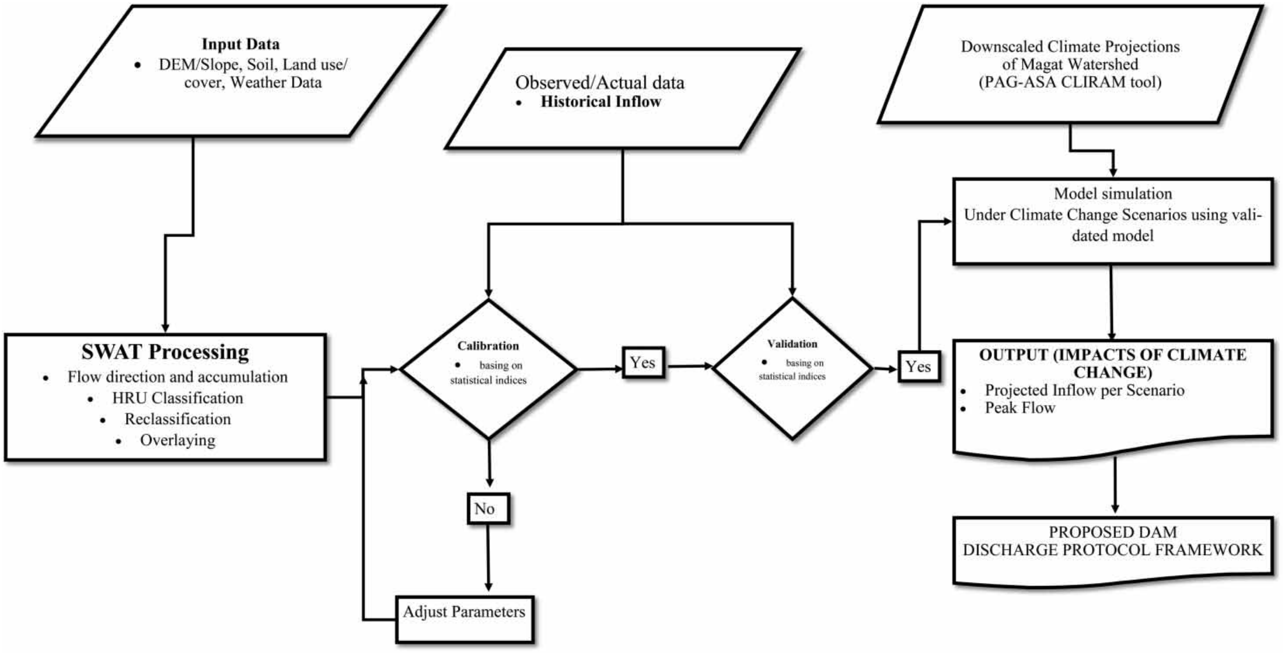
Understanding the impact of climate change on watersheds using hydrologic models is timely and vital to dam management. The study predicts changes in the inflow of the Magat reservoir using the Soil and Water Assessment Tool (SWAT) under the two Representative Concentration Pathway (RCP) scenarios for future centuries. The monthly calibration process (18 years) and validation process (10 years) of the model resulted in an NSE of 0.73, R^2 of 0.74, RSR of 0.52, PBIAS of 8.38, NSE of 0.56, R^2 of 0.62, RSR of 0.66, and a PBIAS of 17.3, respectively. Under RCP 4.5 and RCP 8.5 scenarios, the model predicted that during the dry and normal years, there will be an average decrease of inflow of 18.56 and 5.41% but an increase of 19.25% during the wet years. Peak flow will likely occur in September for all the scenarios, with a maximum discharge of up to 342.46 m^3/s. The study recommends the integration of the model results to update the dam discharge protocol on the forecasting of monthly and annual inflows of the Magat dam to aid the dam management in observing long-term changes in the flow of water going into the reservoir.

Key words: climate change, framework, inflow, Magat reservoir, SWAT, watershed

HIGHLIGHTS

- This study is the first of its kind to imply modeling tools to predict the long-term impacts of climate change on the dam in relation to the Magat reservoir.
- The study establishes its potential as a decision support system for dam management in river basins in the Philippines and other countries.
- The study emphasizes significant decreases and increases in inflow under different climate change scenarios.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The Philippines is extremely vulnerable to climate change. Climate change threatens the country by increasing the intensity and frequency of storms and droughts (Principe 2012). CAD-PAGASA (2004) reported that the country is likely to be adversely affected by climate change since its economy is heavily dependent on agriculture and natural resources. Furthermore, Tolentino *et al.* (2016) stated in their modeling study that the consequences of climate change on Visayas and Mindanao are projected to be relatively mild in comparison to Luzon, where a major rise in return intervals for maximum river flow rates is forecasted. In the Cagayan Valley, Luzon alone, precipitation is anticipated to increase. In terms of seasonality, the dry months (March–April–May) will remain dry, while during the rainy season, July–November will likely become more noticeably wet months. There are also signs that the frequency of heavy rainfall events, protracted dry spells, and extreme daytime temperatures is increasing (especially in Aparri) (Basconcillo *et al.* 2016). In the year 2020, the Philippines observed five consecutive typhoons from the end of October to early November. These disastrous events happened in less than a month, causing damage in different regions of the Philippines – parts of Manila were shut down, the Bicol region was buried in mud, and Cagayan Valley was extremely flooded. From the recent typhoons, in Cagayan Valley alone, almost 151,600 families were affected by the flood caused by the rising of the Cagayan River. The residents were also very eager to point out that the reason for flooding was the release of water from the Magat Dam, although the dam and reservoir management reiterated that the cause of massive flooding was the extreme, continuous rainfall, and deforestation in the whole basin. With incoming typhoons, protocols of dam management include the release of water from the dam. Hence, people from downstream of the dam and the riverine area had a high chance of being flooded, especially with the excessive amount of rain over the past months.

One main impact area of climate change is on the hydrology of watersheds, where alterations in temperature and rainfall directly influence the dynamics and supply of water resources, and in the long run, the present stakeholders will struggle to meet their water requests (Arnell 1999). Different analysts have considered the possible impact of climate change on water quality and quantity in river basins. Thanh Nguyen *et al.* (2020) observed that extreme rainfall and severe river flooding events are anticipated to increase considerably in the future, ranging from 29 to 35% and 37 to 56% increase in rainfall and streamflow, respectively. Azari *et al.* (2016) found that in the Gorganroud River Basin of Iran, climate change led to a 9.5% increase in annual streamflow and that sediment yield could increase by up to 83.9%. In the Philippines, there have been very few studies examining the threat of climate change. For instance, Panondi & Izumi (2021) found that observed changes in maximum mean annual rainfall and maximum and minimum temperature correspond to increases in runoff (44.58–76.80%), and sediment yield (1.33–26.28%).

With climate change, man-made and land cover changes, the inevitable effects of this phenomenon on the hydrology of these watersheds will be evident in the following years. Hydrologic modeling has long been used by researchers to track these changes as they occur along these basins. To evaluate the impact of climate change on water resources, climate model data is integrated into hydrologic models (Nauman *et al.* 2019). The Soil and Water Assessment Tool (SWAT) is one of the most commonly used modeling softwares for assessing hydrologic impacts (Oo *et al.* 2020). It has been recognized worldwide as an effective tool in water resource management for assessing the impact of the climate on water supplies and nonpoint sources of pollution in watersheds (Guiamel & Lee 2020). In the case of the Magat watershed and its reservoir, it is important to understand the impact of climate change on the inflow of the dam using hydrologic models. However, no current studies are being undertaken and there are no model-based forecasts for long-term or seasonal flows.

Taking into account the probability of streamflow changes might help water resource stakeholders make better decisions (Sivakumar 2011; Ouyang *et al.* 2015). Better decisions in this context can be the outcomes of a strong impact assessment toward reducing climate change risks through adaptation strategies, perhaps, for the agriculture sector (Abbasi *et al.* 2020). One of the most difficult aspects of reservoir operations management is estimating inflow parameters accurately (Fourcade & Quentin 1994). Reservoir managers in the Philippines base their inflow estimates on water level information (Sarmiento *et al.* 2010). For instance, the Magat dam reservoir is presently operated by an operation rule curve jointly developed in 1985 to optimize the utilization of the water stored in the Magat reservoir. The 37-year discharge protocol of dam management needs updating using current science-based tools.

In the absence of alternative estimation and forecasting techniques, the Magat reservoir managers adapt their management policies to the present measurements and rainfall statistics. Moreover, the temporal distribution of river discharge, especially the extreme value, brings water-related disasters. Thus, the operation of reservoirs has been a great concern in the field of operational hydrology. It is not easy, however, to construct new facilities to cope with the situation, yet non-facility-based countermeasures like the effective utilization of dam reservoirs are getting more important.

The main objective of this study is to assess the impacts of climate change on the inflow of the Magat reservoir using the SWAT model toward the development of a dam discharge protocol framework. Climate forecasts from the Representative Concentration Pathway (RCP) scenarios were used to project inflow changes in the watershed during the mid- and late-21st centuries. The methodology of the study is presented in Section 2. The results and discussion are presented in Section 3, followed by the conclusion of the study in Section 4.

2. MATERIALS AND METHODS

2.1. The study area

The Magat watershed and its reservoir are located in the northern part of the Philippines, covering major portions of Ifugao, Nueva Vizcaya, and parts of Isabela provinces (see Figure 1). The Magat watershed with its seven sub-basins is highly forested with a predominant soil classification of clay loam and highly steep slopes (see Figure 2). Located within the watershed, the Magat dam and its reservoir are one of the largest dams in the Philippines. It is a multipurpose dam that is used primarily for irrigating 86,887 hectares of agricultural land, flood control, and power generation through the Magat hydroelectric power plant. The dam was constructed in 1978 and completed on October 27, 1982.

2.2. Data used

The spatial data that were used in the study included a 5×5 m resolution Digital Elevation Model (DEM) 2015 of land use/cover, soil classification, and 31-year historical climatic/weather data. The input parameters for reservoir and dam operation were obtained from the National Irrigation Administration Magat River Integrated Irrigation System Dam and Reservoir Division (NIA-MARIIS DRD). The DEM of the Magat watershed, which was extracted from the Digital Terrain Model (DTM) issued by the National Mapping and Resource Information Authority (NAMRIA), was subjected to watershed delineation. Moreover, the weather data were taken from the meteorological station of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), while the daily rainfall data were provided by the NIA-MARIIS DRD specifically from the two rain gauge stations inside the basin. On the other hand, the land cover map was obtained from NAMRIA, while the soil map was from the Bureau of Soil and Water Management (BSWM). Some of the soil and land cover data were validated and gathered from the field survey per subbasin.

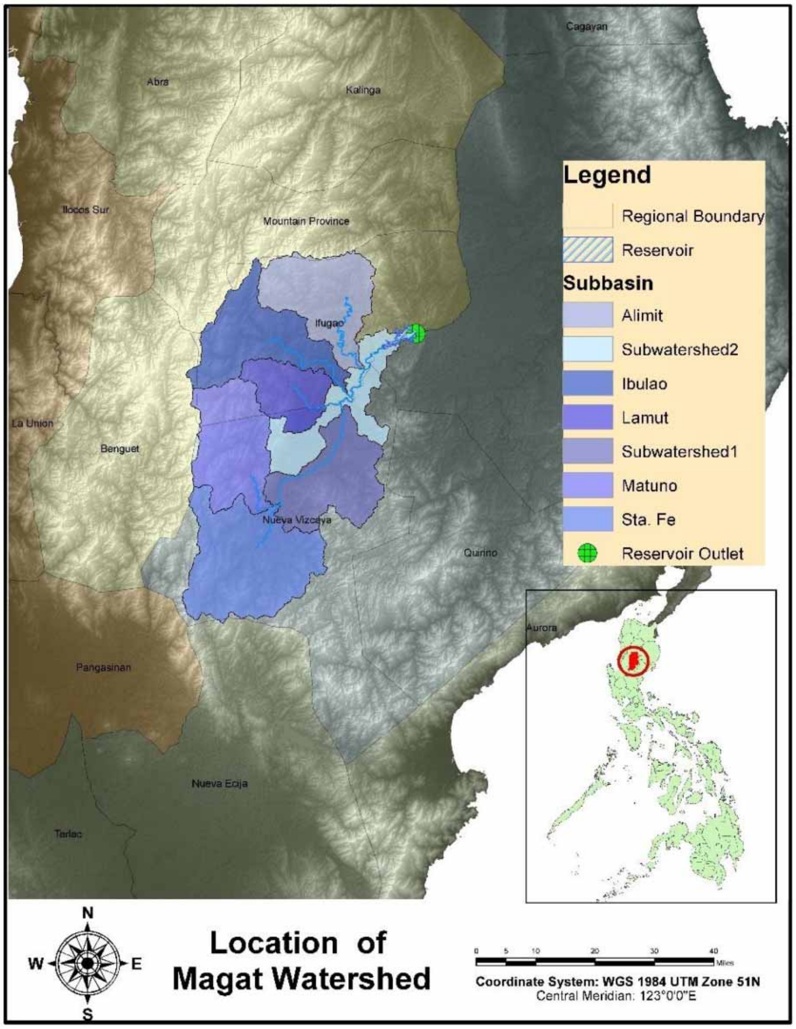


Figure 1 | Location of the Magat watershed and its sub-basin.

The monthly inflow data (1993–2020) that were used as a baseline in the study were gathered from the NIA-MARIIS DRD.

2.3. SWAT model

2.3.1. Description of the SWAT model

In several watersheds, the SWAT model has been used to model the effects of climatic change on hydrologic and biogeochemical cycles (Arnold *et al.* 1998). SWAT employs Hydrologic Response Units (HRUs) to explain spatial variation in land cover and soil types within a watershed as a physically based model. For each HRU, the model calculates essential hydrologic components such as surface runoff, baseflow, ET, and soil moisture change. According to Neitsch *et al.* (2011), the simulation of the hydrological cycle in SWAT is separated into a land phase and a water phase. The land phase is based on the water balance equation, which is calculated separately in each sub-watershed using the following formula:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \tag{1}$$

where SW_t is the final soil water content at time t (mm), SW_0 is the initial soil water content (mm), t is the time (days), R_{day} is the total precipitation on day i (mm), E_{a} is the total evapotranspiration on day i (mm), Q_{surf} is the total surface runoff on day i (mm), w_{seep} is the seepage from the bottom soil layer on day i (mm), and Q_{gw} is the total groundwater flow on day i (mm).

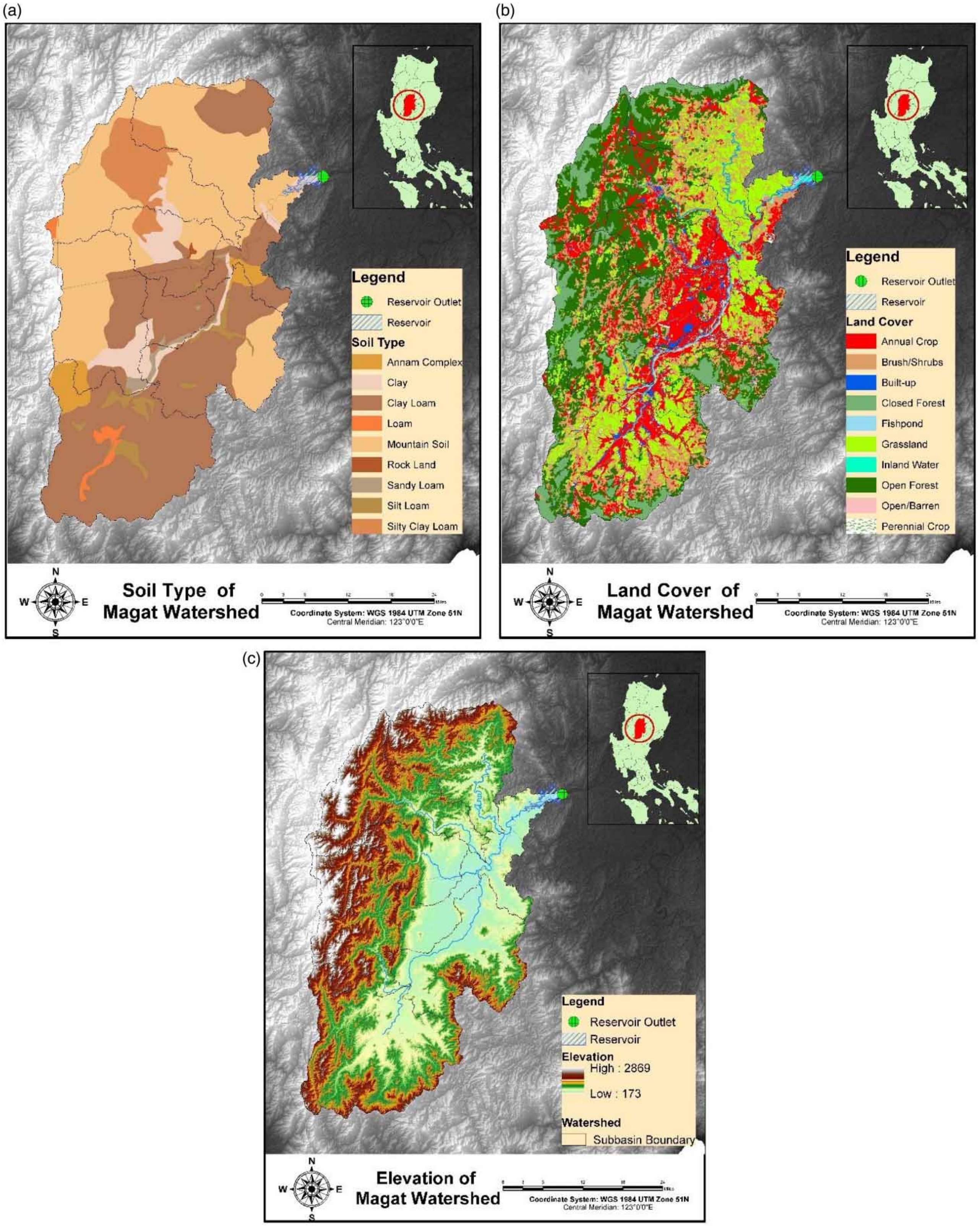


Figure 2 | Soil type (a), land cover (b), and elevation (c) of the Magat watershed.

On the other hand, the water phase of the hydrologic cycle depicts the routing of runoff in the stream channel using either a variable storage coefficient method or the Muskingum routing method. The concentration–time in the watershed is estimated using Manning's formula, which considers both the overland and channel flow. Meanwhile, surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. Using the daily rainfall data, SWAT simulated the surface runoff using the Soil Conservation Service Curve Number (SCS CN) method (USDA-SCS 1972) with the following formula:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \tag{2}$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_{a} is the initial abstractions, including surface storage, interception, and infiltration prior to runoff (mm), and S is the retention parameter (mm).

This study applied the following procedure to predict the inflow of the Magat reservoir using SWAT. The method used throughout the model simulation was clearly required for each phase. A clear overview of the approaches used with the SWAT model is also provided in Figure 3, which summarizes the analytical process.

First, input weather datasets were prepared to match the required input formats. The processed weather dataset was loaded and utilized for the entire modeling process. The Magat watershed underwent processing and unmasking of the geospatial information, including the DEM, land use, and land cover. The watershed is then delineated in order to establish the direction of the flow and the accumulation. The HRUs were produced by ArcSWAT using the processed land use and land cover. Then, initial values of the parameters were set up and adjusted after calibrating simulation results using the Soil and Water Assessment Tool Calibration and Uncertainty Procedures (SWAT-CUP) SUFI2 and manual calibration. Actual inflow data were divided to be used during the calibration and validation processes. Once the model was deemed acceptable, further simulations incorporating the climate projections by PAGASA were done to determine the impacts of climate change on the inflow of the reservoir. Based on this, a proposed dam discharge protocol framework was recommended.

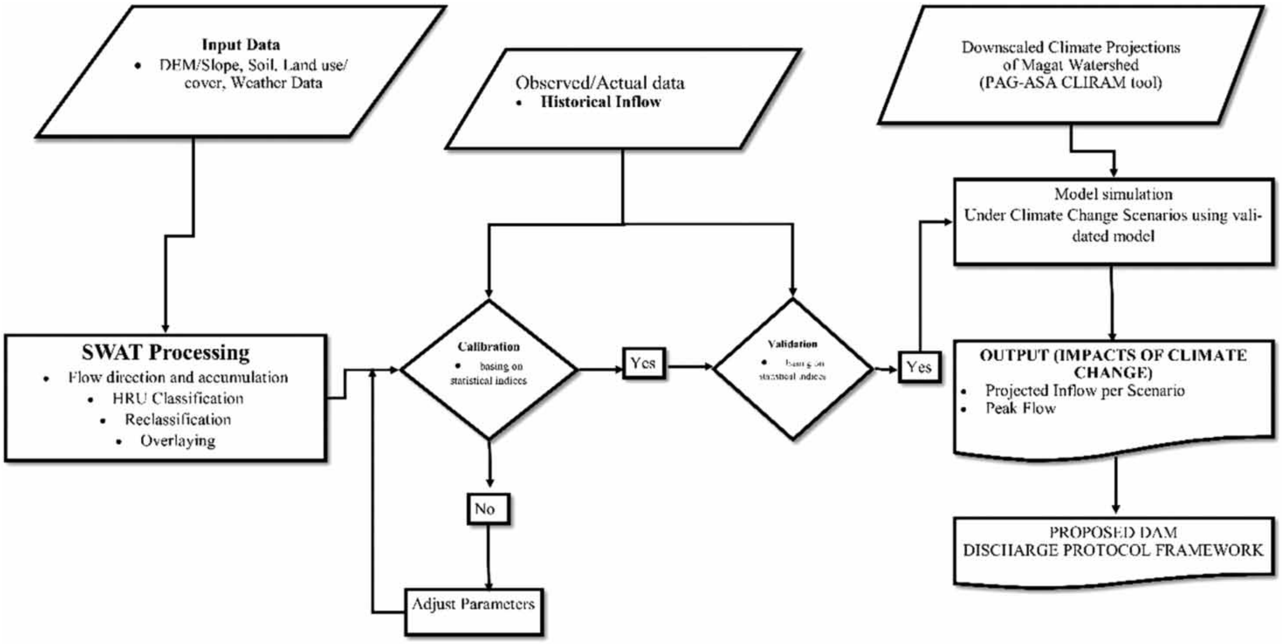


Figure 3 | Methodological framework of the SWAT model used in the study.

2.3.2. SWAT model set-up

Simulation, calibration, and validation were done using long-term inflow data gauged along the Magat River. Also, 31-year (1990–2020) historical data was simulated with a 3-year warm-up period (1990–1992). Moreover, 18 years (1993–2010) of the monthly simulated historical data were used in calibration.

In this study, calibration was done both ways, manually using the trial-and-error method and SWAT-CUP SUFI2. The initial calibration was performed manually by means of adjusting the most influential parameters. The trial-and-error approach was done until the model was already statistically acceptable. The result was imported to SWAT-CUP SUFI2, a software used for further calibration.

On the other hand, evaluation statistics were used to determine the reliability of the calibrated model. The Coefficient of Determination (R^2), Nash–Sutcliffe Model Efficiency (NSE), Root Mean Square Error-Observations Standard Deviation Ratio (RSR), and Percent Bias (PBIAS) were used to measure the acceptability of the SWAT model to imitate the temporal trends of the observed data (Table 1).

2.4. Climate change scenarios

Projected climate scenarios used in the assessment were based on the recent climate projections published by the Department of Science and Technology-Philippine Atmospheric, Geophysical, and Astronomical Services Administration (DOST-PAGASA), which is responsible for providing weather updates, forecasts, and projections produced by these climate projections. The projected effects of climate change include percentage increases in temperature and changes in rainfall in the mid-21st century (2036–2065) and late-21st century (2070–2099). These scenarios were primarily chosen for the study because these would likely happen in the future and be used for impact studies (DOST-PAGASA 2018). They suggested two greenhouse gas (GHG) emission trajectory options for the future: the moderate level (RCP 4.5) and the high level of GHG emissions (RCP 8.5). The second was recommended for impact studies, with the first being the scenario that is most likely to occur in the future. For the two time slices, there are uncertainties in both climate change scenarios. In addition, the medium-range emission scenarios were based on historical trends, while the high-range was developed for impacts and adaptation points of view. The medium-range scenario represents a carbon dioxide (CO_2) level that is projected to reach 703 ppm in 2100, while the high-range scenario predicts up to 836 ppm. The mid- and high-range scenarios were then further categorized into three percentiles: lower bound, which means the driest possible change; normal bound, which denotes the normal possible change; and the upper bound, which indicates the wettest possible change. For the two time slices, there are uncertainties in both climate change scenarios. The projections of changes in both time periods for the dry, normal, and wet years reflected this uncertainty. This indicates that there are three possible outcomes for the middle of the 21st century, between 2036 and 2065, and the late-21st century, between 2070 and 2099: dry years (severe drought), wet years (extreme rainfall events), and normal years (no extreme drought or extreme rainfall conditions). The resolution of the projections is 25 km × 25 km.

2.5. Dam discharge protocol framework development

The framework was developed to include the results of the model and the study as a basis for long-term forecasting of dam management. The localized SWAT model developed can be used as the engine to a decision support system to estimate the seasonal and monthly changes in reservoir inflow. They can modify their monthly operational rule curve depending on the changes in climate using the local SWAT model.

Table 1 | Model performance evaluation indices

Indices	Statistically accepted value
Coefficient of determination (R^2)	>0.5 (50%)
Nash–Sutcliffe efficiency (NSE)	>0.5 (50%)
Root Mean Square Error (RMSE)-observations standard deviation ratio (RSR)	Low *RSR*, <0.70 (70%)
Percent Bias (PBIAS)	±25%

3. RESULTS

3.1. Climate projections in the Magat watershed

- Projected rainfall for the mid-21st century. During these years, up to 48.4% increase in rainfall can be noted under RCP 4.5, while up to 39.9% increase in precipitation can be seen under RCP 8.5. These increases in rainfall will likely happen during the wettest years. A decrease in rainfall up to 35.8% can also be noted under RCP 4.5 while for RCP 8.5, a notable decrease of 27.8% can happen. These descending changes will likely happen during the driest years.
- Projected mean temperature for the mid-21st century. An increase in temperature in the watershed under both scenarios can be observed from the tables below. Under RCP 4.5's driest, normal, and wettest years, the increases in temperature were noted to go up to 1, 1.3, and 2.0 °C, respectively. Furthermore, under RCP 8.5, an increase in temperature by 1.4, 1.7, and 2.5 °C can be observed for its driest, normal, and wettest years, respectively.
- Projected rainfall for the late-21st century. During the 21st century, a projected increase of rainfall under RCP 4.5 can go up to 49.6%, while for RCP 8.5, it can go as high as 51.1%. These events will likely happen during the wettest years. On the other hand, projected rainfall can decline up to 26.8% under RCP 4.5, while for RCP 8.5, it can go down to a 36% decrease in rainfall. These declines in rainfall will likely happen during the driest years.
- Projected mean temperature for the late-21st century. Similar to the mid-21st century, there will be a notable increase in temperature for both scenarios. During RCP 4.5's driest year, the temperature can increase up to 1.4 °C while during the normal years, it can go as high as a 1.8 °C increase of temperature. Meanwhile, in the wettest years, the temperature can increase by up to 2. 7 °C. Furthermore, RCP 8.5's driest, normal, and wettest years noted an increase in temperature by 2.8, 3.4, and 4.5 °C, respectively.

3.2. Simulation, calibration, and validation results of the SWAT model

3.2.1. Model parameters

Table 2 shows the 17 most influential parameters that were calibrated in the model using manual and SWAT-CUP calibration. These parameters directly influence the inflow along the Magat watershed into the reservoir. These parameters were related to groundwater (ALPHA_BF, GW_DELAY, GWQMN, GW_REVAP, and RCHRG_DP), soil properties (SOL_AWC, SOL_K,

Table 2 | Calibrated parameters in the SWAT model

Parameter	Description	Calibrated value
1. CN2.mgt	Initial SCS curve number for moisture condition II	0.157
2. ALPHA_BF.gw	Baseflow Alpha Factor	0.98
3. GW_DELAY.gw	Groundwater delay	0.1
4. GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur	600
5. GW_REVAP.gw	Groundwater 'revap' coefficient	0.02
6. ESCO.hru	Soil evaporation compensation factor	1
7. EPCO.hru	Plant uptake compensation factor	1
8. CH_K2.rte	Effective hydraulic conductivity in the main channel alluvium	142.31
9. ALPHA_BNK.rte	Baseflow Alpha Factor for bank storage	0.98
10. SOL_AWC ().sol	Available water capacity of the soil layer	0.01
11. SOL_K ().sol	Saturated hydraulic conductivity	193.69
12. SOL_BD ().sol	Moist bulk density	1.2
13. OV_N.hru	Manning's value for overland flow	0.01
14. RCHRG_DP.gw	Deep aquifer percolation factor	0.01
15. HRU_SLP.hru	Average slope steepness	0.6
16. SURLAG.bsn	Surface runoff lag coefficient	4
17. LAT_TIME.hru	Lateral flow travel time	30

and SOL_BD), HRU factors (HRU_SLP, LAT_TIME, ESCO, and EPCO), routing (CH_K2, ALPHA_BNK), watershed management (CN2), and basin management (SURLAG).

3.2.2. Calibration and validation results

The calibration and validation resulted in a satisfactorily acceptable model. Calibration showed that the model had an NSE of 0.73, R^2 of 0.74, RSR of 0.52, and PBIAS of 8.38, which were all considered statistically acceptable when compared to the indices that were set. From Figure 4(a), the graph shows that the model generally underestimated the peak flows. This is one of the known limitations of the SWAT model. Although studies pertaining to the modeling of the inflow of a reservoir is very limited in the country, studies regarding streamflow, which is mostly associated with and similar to inflow, are conducted. For instance, Alejo & Ella (2019) satisfactorily calibrated and validated a SWAT model in the Maasin River Watershed in Laguna, the Philippines, using actual streamflow. The calibration process resulted in 0.82 R^2, 82% NSE, 0.024 RSR, and PBIAS of −3.7%. This suggests that SWAT can be locally applied in river basin conditions in the country.

Moreover, the validated SWAT model yielded satisfactory results. The model had an NSE of 0.56, R^2 of 0.62, RSR of 0.66, and a PBIAS of 17.3. This means that the model satisfactorily predicted the inflow of water to the Magat reservoir based on the validation results. However, like the calibration results, the model underestimated most of the peak flows as seen in Figure 5(a). Validation results showed model accuracy values on NSE, R^2, PBIAS, and RSR of 0.41, 0.57, 25.09%, and 0.71, respectively. Although the model was considered satisfactory, it can be observed that there was a drop in the performance of the validation results compared to the calibration results.

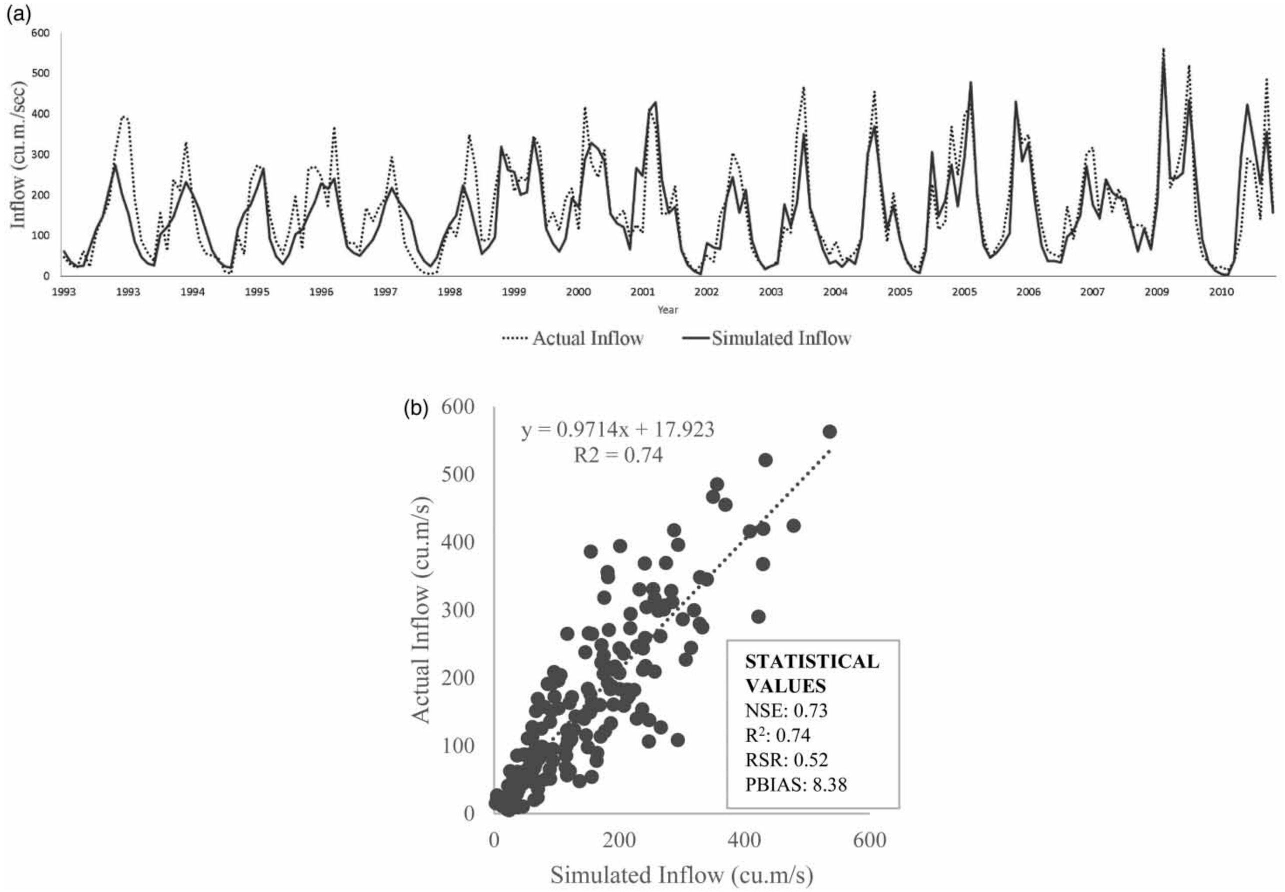


Figure 4 | Monthly simulated and actual inflows for the calibration period (a) and the scatter diagram of the simulated inflow and actual inflow (b).

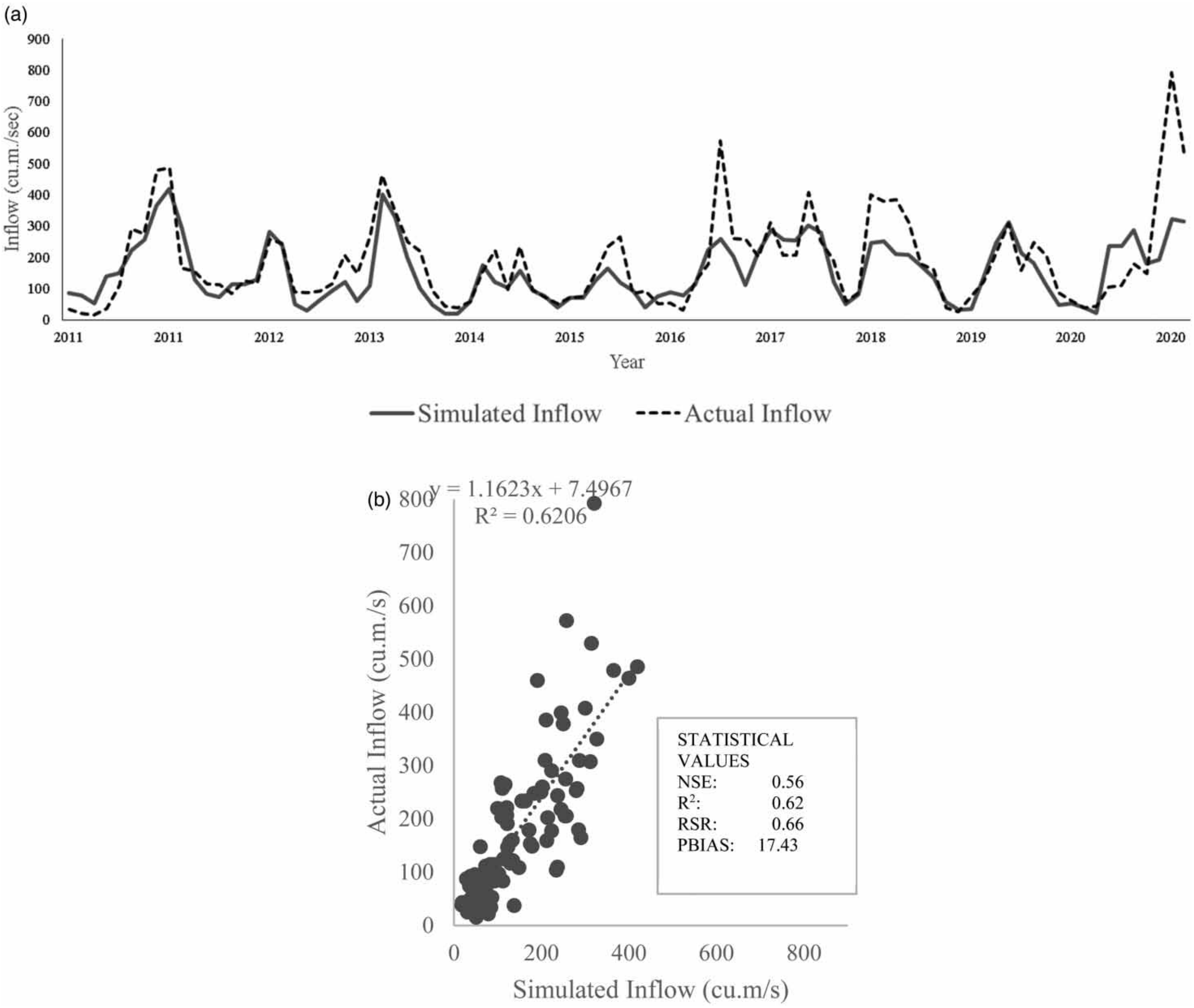


Figure 5 | Monthly simulated and actual inflows for the validation period (a) and the scatter diagram of the simulated inflow and actual inflow (b).

3.3. Impact of climate change on the inflow of water to the reservoir

To understand the impact of increasing temperatures and rainfall changes on the water balance of the watershed, the calibrated SWAT model was used. The downscaled climate projection provided by PAGASA was used as the future scenario for both changes in rainfall and temperature. There are no current studies observing the impacts of climate change on the inflow of the Magat reservoir or any river basin in the country in particular.

However, numerous analyses of the effects of climate change on the streamflow of these basins exist. An assessment of climate change impacts on the streamflow of the Mun River in the Mekong Basin, Southeast Asia, using the SWAT model was conducted by Li & Fang (2021). Using the SWAT model, they predicted that under scenarios RCP4.5 and RCP8.5, the mean annual streamflow of the basin decreased by 11.1 and 7.6%, respectively, during the 2030s and increased by 40.9 and 43.3% during the 2060s. Streamflow was projected to increase by 3.1 and 5.3% in the 2080s under the RCP4.5 and RCP8.5 scenarios, respectively. However, during the wet years, the streamflow was projected to increase by 45.7 and 48.9% under RCP4.5 and RCP8.5, respectively. Notably, the streamflow in the dry season was projected to decrease in all future decades under these RCP scenarios – especially at the end of the century. From this example study, the impact of climate change on the flow of water is shown below, corresponding to Scenarios 1–4.

3.3.1. Scenario 1: RCP 4.5 (mid-21st century)

For the RCP 4.5 scenario for the mid-21st century, the model predicted that there will be a decrease of inflow by 18.27% for dry years and 7.42% for normal years, but for wet years, there will be an increase of inflow by 10.79% (Figure 6).

3.3.2. Scenario 2: RCP 8.5 (mid-21st century)

The model estimated a 15.21% decline in inflow during the dry years for the RCP 8.5 scenario in the mid-21st century. However, there will be a 0.53 and 21.88% increase in inflow during normal and wet years, respectively (Figure 7).

3.3.3. Scenario 3: RCP 4.5 (late-21st century)

Under this scenario, the model projected that the inflow would reduce by 17.41 and 4.51%, in the dry and normal years respectively but during the wet years, there will be an 18.57% increment of inflow (Figure 8).

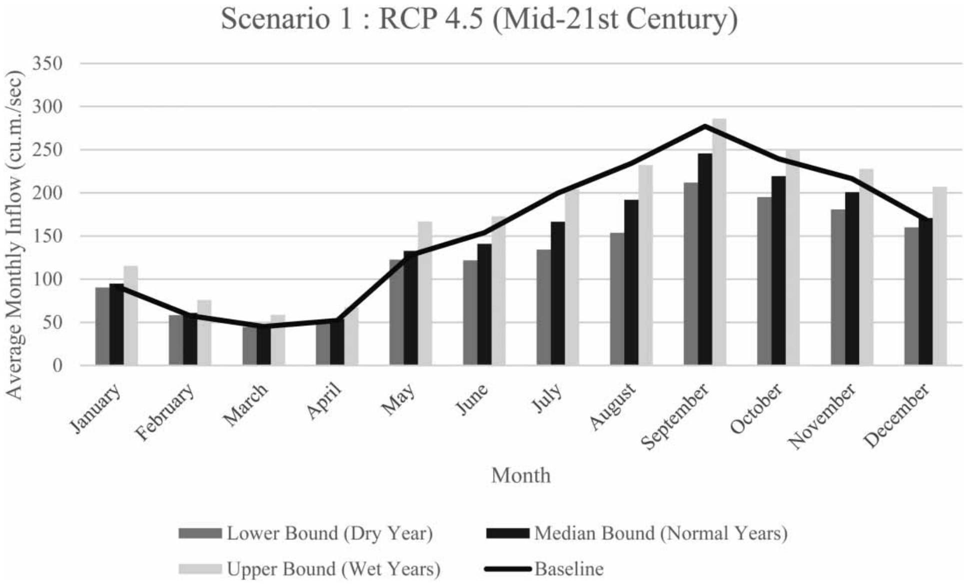


Figure 6 | Monthly estimation of the future inflow under the RCP 4.5 scenario during the mid-21st century.

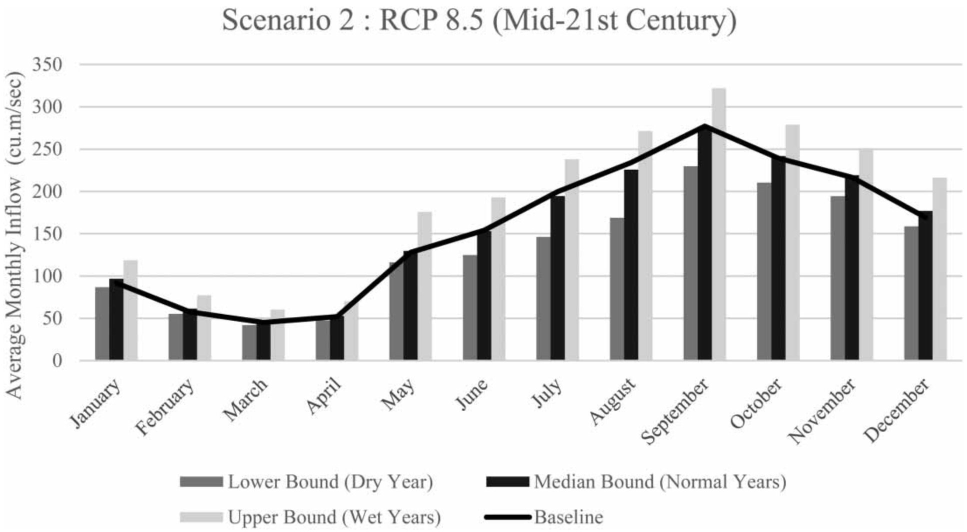


Figure 7 | Monthly estimation of the future inflow under the RCP 8.5 scenario during the mid-21st century.

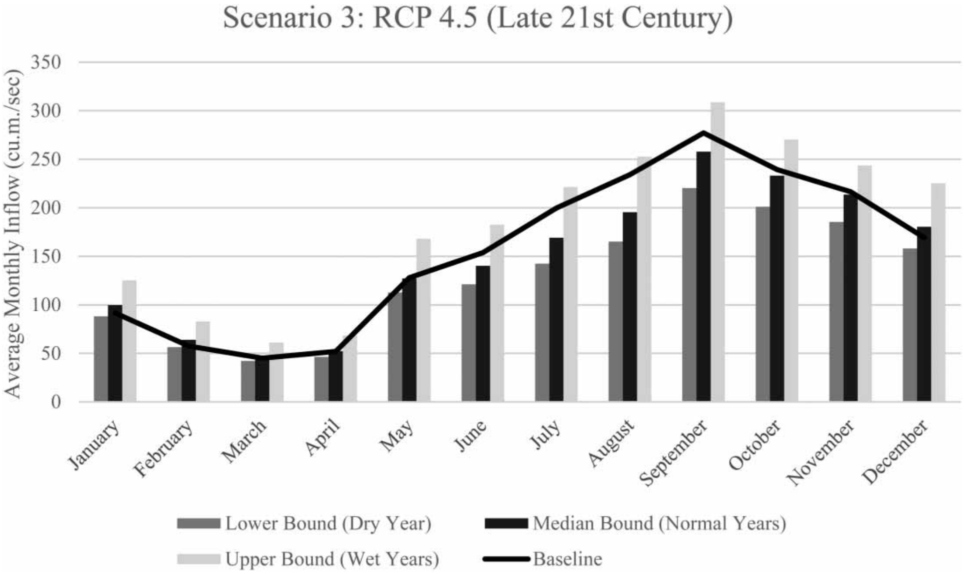


Figure 8 | Monthly estimation of the future inflow under the RCP 4.5 scenario during the late-21st century.

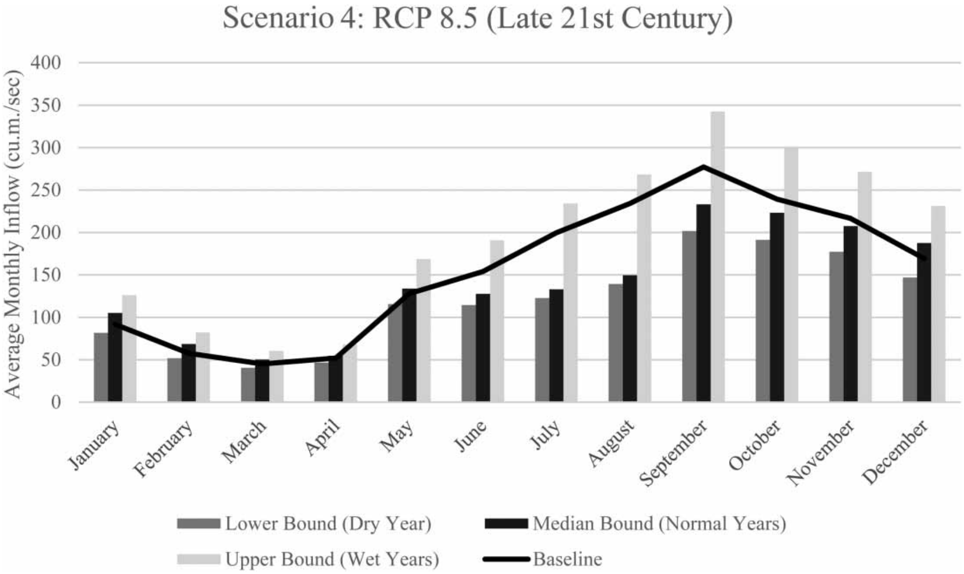


Figure 9 | Monthly estimation of the future inflow under the RCP 8.5 scenario during the late-21st century.

3.3.4. Scenario 4: RCP 8.5 (late-21st century)

Both normal and dry years were estimated to decline by 23.33 and 10.21% under the RCP 8.5 scenario for the late-21st century, respectively. However, the wet years for this century were estimated to increase by 25.76% (Figure 9).

3.4. Future peak flow

3.4.1. Scenario 1: RCP 4.5 (mid-21st century)

For the RCP 4.5 scenario for the mid-21st century, the predicted peak flow for dry, normal, and wet years will most likely occur in the month of September with an average of at least 187.08, 227.09, and 264.77 m^3/s, respectively (see Table 3).

Table 3 | Peak flow for the RCP 4.5 scenario for the mid-21st century

Scenario	Peak flow	*Q* (m^3/s)
Dry (lower bound)	September	211.88
Normal (median bound)	September	245.76
Wet (upper bound)	September	285.88

3.4.2. Scenario 2: RCP 8.5 (mid-21st century)

The estimated peak flow will take place in the month of September for dry, normal, and wet years, respectively. The Magat reservoir is expected to have an average peak flow of at least 229.72 m^3/s for the dry years, 275.69 m^3/s for the normal years, and 321.98 m^3/s for the wet years, as shown in Table 4.

3.4.3. Scenario 3: RCP 4.5 (late-21st century)

The predicted peak flow will most likely happen during the month of September. For the dry years, the average peak flow is expected to be at least 220.36 m^3/s. During the normal and wet years, the average peak flow is expected to be between 257.84 and 308.73 m^3/s (see Table 5).

3.4.4. Scenario 4: RCP 8.5 (late-21st century)

Under the RCP 8.5 scenario during the late-21st century, the peak flow will most likely happen during the month of September for the dry years, with at least 201.70 m^3/s. Similarly, during the wet years and normal years, the peak flow will likely happen during the month of September with 342.46 and 233.14 m^3/s, respectively, as shown in Table 6.

3.5. Recommendation of framework toward the development of dam discharge protocol

Figure 10 shows the recommended framework for the upgrading of the dam discharge protocol of the Magat reservoir incorporating the developed SWAT model emphasizing the predictions for annual and monthly streamflow forecasting.

Table 4 | Peak flow for the RCP 8.5 scenario for the mid-21st century

Scenario	Peak flow	*Q* (m^3/s)
Dry (lower bound)	September	229.72
Normal (median bound)	September	275.69
Wet (upper bound)	September	321.98

Table 5 | Peak flow for the RCP 4.5 scenario for the late-21st century

Scenario	Peak flow	*Q* (m^3/s)
Dry (lower bound)	September	220.36
Normal (median bound)	September	257.84
Wet (upper bound)	September	308.73

Table 6 | Peak flow for the RCP 8.5 scenario for the late-21st century

Scenario	Peak flow	*Q* (m^3/s)
Dry (lower bound)	September	201.70
Normal (median bound)	October	233.14
Wet (upper bound)	September	342.46

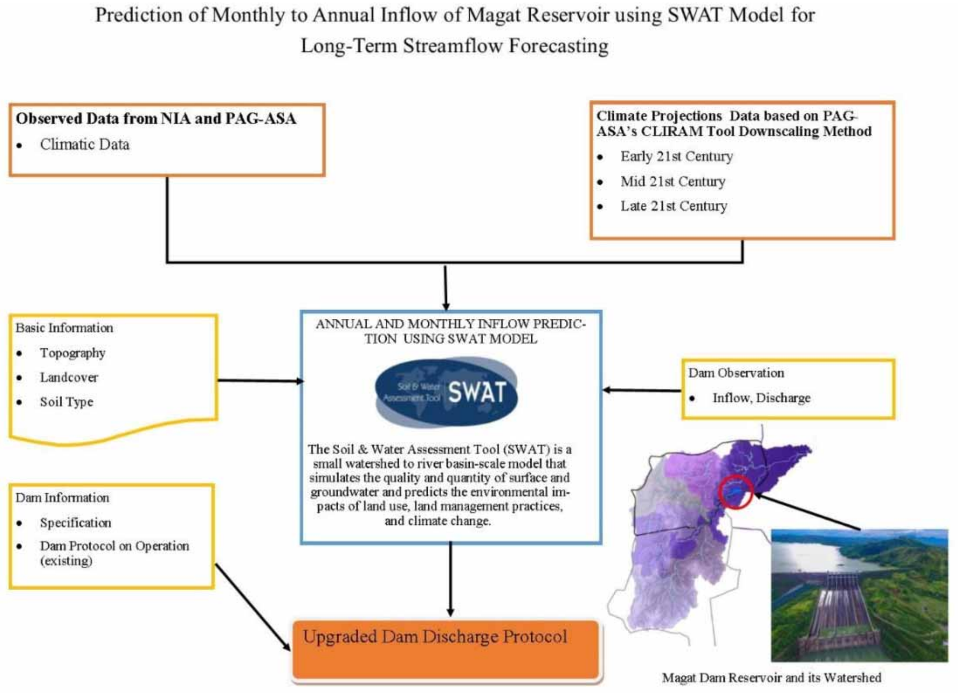


Figure 10 | Framework for upgrading the dam discharge protocol using the SWAT model.

The amount of rainfall that will trigger prerelease in the dam depends on the current elevation of water in the dam. For example, the dam management decided to release about 189 m^3/s during Typhoon Ulysses (International name Vamco) in 2020, when the current dam elevation was 190.92. The typhoon brought almost 300 mm of rainfall in the Magat watershed, which brought about 7,200 m^3/s per second of dam inflow.

Rule curves for reservoirs are based on desired end-of-month storage; as a result, the key choice to be made each month is how much storage to provide for the reservoir. Once the monthly inflows are known, the monthly outflows through the turbines and gates are determined. The end-of-month storage targets depend on many factors that require inputs, especially on the water demands from irrigation, hydropower, and domestic water supply. This study, however, is limited to providing the monthly inflows and proposing a framework for dam management use.

The proposed framework is focused on the forecasting of monthly and annual inflows of the Magat dam. For particular cases, it can also be used for seasonal forecasting along the river basin. This will help the dam management to observe long-term changes in the flow of water going into the reservoir. This will contribute to the awareness of the availability of water to be stored. With PAGASA's latest initiative in climate projections, the impacts of any changes in the climate will also be anticipated. The upgraded dam discharge protocol should be used by the NIA-MARIIS DRD to aid decision-making on seasonal scenarios, particularly on the inflow of the Magat reservoir.

4. DISCUSSION

Climate change will lead to increased reservoir inflow during wet years, largely due to a substantial increase in rainfall input to the watershed. It will also lead to a significant reduction in reservoir inflow during dry years due to decreased rainfall. Hydrological models provide a helpful platform for reliable estimates of water supply under many drivers of change in watersheds, which include climate change. The SWAT model has been continuously supporting many water resources research in this avenue. The majority of these researchers in the Philippines have studied the ability of the SWAT model for streamflow estimates. For example, Alejo & Ella (2019) used SWAT for streamflow estimates for irrigable area determination and Araza *et al.* (2021) for river flow analysis. Other local SWAT studies focused solely on land use change impact assessments and streamflow changes (Araza *et al.* 2021). Similarly, Alejo & Ella (2019) satisfactorily calibrated and validated a SWAT model in the Maasin River Watershed in Laguna, Philippines using actual streamflow. Reyes (2017) also applied the

SWAT Model to predict streamflow and sedimentation in Wahig-Inabanga Watershed, Bohol, Philippines. This study focused on the calibration and validation of reservoir inflow using the SWAT model as support to dam management actions and plans.

The most sensitive parameters for reservoir inflow were ALPHA_BF, GW_DELAY, GWQMN, GW_REVAP, RCHRG_DP (groundwater), SOL_AWC, SOL_K, SOL_BD (soil properties), HRU_SLP, LAT_TIME, ESCO, EPCO (HRU factors), CH_K2, ALPHA_BNK (routing), CN2 (watershed management), and SURLAG (basin management). The parameters calibrated in this study can also be seen in a SWAT study conducted by Panondi & Izumi (2021) in the Pulangi River Basin (PRB), which is located on the Mindanao Island of the Philippines. They pointed out that CN2, SOL_AWC, HRU_SLP, GW_DELAY, and CNCOEFF are the most sensitive parameters in the combined simulation analysis of streamflow and sediment yield. A reservoir modeling study by Beharry *et al.* (2021) found 16 sensitive parameters (ALPHA_BNK, CH_K2, GW_DELAY, ALPHA_BF, CH_N2, CN2, EPCO, OV_N, Representation of Vegetation and Aquatic Processes for Nutrients (REVAPMN), SURLAG, SOL_K, SOL_BD, GWQMN, SOL_AWC, and GW_REVA) in their study. Almost the same parameters were deemed sensitive in this study.

Meanwhile, a study conducted by Araza *et al.* (2021) in the Abuan Watershed found that parameters directly influencing its peak and low flows were the coefficients on runoff (CN2 and SURLAG), baseflow (ALPHA BF), soil evaporation (ESCO), and soil depth for baseflow (GWQN). The model underestimated the peak flows in the study area, which has been common in many SWAT studies (Tolentino & Ella 2016; Le & Pricope 2017). According to research by Gassman *et al.* (2007), SWAT overestimated streamflow during dry years when low flows occurred and underestimated streamflow during wet years when big flows are presumably anticipated. In a separate USDA study, it was shown that SWAT underestimated river flows in the summer but overestimated them in the winter.

The SWAT performance was better during calibration, which has been commonly observed in other SWAT studies. This was also seen in the SWAT model study by Briones *et al.* (2016). Their validation also yielded acceptable simulation results, although NSE and R^2 dropped to 0.61 and 0.68 from calibrated results of 0.85 and 0.86. They also stated that this marked decrease in the model's performance can be attributed to several factors, one of which can be associated with land use land cover (LULC) changes between the calibration and validation periods. In order to estimate streamflow, Reyes (2017) also successfully calibrated and verified the SWAT model. However, it should be emphasized that the calibration and validation periods for these studies are shorter (4–6 years) and they are almost the same duration. In comparison, the SWAT model used in the current study for the Magat watershed is significantly longer, lasting 18 and 10 years, respectively. It is crucial to use longer calibration and validation periods since they tend to produce better model results than shorter ones, mostly because of making effects. Additionally, there is a significant difference in simulation length between calibration and validation, which might justify the impact of simulation length on the model results of the present study.

It has been crucially shown that there would be projected shifts in the months where the peak reservoir inflow occurs. Furthermore, because of the significant increase in rainfall input to the Magat watershed brought on by climate change, there will be an increase in reservoir inflow during rainy years. Less rainfall during dry years will also result in a large decrease in reservoir inflow. Moreover, it has also been importantly shown that there will be projected shifts in months where peak inflow occurs. Various studies have shown the adverse varied impacts of climate change on water resources in the Philippines. Climate change has been shown to decrease water availability in reservoirs as a result of decreased water supply and increased water demand, which will eventually lead to reduced irrigable areas, especially in dry years (Alejo & Alejandro 2022). The threat of severe flooding and excessive soil loss due to increased runoff and sediment yield are threats to the sustainability of ecosystems due to climate change (Panondi & Izumi 2021). Croplands are at risk when this happens and would lead to huge economic losses, as estimated by Araza *et al.* (2021). It is then important that the cropping calendar in the vast service area of the reservoir be made dynamic or retrofitted to future changes in climate to make the irrigation system climate resilient. The fully calibrated and validated SWAT model for the Magat watershed provided adequate estimates of reservoir inflow. The increased peak inflow during wet years might lead to potential flooding downstream of the reservoir when the dam management is not appropriately planned. The significantly reduced inflow during dry years will lead to a reduced water supply for irrigation and hydropower capacity of the dam. These reductions in inflow in the reservoir during dry seasons convey a strong indication that the reservoir may become dry in the near future (Joshi & Makhasana 2020). An increase in the inflow, however, may require a change of the operation rules of the reservoir in order to adapt to the new changing reality (Muhammad *et al.* 2020). However, rule curves for reservoirs are based on desired end-of-month storage; as a result, the key choice to be made each month is how much storage to provide for the reservoir. Once the monthly inflows are known, the monthly outflows through the turbines and gates are determined. The end-of-month storage targets depend on many factors that require inputs, especially on the water demands from irrigation, hydropower, and domestic water supply. This study, however, is limited to providing the monthly inflows and proposing a framework for dam management use. The SWAT model developed can provide a basis for predicting monthly and annual reservoir inflow trends for long-term projections.

5. CONCLUSION

The impact of climate change on water resources is inevitable, however, through hydrologic models, it is quantifiable. This study using the SWAT model implies that this method can adequately predict the monthly inflow of the Magat reservoir under different climate change scenarios for the mid-21st century and late-21st century. The latest and most accurate data from different agencies were used as inputs in the model as well as the downscaled climate projection from PAGASA. Model performance was deemed satisfactory as the model attained an NSE of 0.73, R^2 of 0.74, RSR of 0.52, PBIAS of 8.38, and NSE of 0.56, R^2 of 0.62, RSR of 0.66, and a PBIAS of 17.3, respectively. However, the model tends to underestimate the peak flows, which is a known limitation of the SWAT model. The study found that if the climate change would worsen and reach the RCP 4.5 and RCP 8.5 scenarios in the basin level, there will be a significant decrease in inflow during their dry and normal years, but a substantial increase will occur during the wet years. These decreases in reservoir inflow during dry seasons serve as a clear warning that the reservoir may soon become dry. However, a rise in the inflow might necessitate modifying the reservoir's operating guidelines in order to accommodate the new, shifting reality. In addition, the highest inflow of water to the reservoir is anticipated from the months of September, followed by October–December, since this is already the rainy season in the country.

Climate change impact studies have been widely explored for streamflow estimations using SWAT to quantify available river flows and their fluctuations. This study focused on the estimation of reservoir inflow to support dam management actions, decisions, and plans. Given the importance of the dam specifically to the agriculture sector, it is necessary to take steps to review the existing dam and reservoir policy and adopt mitigation strategies for climate change problems. Consequently, this study will contribute to the development of the framework for the upgrading of the dam discharge protocol and dam management, focusing on seasonal forecasting along river basins. This will help the dam management to observe long-term changes in the flow of water going into the reservoir. Also, the results could pave the way toward the design of various interventions to take care of the watershed and its river networks and reduce the negative impacts of climate change on the Magat reservoir in the future. Additionally, the study demonstrated a scientifically sound methodology to quantify the impacts of climate change and its potential as a decision support system for dam management in river basins in the Philippines and other countries.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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