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Assessment of Water Availability in Kalu Ganga Catchment under Climate Change Effects

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Abstract: Kalu Ganga, a major right-bank tributary of Amban Ganga, is one of the perennial rivers of Sri Lanka. Kalu Ganga Dam is a large gravity dam and a vital component of the complex Moragahakanda-Kalu Ganga Project built at Pallegama in the Matale District over the Kalu Ganga. A study was carried out to investigate and evaluate the present and future water availability of the Kalu Ganga reservoir. The present water availability is calculated using historical weather data, and the future water availability is estimated using predicted data extracted from downscaled climate change models. The study employed two Representative Concentration Pathway (RCP) scenarios, RCP 4.5 and RCP 8.5, of six climate models. Before being used, the climate change-predicted rainfall and temperature data were bias-corrected. Subsequently, the water availability was calculated using the rainfall-runoff model, Soil Water Assessment Tool (SWAT). The SWAT model was calibrated and validated using observed flow series at Laggala stream gauge on the Kalu Ganga. Using the same calibration settings, the SWAT model was then used to evaluate the potential impacts of climate change on streamflow in future scenarios. The SWAT, HEC-ResSim models and the climate change forecasted data have been shown to be useful tools for identifying climate change-driven water availability challenges, which can help with strategic water resources planning.

Keywords: Water availability, Climate change, Bias correction, Kalu Ganga reservoir, SWAT, HEC-ResSim

1. Introduction

1.1. General

Water is a basic necessity of life, referred to as the primary commodity of the twenty-first century, and water scarcity causes the degradation of landscape components such as soil, flora, and fauna, leading to the abandonment of the landscape and a gradual deterioration of lifestyle [26]. Furthermore, water demand is constantly increasing, and this increased water demand is primarily met by managing available water resources through construction of infrastructure such as storage reservoirs/weirs [16]. Reservoirs allow for the accumulation of water in operational storage capacity ensuring water availability for people, agriculture, and industry [33].

Some documented hydrologic changes associated with global climate change include changes in precipitation patterns, rising surface temperatures, and increases in the frequency and intensity of floods and droughts [13]. Also, rainfall events are expected to become significantly more intense as a result of global warming [37]. Furthermore, as global temperatures rise, so will the demand for irrigation systems and domestic water supplies [4]. The impact of climate change on catchment hydrology reduces water regimes, such as changes in the magnitude availability due to changes in river flow and timing of flow [37]. These drastic changes in river flow regimes have a direct impact on the dependability of water resources and the availability of water supplies from reservoirs [33]. Therefore, understanding the spatial and temporal variability of current and future hydrologic regimes is thus critical for developing a sustainable water-resources monitoring and management system [14].

1.2. Climate and climate change in Sri Lanka

Despite the country's water scarcity, food crop cultivation is primarily conducted in the country's dry zone because all other conditions in the dry zone (flat terrain, fertile soil, and sunshine) are favorable for paddy cultivation [31]. The Maha season, associated with the

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Second inter-monsoon and Northeast monsoons (October-March), and the Yala season, associated with the First inter-monsoon and Southwest monsoon (April-September), are the two main agricultural seasons in Sri Lanka [36]. Sri Lanka's mean annual rainfall varies spatially from about 900 mm to 5000 mm, with a mean of 1850 mm and significant spatial and intra-annual variations [11] and high year-to-year variability. Low rainfall and high variability have been observed in the dry zone when compared to the wet zone [11], making droughts much more severe and prevalent in the dry zone.

The general climate of Sri Lanka is changing, and it is clear that the country's average temperature is significantly increasing at a rate of 0.01-0.03 ºC per year; however, there are no discernibly significant trends or variability in seasonal and annual rainfall due to high interannual variability [20]. However, it was evident that the variability of seasonal rainfall during the recent decade (2001–2010) has increased compared to the previous decade (1991–2000) in most places of the island across all three climatic zones, with the occurrence of more frequent drought and flood conditions [20]. Further, Punyawardena and Premalal [29] predicted an apparent increase in the occurrence of extreme positive rainfall anomalies in the country's central hills from 2006 to 2010.

1.3. Why Climate Change Study is Required

The overwhelming scientific evidence has shown that ambient temperatures in the Sri Lankan climate are rising, resulting in increased heat stress [20]. As a result of climate change effects, high-intensity rainfall events, prolonged dry seasons and rainfall shifts, will become more common [11]. These climate change effects would have a direct impact on the water availability of the Kalu Ganga catchment in Sri Lanka, where the Kalu Ganga Reservoir project was recently completed. In the local language, a river is referred to as the 'Ganga'. However, the issue of climate change was not addressed during the planning stage. Thus, there is a clear need to analyze the effects of weather extremes on the surplus water availability of Kalu Ganga Reservoir to plan its proper operation in order to improve water supply reliability and reduce exposure to risks.

2. Study Area

Mahaweli Development Programme (MDP) is Sri Lanka's most extensive water resources development program [19]. The objectives of the MDP are to increase agricultural production in the dry zone areas, hydropower generation, drinking water supply, flood mitigation, inland fisheries and employment generation [1], and this programme was implemented in accordance with the Mahaweli Master Plan [34]. The MDP spreads over 12 river basins to develop 13 large irrigation systems, conveyance systems, and multipurpose reservoirs. Some of the infrastructure proposed under MDP has already been built, while others are still to be built.

The Kalu Ganga Reservoir, the subject of this paper, was built across Kalu Ganga, a perennial river that is a tributary of the Amban Ganga. The Amban Ganga is the main tributary of the Mahaweli Ganga. The Kalu Ganga-Moragahakanda Reservoir Project (Figure 1) was commissioned in 2018-19.

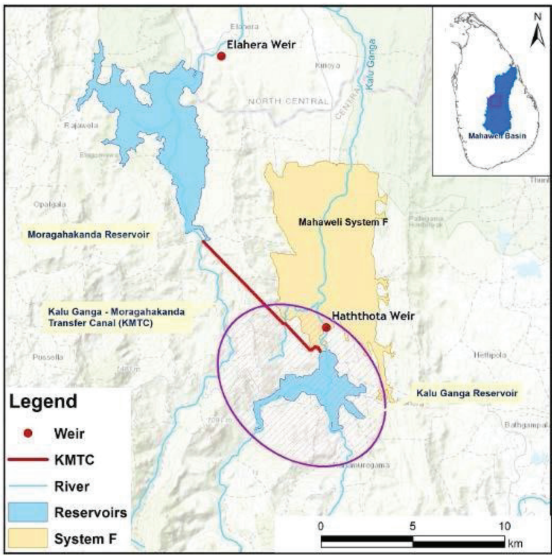


Figure 1 - Layout Map of Kalu Ganga Reservoir [19]

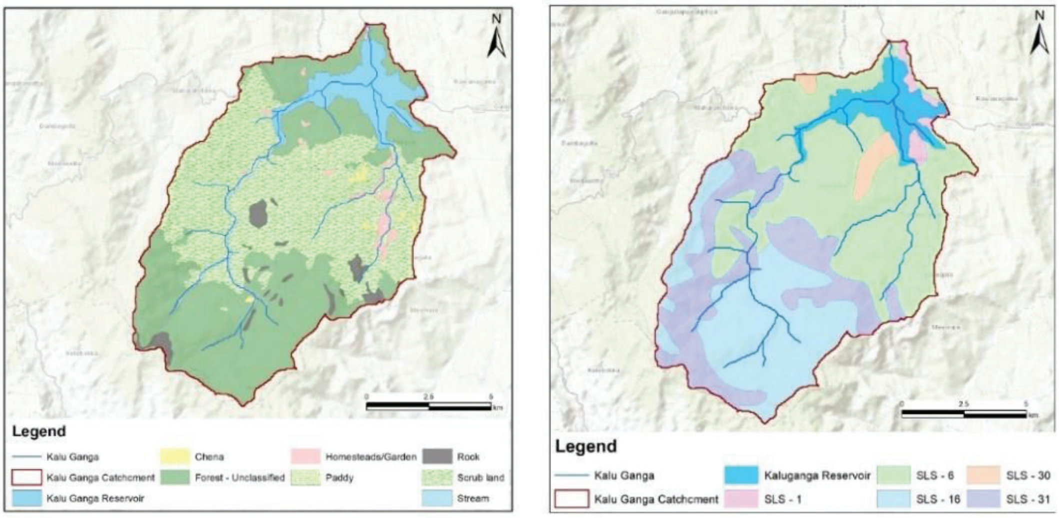
The main goal of constructing the Kalu Ganga Reservoir is to meet the water needs of Mahaweli Irrigation System F and divert excess water to the Moragahakanda Reservoir to improve agricultural and drinking water supplies [18]. The total catchment area of the reservoir is 116 km^2 with forests covering approximately 90% of the catchment. The Kalu Ganga Reservoir and conveyance structures were designed based on hydrological assessments performed on a monthly timestep model in 2004 [18] with no consideration given to climate change. The Kalu Ganga Reservoir Project's objectives may not be met if expected water availability is reduced due to changing climate patterns. Unfortunately, due to climate change (CC) induced droughts and uncontrolled spills during high-intensity rainfalls, water availability has been reduced in many parts of the world including Sri Lanka [26]. Therefore, it is worthwhile to assess the potential impacts on the catchment hydrology due to CC effects which will help in evaluating the resilience of the catchment and reservoir to absorb the adverse impacts of CC and sensitivity. This will also identify potential operational practices, such as rule curves, to follow to mitigate CC impacts.

3. Data and Methodology

The Soil Water Assessment Tool (SWAT) [3] was used to simulate the catchment hydrology in the historical and future climate-predicted scenarios. The SWAT is a river basin or watershed scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields over long periods in complex watersheds with varying soils, land use, and management conditions. The model is physically based and computationally efficient, uses readily available inputs, and allows users to investigate long-term impacts [2]. Input data for the SWAT includes Digital Elevation Model (DEM), land use data, soil data, and climate data (rainfall and temperature).

Table 1 - Details of Collected Data [19]

Data Type	Data	Data Source
Topography	Digital elevation model (DEM) (30 m × 30 m)	Shuttle Radar Topography Mission (SRTM) Downloaded from https://www2.jpl.nasa.gov/srtm/
Landuse	Landuse map (1:50,000)	Department of Survey, Sri Lanka (Developed in 2013/14)
Soils	Soil map (1:500,000)	Landuse Division, Department of Irrigation, Sri Lanka
Climate	Meteorological data (Rainfall, Temperature)	Department of Meteorology, Sri Lanka
Hydrology	Measured streamflow data (Laggala Gauging Station)	Department of Irrigation, Sri Lanka



Landuse map

Soil map*

Figure 2 - Landuse and Soil Maps of Kalu Ganga Catchment [19]

* SLS 01-Reddish-brown Earths and low humic gray soils undulating terrain, SLS 06-Reddish-brown Earths and Immature brown looms, rolling, hilly and steep terrain, SLS 16-Red-yellow podzolic soils and mountain regosoils mountainous terrain, SLS 30-Erosional Remnants, SLS 31-Steep Rockland and Lithosols

These data were obtained for the study from various sources which are listed in Table 1. In addition, outlet points were identified for the model calibration, validation, and observed flow series.

The Kalu Ganga catchment has eight land use types and five soil types identified with forest covering approximately 90% of the catchment. Figure 2 depicts the available land use and soil classes in the Kalu Ganga catchment.

A SWAT model for the Kalu Ganga catchment was developed, calibrated, and validated using the measured streamflow series at the Laggala gauging station. The calibrated SWAT model was used to simulate catchment hydrology under the changing rainfall and temperature conditions, assuming that all other factors relevant to the catchment hydrology remained constant. The climate-predicted inflow series were derived in selected General Circulation Models (GCM) for selected RCP scenarios, and those flow series were used in the subsequent analysis.

3.1. Climate Change Data

Although GCMs are the primary source of information for future climate change studies, the representation of hydrological changes in GCMs is generally insufficient for hydrological modelling because GCM data are too coarse to be used directly at the regional or field level [12]. Regional climate models (RCM) explicitly simulate the interactions between the large-scale weather patterns simulated by global models and local terrain [30]. Processes governing regional to local scale extreme events, in particular, are not well represented in GCMs [21] and have limitations in the application at local/regional scales due to scale differences between GCMs/RCMs and field-scale (or modelling) resolutions. Because the impacts of climate change are frequently quantified by impact models, which typically require high-resolution unbiased input data, these discrepancies may create significant uncertainties in future water resource planning for sustainable water resources management [17].

Based on the model performance of historical runs conducted using NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), Herath and Jayawardena [15] recommended the six GCMs listed in Table 2 as suitable for evaluating climate projections for Sri Lanka [6]. Also, NEX-GDDP downscaled models captured the bimodal pattern of the annual cycle of rainfall in Sri Lanka as well as the spatial pattern of annual average and seasonal average rainfall [15]. The Department of Meteorology, Sri Lanka provided daily rainfall and temperature time series obtained by downscaling GCMs for two RCPs and historical data, with a downscaled resolution of 0.25° (approximately 27.5 km grid).

The period 2041-2060 is selected to represent the median year of 2050 because far future data (e.g., 2080) may not provide a reliable prediction of weather events, and more reliable data with better estimation methods would be available in the future. The period 1985-2004 was selected as the study's baseline based on available rainfall data from observed and generated historical data from climate models.

Table 2 - GCMs Used for the Study

No	GCM	Description
1	CANESM2	The Second Generation Coupled Global Climate Model Canadian Centre for Climate Modelling and Analysis (2.8x2.8)
2	CNRM-CM5	National Centre for Meteorological Research/ Meteo-France (1.4x1.4)
3	CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organization (CSIRO)and the Queensland Climate Change Centre of Excellence (QCCCE). (1.895x1.875)
4	GFDL-CM3	Geophysical Fluid Dynamic Laboratory NOAA, USA Coupled Climate Model (2x2.5)
5	MRI-CGCM3	Global Climate Model of the Meteorological Research Institute, Japan (1.132x1.125)
6	NCAR-CCSM4	National Center for Atmospheric Research, USA Coupled Climate Model (0.942x1.25)

The bias correction is used to adjust the GCM generated simulation statistics, match monthly means, variances, or wet-day probabilities, and match observations during a present-day calibration period [21]. In addition, this is used to generate a data set from an observed data set and a bias (relative multiplicative bias) calculated for GCM and observations in a reference period [10]. Due to its relative simplicity, computational demand, and growing global and regional climate model simulation databases, bias correction has grown in popularity [21].Furthermore, bias-corrected climate model data may be used as the basis for real-world adaptation decisions and thus should be plausible, defensible, actionable, and widely used [6]. On an average monthly basis, the Delta Change method was used for bias correction. Because it is based on a map of differences between observed and simulated values, the delta method assumes bias to be location-specific, and model bias is constant over time [8]. The Delta Change method has been used in many climate-related bias-correction applications [28] mainly due to its simplicity. Furthermore, its statistical approach to bias correction outperforms other physical-based approaches in terms of computational efficiency [28]. However, bias correction using the Delta Change method affects only the average, maxima, and minima of the climatic index in scenarios, leaving all other properties unchanged, such as the number of wet/dry days and temperature variance [12].

3.2. HEC-ResSim Software Package

HEC-ResSim [35] software was used to simulate the Kalu Ganga Reservoir and related infrastructure system. The HEC-ResSim was developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers (USACE). The HEC-ResSim can be used to simulate the operation of multiple reservoirs, irrigation releases, diversions, pumps, and hydropower stations, among many [9]. The HEC-ResSim tool has been extensively used in many studies around the world for a wide range of purposes. These include reservoir system simulation, hydropower simulation, flood management, reservoir operation rules development, water resources optimization, climate change studies, navigation and benefit sharing among water users [23, 22, 25, 7, 9 and 32].

3.3. Surplus Water Availability in Kalu Ganga Reservoir under CC Impacts

The surplus water availability of Kalu Ganga Reservoir under climate change impacts was evaluated by simulating CC-affected catchment inflows and CC-affected demands with the HEC-ResSimwater allocation simulation model. First, the SWAT model was used to calculate the CC-affected catchment inflows of Kalu Ganga. Then, with other parameters remaining constant, CC-affected irrigation demands were recalculated using CC-affected temperature and rainfall data. Also, for this simulation, the e-flow regime is not changed, and it is assumed that spare storage is available in the Moragahakanda reservoir to capture the water diverted from the Kalu Ganga. Finally, the HEC-ResSim model developed for the water balance assessment was used to calculate the surplus water quantity available to divert from the Moragahakanda Reservoir after releasing e-flow and meeting the irrigation demands of System F and Haththota Amuna system.

4. Results and Discussion

The SWAT model was calibrated to improve the statistical and graphical relationship between the measured streamflow series of the Laggala gauge and the statistical indices indicate a clear and strong relationship between the observed flow series and the simulated flow series as per the suggested best-fit ranges for model performance indicators to evaluate the quality of the model calibration [24, 5]. Figures 3 and 4 show a comparison of the observed rainfall, measured and simulated flows for the calibration and validation periods.

The model closely simulated base flows, lag-time, and recession limbs of hydrographs but failed to simulate peaks, despite the fact that peak dates overlap. The Laggala gauging station's rating curve has been developed for low flows, and high discharges with overbank flows have not been measured due to inaccessibility. Therefore, peak flows are estimated by extrapolating the rating curve for the river section, which may result in inaccurate estimates [27].

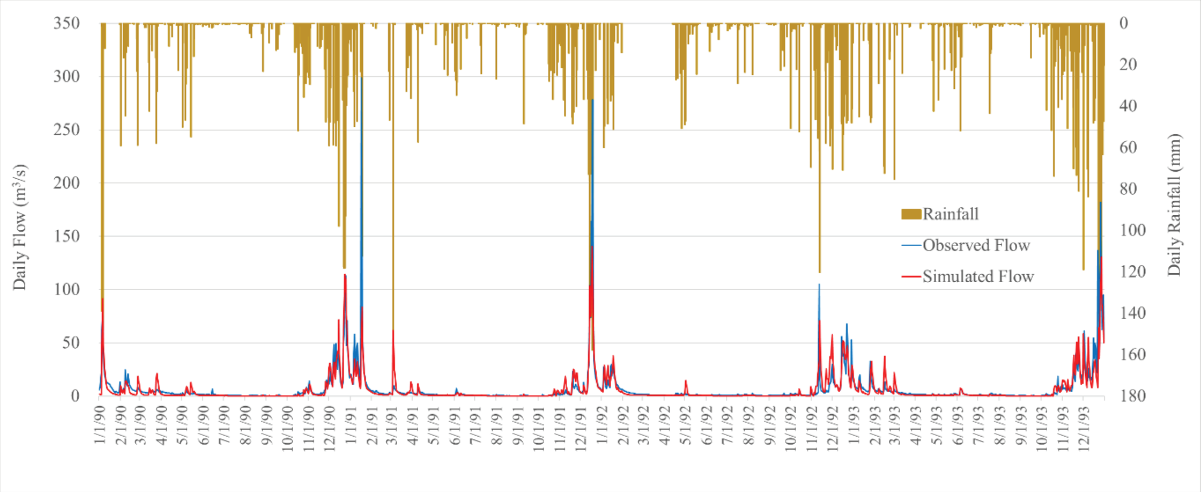


Figure 3 - Comparison of Rainfall and Daily Flows in the Calibration Period (1990-1993) (m³/s)

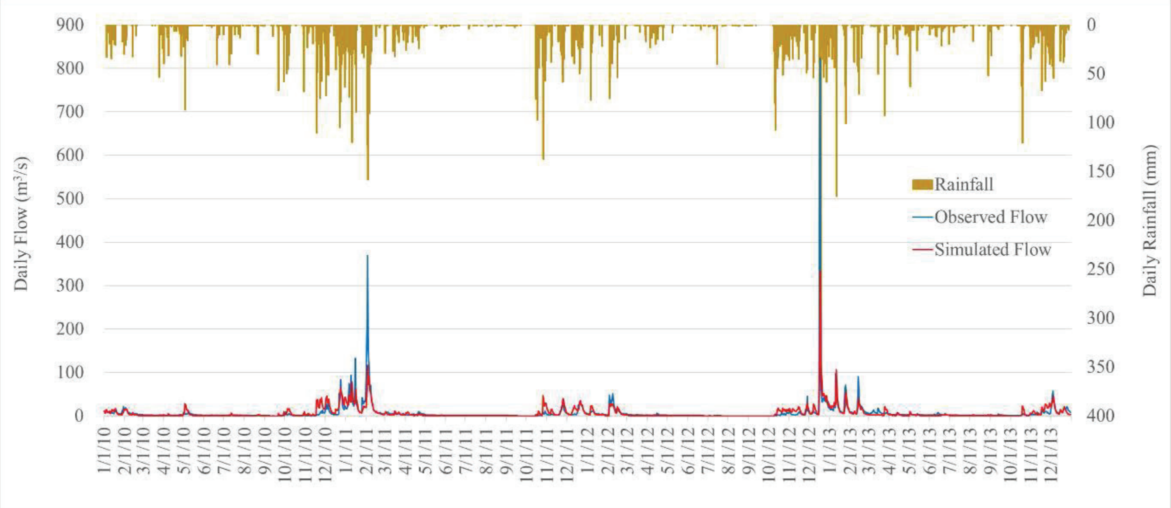


Figure 4 - Comparison of Rainfall and Daily Flows in the Validation Period (2010-2013) (m³/s)

4.1. Temperature Data

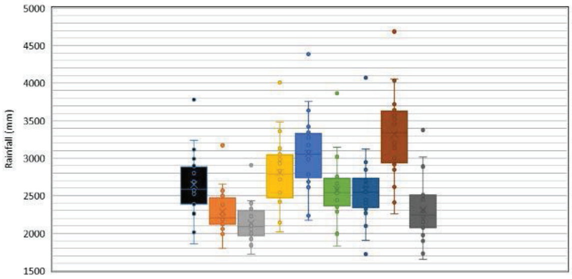
The average minimum and maximum temperature values were calculated for all 12 scenarios, and it was discovered that the increase in maximum temperature is 2.52ºC while the increase in minimum temperature is 2.65ºC. This means that the increase in daily minimum temperature is more intense than the maximum temperature.

4.2. Rainfall Data Used for the Streamflow Generation

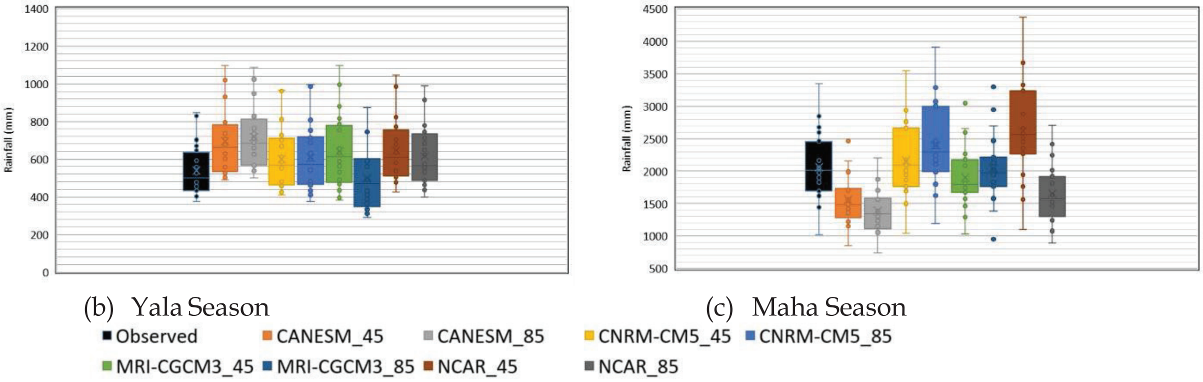
The Thiessen Polygon method was used to calculate the representative catchment rainfall of the Kalu Ganga catchment using rainfall data from all six models. CSIRO-MK3-6-0 and GFDL-CM3 models were then found to overestimate the rainfall, so they were excluded from further investigation as unrealistically extreme cases. Therefore, only four remaining models (CANESM, CNRM-CM-5, MRI-CGCM3 and NCAR) were applied to the SWAT model for further analysis. Table 4 shows the monthly, seasonal, and annual distributions of rainfall predicted by various models. In addition, the Whisker plots in Figure 5 show the catchment's cumulative annual and seasonal rainfall under different scenarios.

Table 3 - Predicted Monthly, Seasonal and Annual Distribution of Rainfall

	Monthly rainfall (mm)												Annual rainfall (mm)		Maha seasonal rainfall (mm)		Yala seasonal rainfall (mm)	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	volume	% change	volume	% change	volume	% change
Observed	458	218	145	194	113	51	48	49	85	292	445	548	2646	0%	2106	0%	540	0%
CANESM_45	326	253	139	204	119	78	93	97	104	249	331	294	2288	-14%	1592	-24%	696	29%
CANESM_85	333	213	133	210	128	96	93	84	107	197	265	274	2133	-19%	1415	-33%	718	33%
CNRM-CM5_45	440	206	125	221	114	51	42	70	102	337	438	664	2811	6%	2209	5%	601	11%
CNRM-CM5_85	500	175	163	232	118	38	49	66	105	409	482	725	3062	16%	2454	17%	607	12%
MRI-CGCM3_45	309	139	126	205	111	25	55	85	161	339	582	448	2583	-2%	1943	-8%	641	19%
MRI-CGCM3_85	518	135	55	121	79	16	40	85	157	344	669	360	2580	-2%	2081	-1%	499	-8%
NCAR_45	676	93	103	251	147	55	60	50	83	313	638	853	3323	26%	2677	27%	646	20%
NCAR_85	151	56	68	182	163	40	49	58	123	359	546	518	2313	-13%	1698	-19%	615	14%
* % changes are calculated with respect to the annual, seasonal observed values																		



(a) Annual



(b) Yala Season

(c) Maha Season

Figure 5 - Whisker Plots Showing the Cumulative Annual and Seasonal Rainfall of Kalu Ganga Catchment Under Different Scenarios

In terms of relative changes, the average annual rainfall values of different GCMs given in Table 4 and Figure 5 show mixed results. This annual average rainfall varies from -19% in the CANESM model's RCP 8.5 scenario and 26% increase in the NCAR model's RCP 4.5 scenario. The Maha seasonal rainfall follows the same pattern as the annual values, but the magnitudes are different. This ranged from - 33% in the CANESM model's RCP 8.5 scenario and a 27% increase in the NCAR model's RCP 4.5 scenario. This is due primarily to the fact that the Maha season receives the majority of the annual rainfall. The Yala seasonal rainfall, on the other hand, shows an increase in all the cases except -8% in the RCP 8.5 scenario in MRI-CGCM3, and the highest increase is 33% in the RCP 8.5 scenario of the CANESM model.

4.3. Streamflow

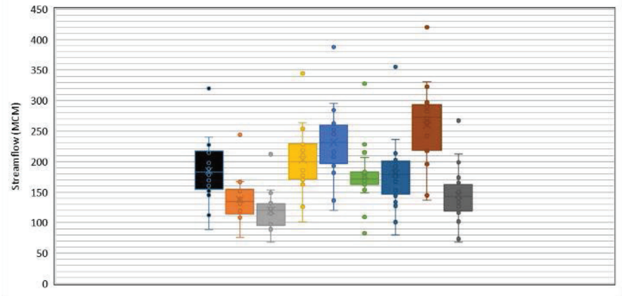
Climate change rainfall and temperature predictions from GCMs CANESM, CNRM-CM-5, MRI-CGCM3, and NCAR were used to simulate catchment hydrology in SWAT models. Table 5 shows the monthly, seasonal and annual streamflow predicted from the SWAT models.

Figure 6 shows whisker plots of cumulative annual and seasonal streamflow of the Kalu Ganga under different scenarios.

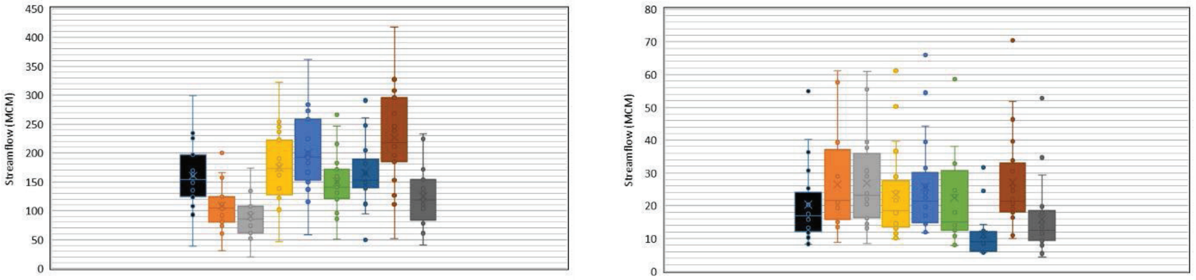
Table 4 - Monthly, Seasonal and Annual Streamflow Volumes Simulated from SWAT Models

	Monthlystreamflow (MCM)												Annual streamflow (MCM)		Maha seasonal streamflow (MCM)		Yala seasonal streamflow (MCM)	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	volume	% change	volume	% change	volume	% change
Observed	44.8	21.0	9.8	7.9	6.2	2.1	1.5	1.3	1.4	9.0	29.6	50.5	185.0	0%	164.7	0%	20.4	0%
CANESM_45	28.2	21.2	9.1	7.7	6.3	2.9	3.3	3.5	2.6	8.4	20.4	24.2	137.9	-25%	111.5	-32%	26.4	30%
CANESM_85	27.8	17.5	7.5	7.5	6.6	3.9	3.5	3.0	2.5	5.7	13.8	20.3	119.5	-35%	92.6	-44%	26.9	32%
CNRM-CM5_45	44.7	19.9	8.2	9.1	6.8	2.2	1.5	1.7	2.0	12.9	31.5	62.1	202.5	9%	179.2	9%	23.3	15%
CNRM-CM5_85	51.4	18.3	10.5	10.6	7.5	2.1	1.6	1.8	2.1	17.7	38.1	69.9	231.7	25%	206.0	25%	25.8	27%
MRI-CGCM3_45	30.1	12.4	6.5	7.5	5.9	1.5	1.3	1.9	4.2	15.4	45.3	44.6	176.9	-4%	154.5	-6%	22.4	10%
MRI-CGCM3_85	48.2	14.6	3.4	2.6	2.1	1.0	0.9	1.2	3.4	13.7	51.6	37.9	180.7	-2%	169.4	3%	11.3	-45%
NCAR_45	70.5	14.3	5.5	9.9	9.1	2.8	2.1	1.7	1.5	10.4	47.2	85.1	260.0	41%	232.9	41%	27.1	33%
NCAR_85	16.9	4.1	2.2	3.7	6.2	1.6	1.1	1.2	2.1	14.3	40.9	50.5	144.8	-22%	128.9	-22%	15.9	-22%

* % changes are calculated with respect to the annual, seasonal observed values



(a) Annual



(b) Maha Season (c) Yala Season

Figure 6 - Whisker Plots Showing the Annual and S seasonal Streamflow Volumes of Kalu Ganga Catchment Under Different Scenarios

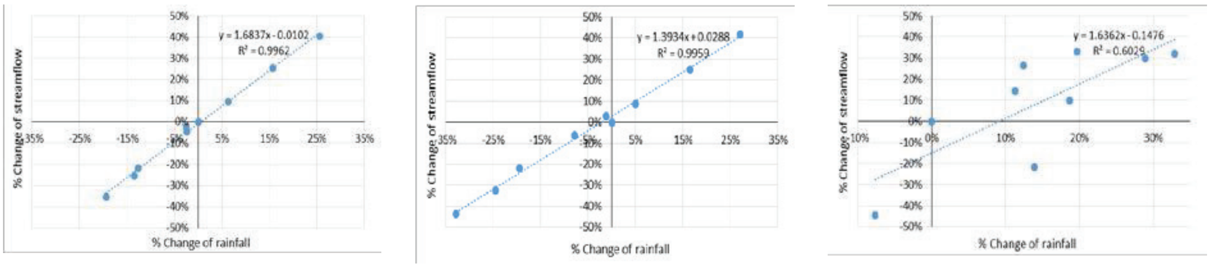
As shown in Table 5 and the annual graph given in Figure 6, the average annual streamflows of different GCMs produce mixed results in terms of the relative streamflow change in different scenarios. The annual average streamflow varied from (-35%) in the CANESM RCP 8.5 scenario and a 41% increase in the NCAR RCP 4.5 scenario. The Maha seasonal streamflow follows a similar pattern to the annual values, but the magnitudes differ, mainly due to the Maha season accounting for the majority of the annual streamflow. The Maha seasonal flow volume varied from -44% in the CANESM model's RCP 8.5 scenario to a 41% increase in the NCAR model's RCP 4.5 scenario. Except for - 45% in the RCP 8.5 scenario in MRI-CGCM3 and -22% in the RCP 8.5 scenario in the NCAR model, the Yala seasonal streamflow rainfall is mostly increasing. In the NCAR model, the highest increase is 33% in the RCP 4.5 scenario.

4.4. Sensitivity of Streamflow with the Change of Catchment Rainfall

Table 6 shows the percentage changes in annual and seasonal rainfall and simulated streamflows, where the percentage changes are calculated using the relevant observed annual and seasonal flows. Also, the annual and seasonal sensitivity of catchment rainfall to catchment inflow is examined. The resultant graphs are shown in Figure 7.

Table 5 - % of Changes in Annual and Seasonal Rainfall and Streamflow

Scenario	Annual rainfall (mm)	%Change of rainfall	Annual streamflow (MCM)	%Change of flow	Maha seasonal rainfall (mm)	%Change of rainfall	Maha seasonal streamflow (MCM)	%Change of flow	Yala seasonal rainfall (mm)	%Change of rainfall	Yala seasonal streamflow (MCM)	%Change of flow
Observed	2646	0%	185.0	0%	2106	0%	164.7	0%	540	0%	20.4	0%
CANESM_45	2288	-14%	137.9	-25%	1592	-24%	111.5	-32%	696	29%	26.4	30%
CANESM_85	2133	-19%	119.5	-35%	1415	-33%	92.6	-44%	718	33%	26.9	32%
CNRM-CM5_45	2811	6%	202.5	9%	2209	5%	179.2	9%	601	11%	23.3	15%
CNRM-CM5_85	3062	16%	231.7	25%	2454	17%	206.0	25%	607	12%	25.8	27%
MRI-CGCM3_45	2583	-2%	176.9	-4%	1943	-8%	154.5	-6%	641	19%	22.4	10%
MRI-CGCM3_85	2580	-2%	180.7	-2%	2081	-1%	169.4	3%	499	-8%	11.3	-45%
NCAR_45	3323	26%	260.0	41%	2677	27%	232.9	41%	646	20%	27.1	33%
NCAR_85	2313	-13%	144.8	-22%	1698	-19%	128.9	-22%	615	14%	15.9	-22%
* % changes are calculated with respect to the annual, seasonal observed values												



Annual Maha Season Yala Season

Figure 7 - Relationship Between % Changes of Rainfall and Streamflow

Changes in annual and Maha seasonal rainfall are susceptible to streamflow because the percentage change in streamflow is typically greater than the percentage change in rainfall. For example, in CANESM model's RCP 4.5 case, a 14% decrease in annual rainfall results in a 25% decrease in annual streamflow, whereas a 24% decrease in Maha seasonal rainfall results in a 32% decrease in Maha seasonal streamflow. However, different cases are available for the Yala season. The Yala seasonal flow is a small percentage of the annual flow (11% in the observed scenario), which is dependent on the Yala seasonal rainfall as well as rainfall in the final weeks of the Maha season (March). Therefore, these differences could be explained by a slight change in the Yala seasonal flow caused by March rainfall changes. Figure 7 shows that a percentage change in the catchment rainfall results in a higher percentage change in streamflow.

4.5. CC Affected Surplus Water Availability in Kalu Ganga Reservoir

The HEC-ResSim model was used to assess Kalu Ganga Reservoir's surplus water availability after the CC altered streamflow and demands. Table 7 provides the monthly and yearly distribution of available surplus water for diversion to the Moragahakanda Reservoir.

Table 6 - Monthly / Annual Surplus Water Availability of Kalu Ganga Reservoir Under CC Scenarios

	Monthly diversion (MCM)												Annual diversion	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	volume	% change
Observed	34.3	16.8	6.8	4.7	1.3	0.0	0.0	0.0	0.0	0.1	5.0	22.8	91.8	0%
CANESM_45	10.1	12.0	5.8	3.5	1.4	0.0	0.0	0.0	0.0	0.0	1.8	4.4	39.0	-58%
CANESM_85	6.2	6.2	4.0	2.2	1.6	0.0	0.0	0.0	0.0	0.0	0.7	1.4	22.1	-76%
CNRM-CM5_45	38.3	16.9	5.5	5.6	1.6	0.0	0.0	0.0	0.0	0.8	6.9	32.0	107.6	17%
CNRM-CM5_85	46.6	18.2	7.7	6.9	1.9	0.1	0.0	0.0	0.0	1.7	13.9	40.5	137.4	50%
MRI-CGCM3_45	20.9	7.7	3.7	3.7	1.2	0.0	0.0	0.0	0.0	1.6	15.1	27.0	80.9	-12%
MRI-CGCM3_85	34.9	11.3	1.6	0.5	0.0	0.0	0.0	0.0	0.0	0.8	14.2	22.5	85.8	-7%
NCAR_45	59.7	25.4	5.4	6.2	3.0	0.1	0.0	0.0	0.0	0.5	14.4	51.2	165.9	81%
NCAR_85	9.6	0.5	0.1	0.1	1.4	0.0	0.0	0.0	0.0	0.9	9.7	27.6	49.9	-46%
* % changes are calculated with respect to the annual, seasonal observed values														

Whisker plots that show the average annual surplus water availability of the Kalu Ganga under different CC scenarios are shown in Figure 8.

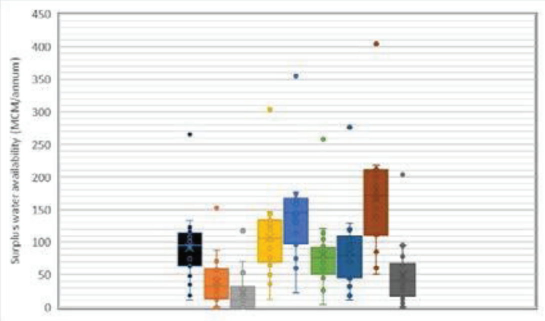


Figure 8 - CC Affected Surplus Water Availability of Kalu Ganga Reservoir

As shown in Table 3.5 and the annual graph in Figure 8, the average annual diversions under different GCMs produce mixed results in terms of relative changes in the availability of surplus water. The annual average streamflow ranged from (-76%) in the CANESM RCP 8.5 scenario to an increase of 81% in the NCAR RCP 4.5 scenario. The expected range of streamflow generation (-35% to 41%) is lower than the predicted range of changes in excess water availability (-76% to 81%). The monthly, yearly, and seasonal distribution of streamflow values predicted from selected models are shown in the graphs in Figure 9.

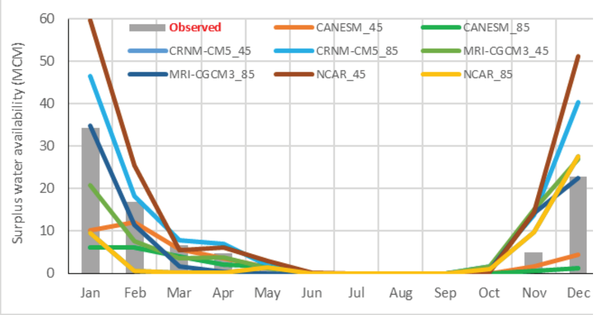


Figure 9 - Monthly Distribution of CC Affected Surplus Water Availability of Kalu Ganga Reservoir

The graphs in Figure 9 illustrate a significant range in the average surplus water availability. Importantly, the NCAR model's RCP 4.5 scenario depicts a greater increase in December and January, while the CANESM model's two RCP scenarios depict a considerable decline in the availability of surplus water in November, December and January. Also, the surplus water availability is significantly reduced in March and April according to the MRI-CGCM3 and NCAR RCP 8.5 scenarios.

5. Conclusions

This study examines the effects of climate change on the hydrology of the Kalu Ganga catchment and the surplus water availability of the Kalu Ganga Reservoir. It also conducts a qualitative and quantitative analysis of how such effects will alter streamflow and surplus water availability. The streamflow of the Kalu Ganga was estimated using the SWAT model utilizing the expected temperature and rainfall due to climate change data produced by numerous climate models. Since it could be used to assess numerous cases of rainfall and temperature data series and their impact on catchment hydrology, such as streamflow, the SWAT model's implementation in the study was successful. SWAT is therefore strongly advised for similar climate change investigations. Data on temperature and rainfall provided by various climate models were used to anticipate how the climate will evolve. The SWAT model's implementation in the study was successful because it allowed for the evaluation of numerous temperature and rainfall data series as well as their impact on catchment hydrology, including streamflow. SWAT is therefore strongly advised for similar climate change investigations.

According to the study, the average temperature for the 2040–2060 period would be 0.7–1.7°C higher than the baseline period's average temperature. The potential evapotranspiration will rise by 1 to 4.5% due to the rise in temperature, increasing Irrigation System F's need for irrigation. Therefore, it is necessary to identify appropriate adaptation strategies to lower irrigation demand, such as upgrading the water delivery system, enhancing on-farm water management, and altering cropping practices. Changing planting dates to prevent flowering during hot spells and creating heat-tolerant crop varieties are other ways to prevent crop loss brought on by high temperatures.

Depending on the situation, the mean annual rainfall might vary from -19% to 26%. Rainfall during the Maha season has a similar pattern to rainfall throughout the year, possibly because the Maha season accounts for a sizable amount of the yearly rainfall. On the other hand, with the exception of the MRI-CGCM3 RCP 8.5 case, the Yala seasonal rainfall is increasing. As a result, it is generally acknowledged that the seasonal rainfall in Yala has increased by up to 33% since the baseline. The Maha seasonal streamflow likewise exhibits a similar trend, with a range of -44% to 41%, while the mean annual streamflow volume exhibits variable results in different circumstances with a range of -35% to 41%. The Yala seasonal streamflow, on the other hand, is typically growing, albeit this rise is not particularly significant given how little the Yala streamflow is in relation to the annual total flow. On annual and seasonal periods, the percentage change in streamflow is always greater than that of rainfall, highlighting streamflow's extreme sensitivity to variations in rainfall.

The HEC-ResSim tool also simulates historical and CC-driven inflows and outflows successfully. Therefore, HEC-ResSim is highly advised for CC investigations. Regarding the relative changes in the availability of surplus water, the average annual diversions under the various GCMs produce a variety of results. The yearly streamflow varied from -76% to an 81% increase. The yearly streamflow ranged from -76% to 81%. The expected range of streamflow generation (-35% to 41%) is lower than the predicted range of excess water availability (-76% to 81%).

The capacity to predict the effects of climate change during the Maha season is limited by the inconsistent findings of the research about rainfall and streamflow during the Maha season. But the Maha season is when most of the water is produced. Therefore, accurate streamflow forecast for the Maha season is crucial for creating Kalu Ganga Reservoir operational guidelines. Therefore, further research on the effects of climate change in this region is advised in order to obtain more accurate results, especially given the Maha season. For this, other CC datasets and bias correction techniques can be tested.

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