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Impact of Climate Change on Surface Runoff for Myponga Reservoir Catchment in South Australia, Australia

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Authors' contributions

This work was carried out in collaboration between both authors. Author SM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author AMH supervised and guided the research work. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This paper is aimed to assess the future impact of climate change on some selected climatic variables and on surface runoff from Myponga catchment, South Australia.

Methodology: The six global climate models recommended for South Australia were compared among each other based on their performance to simulate observed climates in the study area. The monthly average statistically downscaled evapotranspiration and rainfall data for the period 2000-2005 were compared with respective observed climate data, graphically and statistically. On the other hand, four hydrological models in Australian rainfall-runoff library (RRL) were evaluated and compared among each other based on their performance in simulating surface runoff in the study area. Then, two GCMS, CanESM2 and MIROC5, and one hydrological model, AWBM, were selected for their better performance and used for climate projections and for runoff simulation for both base period (1990-2005) and future period (2026-2035) under two emission scenarios (RCP 4.5 and RCP 8.5), respectively. Finally, the impacts of climate change were estimated by

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comparing the long year’s average values of the climate projections and simulated runoff in the base and the future periods for different percentile values (10th, 50th, and 99th) under the two emission scenarios.

Results: The result showed that compared to the base period (1990-2005), by 2030s (2026-2035), for both climate models, two emission scenarios, and all the percentiles, the average annual evapotranspiration would generally increase, but the average annual rainfall would decrease. The average annual runoff showed different patterns across the climate model and emission scenarios. But, on average, percentage changes across climate models show a rise in average annual runoff in the range from 3.72 to 5.47 % across percentiles for the intermediate scenario and decline in the range from 17.13 to 20.15 % across percentiles for the high emission scenario.

Conclusion: It is expected that by 2030 there would be no significant problem with respect to water availability, drought, and flooding at an annual time scale under the intermediate emission scenario but there would be drier conditions in the catchment relative to the base period under the high emission scenario.

Recommendation: Therefore, adaptation and mitigation measures should be identified and applied at national and state levels to minimize possible negative impacts in the Myponga reservoir catchment.

Keywords: Climate change; impacts; GCM; statistically downscaled; Australian rainfall-runoff library (RRL), Myponga.

1. INTRODUCTION

Global warming due to the rise in greenhouse gases has caused the climate to change which in turn subsequently alters hydrological processes. The changes observed in the last several decades have constantly altered components of hydrological processes such as precipitation amount and pattern, surface runoff, soil water content, ice and snow coverage, and evaporation from land and water surfaces. Such alterations in hydrological processes are owing to the fact that hydrological systems are highly linked to the climate systems. In the future, further climate change is inevitable at least owning to already committed warming or past emissions [1]. Clearly, the changes would continue and inevitably would have impacts on the hydrological processes.

South Australia is already the driest state in the driest continent. Additionally, climate change is becoming one of the most important challenges in the effort to ensure a sustainable water supply to the state. Several climate impact studies for several catchments in South Australia show different levels of changes in climate variables and runoff in South Australia. For instance, research on three sub-catchments of Onkaparinga shows that around 14% reduction in mean annual runoff may be experienced between 2016 and 2045. The study further notes that South Australia would more likely face a considerably drier flow regime in the future [2]. CSIRO [3] also reported that the southern Australia region would more likely experience a decline in rainfall and runoff due to climate change in the future. Recently Goyder Institute for Water Research [4] warned that a significant reduction in inflow to reservoirs in South Australia may be experienced. In fact, climate change is expected to be the main source of pressure on water resources in South Australia [5]. To improve understanding of climate impact on water availability, studies of climate impact are crucial. However, climate impact studies on runoff have not been conducted in Myponga catchment in recent times. Thus, this study was conducted over Myponga reservoir catchment to provide information for proper planning of adaption measures so as to cope with climate change impacts and ensure sustainable water supply. The study can ultimately contribute to a better understanding of the climate impact on the water resources of the state.

The impacts of climate change on water resources can be investigated in various ways and at different levels. However, the most widely used approach involves two major processes. The first important process is projecting values of climate variables. This can be done in different ways. The use of different climate scenarios obtained from model outputs is the most commonly used way.

This involves the use of climate models, such as general circulation models (GCMs) and their derivatives, to project climate variables in a study area for a base or a future period [6]. GCMs are the most effective and widely used in global and regional impact assessment studies. There are different GCMs available around the world. The performance of each model varies across geographic locations. For instance, among the 12 GCMs selected for Australia (available in online archive developed by the South Australian government), six of these models are identified as suitable for the different regions in the state [7]. The Second important process in impact studies is assessing the hydrological impact of projected climate variables. The assessments can be done either by employing the concept of elasticity of runoff to historical climate or through hydrological modeling [6]. The choice of impact assessment method varies with data availability, type of analysis required, and catchment size [1]. Yet, hydrological modeling is widely used to study the impact of climate change on runoff owing to the capability of hydrological models to simulate daily or monthly runoff and other hydrological parameters directly from projected climate scenarios or in combinations with other drivers [6].

In this research, impact of global warming on climate variables and runoff in Myponga reservoir catchment were assessed based on data from statistically downscaled climate projections. The climate projections from the system with six GCMs recommended for South Australia were further evaluated against observed past climate data, and two models were selected to represent a range of uncertainties. For runoff simulation, four hydrological models -SIMHYD, Sacramento, SMAR, and AWBM in rainfall-runoff library (RRL) package were evaluated and the best one was selected based on efficiency and used for simulation of runoff for impact assessment. This study was aimed at investigating impact of global warming on some climate variables and runoff by the year 2030's (between 2026 and 2035) relative to the base period (1986 to 2005).

2. METHODOLOGY

2.1 Description of the Study Area

Myponga reservoir catchment is located in Adelaide and Mount lofty ranges and cover an area of 121.23 km^2. The area upstream of Myponga Reservoir is 77.7 km^2 (Fig. 1). The major channel of the Myponga River is located near the intersection of Pages Flat Road and the Adelaide to Victor Harbor Road. This channel has a low grade (approximately 0.6%) while the altitude within the River catchment ranges from 0 to 400 above sea level, the peak at Myponga Hill [8].The river discharges into the Myponga Reservoir and out flowing downstream of the reservoir in a westerly direction to enter Gulf St Vincent [8].

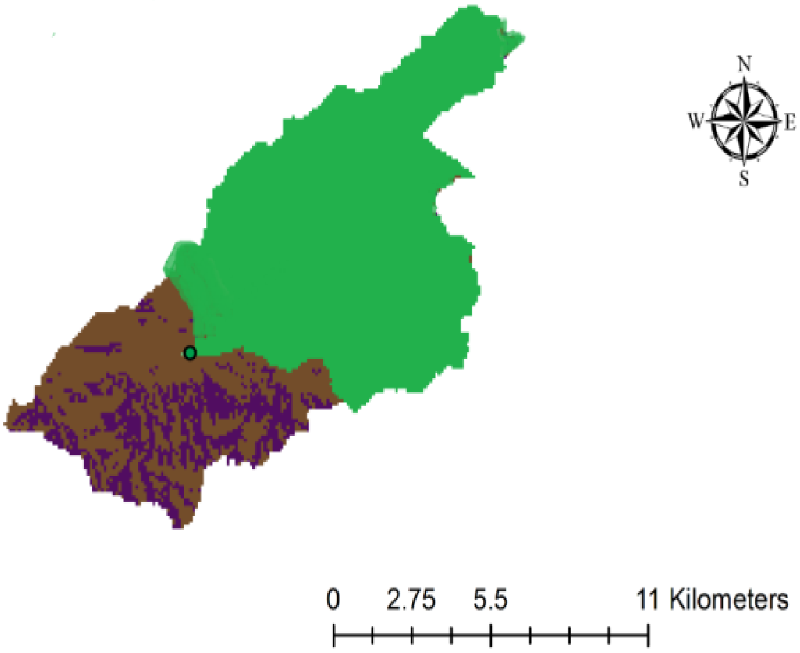

Fig. 1. Myponga catchment and its part upstream of the gauge station (green)

2.2 Description of the Climate Data Sources

The data from global climate models (GCMs) available by government of South Australia (https://data.environment.sa.gov.au) were used in this study. Even though there are 12 GCM–CMIP 5 version available, six of these models (shown in Table 1) are identified as suitable models for climate projection in South Australia [7].

In the online system, CMIP5 versions of GCMs can be run for three scenarios referred as Representative Concentration Pathways (RCPs). RCPs is a term equivalent to the term "emissions scenarios" of IPCC. The three RCPS are: RCP4.5, an intermediate concentration pathway similar to the B1 emissions scenario from IPCC Assessment Report 4 (AR4), and RCP8.5, a high-concentration pathway similar to the A1FI emissions scenario in IPCC AR4, and historic (base line emission). The online system employs inbuilt statistical downscaling approaches- Nonhomogeneous Hidden Markov Modeling (NHMM) for rainfall downscaling and *weather generator* for downscaling non-rainfall variables. These downscaling tools have already been successfully used in several hydrological impact studies [9-11]. The NHMM simulates rainfall at daily basis for one or multiple stations in a catchment. Thus, downscaled daily rainfall projections can be obtained for a station or multiple stations. While the *weather generator* provides downscaled daily projections for non-rainfall climate variables for single or multiple stations [7]. Downscaled daily projections from global climate model (GCM) can be downloaded for 6 climate variables: namely, rainfall, maximum and minimum temperature, areal potential evapotranspiration, solar radiation, and vapor pressure deficit. The system provides 100 possible realizations for each combination of climate model (GCM) and emission scenarios (RCPs) at selected stations. The realizations are domain of possible daily weather projections in the base or future periods [7].

2.3 Description of Hydrological Model

For hydrological modelling, four rainfall-runoff models available in software package called Rainfall-Runoff Library (RRL) were used. The software package is developed by public institution called *eWater* in Australia. The eW*ater* is established to develop software tools for hydrological modelling and implement national hydrological modelling strategy (NHMS). The RRL version 1.0.5 comprises of five models, AWBM, *Sacramento*, *SIMHYD,* SMAR, and Tank model. However, four of most widely used in catchment modelling are AWBM, *Sacramento*, *SIMHYD, and* SMAR. For these models, inputs data need to be on daily basis. For calibration and validation, catchment size, rainfall, evaporation, and stream flow data are required. While, for simulation, catchment size, rainfall, and potential evapotranspiration data together with calibration model parameters are required [12].

2.4 Data Collected

GIS shape files, DEM data file, and coordinates of the flow station were obtained from different sources to delineate catchment (https://data.sa.gov.au, GIS on line, and http://www.bom.gov.au/sa/).

Daily rainfall observation data for 10 years (2000-2010) for 6 rainfall stations across the Myponga catchment were downloaded from http://www.bom.gov.au/sa/. These rainfall stations were selected because their rainfall data is expected to influence areal rainfall for the catchment based on constructed Theisson polygons.

Table 1. Six GCMs identified suitable for South Australia [7]

Model	Institutions
CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada (CCCMA)
CNRM-CM5	Centre National de Recherches Meteorologiques, France (CNRM CERFACS)
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA
IPSL-CM5B-LR	Institute of Pierre-Simon Laplace, France (IPSL)
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine Earth Science and Technology, Japan (MIROC)
MRI-CGCM3	Meteorological Research Institute, Japan (MRI)

Daily Pan- Evaporation data for 11 years (2000-2010) were obtained from Australian Bureau of Metrology (BOM). Downscaled daily projections from global climate model (GCM) were downloaded from https://data.environment.sa.gov.au for two climate variables: namely, daily rainfall and potential evapotranspiration corresponding to the weather station. The daily mean flow data (ML/day) for 11 years (2000-2010) corresponding to the gauge station -A5020502 were downloaded from http://www.bom.gov.au/sa/. This flow data represents runoff from Myponga catchment upstream of the gauge station.

2.5 Procedure for Model Selection and impact Analysis

In this study, two major tasks were carried out. First, climate and hydrological models were evaluated and selected. The climate and hydrological models were evaluated for their performance in the study area to simulate the observed climate and runoff, respectively. Secondly, impact assessment was carried out.

Two best performing GCMs among the six GCMs recommended for South Australia and one best performing hydrological model in the four hydrological models with in the Rainfall Runoff Library (RRL) was used for climate projection and runoff simulation, respectively. Then, the percentage changes in projected climate and runoff for selected future periods relative to base period (2000 to 2005) were estimated. The details of the methods used are described below.

2.5.1 Evaluation of climate model

As already explained the Goyder Institute for Water Research [7] has selected six climate model for South Australia. In this study the six climate models were further evaluated in order to select two best performing models. Two climate models were considered sufficient to represent reasonable range of uncertainties over the study area. To select two climate models, the six climate models (GCMs) recommended for South Australia were evaluated and compared. For this purpose, base period climate projections were downloaded for each of the six GCM- CMIP5 models for period from 2000 to 2005 and for selected single weather station. A set realisation data corresponding to median annual rainfall for each GCM was identified. Therefore, for six models and single weather station, data from 600 realisation files were analysed. On the other hand, observed climate data for the same period was collected and analysed to obtain monthly average daily rainfall and evapotranspiration. To obtain observed monthly average daily evapotranspiration, monthly average daily pan-evaporation was multiplied by pan-coefficients determined. The pan coefficient was determined based on estimated reference evapotranspiration from Penman–Monteith equation (CROPWAT 8 software) and pan evaporation data from the weather station. Then, the observed and projected rainfall and evapotranspiration were compared based on how well they simulate the observed climate data. This approach of comparisons based on ‘Historic accuracy’ is widely used in a number of studies [13,14]. It is based on the assumption that a model that performs better in simulating the observed climate in the past would perform better in future as well. In this study, projected and observed climate were compared graphically and statistically. Graphical comparison was done to visualize how well the models simulate the observed data. Statistically, the calculated sum of the square of errors for projected evapotranspiration and rainfall against observed values were compared for each GCMs**.** These approaches of graphical and statistical comparisons were adopted from similar studies [13,14].

2.5.2 Evaluation of hydrological models

In order to select best model for simulation of runoff for the base and the future periods, firstly, the four hydrological models within the Rainfall Runoff Library (RRL) (SIMHYD, Sacramento, SMAR, and AWBM) were calibrated and validated. To this end, daily rainfall and evapotranspiration data from six weather stations were used. To adjust the pan –evaporation data, monthly pan- coefficients were estimated and used for data scaling in the RRL software during calibration and validation processes. The calibration and validation were performed repeatedly using different combinations of calibration, warm up, and verification periods until the best possible performance are achieved. The performance of the four models were compared based on model efficiency. The efficiency of models in RRL Packages are expressed by Nash-Sutcliffe efficiency (NSE), Coefficient of Efficiency for Calibration (Ec), and Coefficient of Efficiency for validation (Ev) which are automatically calculated for each of the calibration and validation runs**.** The NSE is a standardized measure of the relative proportion of observed data variance to total residual variance. Thus, it measures how well the modeled flow is related to observed daily runoff [15]. Similarly, coefficients of efficiency of calibration and validations indicate how closely the respective calibration and validation observation data sets are related to calculated runoff. Secondly, the most suitable model was selected based on correlation coefficient of calibration and validation. The weighted average rainfall for the watershed was calculated based on constructed Theisson polygons for selected six rainfall stations.

2.5.3 Assessment of climate impact

After the climate and hydrological models were evaluated and selected, the impact assessment was performed. In the process, firstly, the selected climate models were used to download climate projections at three emission scenarios (Historic, RCP 4.5, and RCP 8.5) for 5 weather stations. The projection files were analyzed and GCM realizations at 10th, 50th, and 99th percentiles of rainfall were identified, for 16 years base period (1990 - 2005), and 10 years (2026-2035) for RCP 4.5, and RCP 8.5. The 10th, 50th, and 99th percentiles of rainfall represent low, median, and highest annual flows, respectively. Secondly, runoff was simulated using best performing hydrological model. To simulate runoff over the watershed, projected daily time series of rainfall and evapotranspiration data for 6 grid points from two selected GCMS were used as input in to the calibrated and validated hydrological model. The simulations were run for three percentiles of flow (10th, 50th, and 99th) and three emission scenarios (Historic, RCP 4.5, and RCP 8.5). Finally, the changes in climate variables and runoff due to climate change were estimated.

The percentage changes from annual simulated runoff for base period (1990- 2005) and future period (2026 - 2035) were computed for each of the climate models, emission scenario, and flow percentiles.

3. RESULTS AND DISCUSSION

3.1 Performance of Global Climate Models

Even though the six climate models are already identified as suitable for South Australia, these models were evaluated based on how well they simulate observed rainfall and evapotranspiration for Myponga catchment. For this purpose, five years average (2000- 2005) monthly observed and projected rainfall and evapotranspiration of Myponga reservoir station were compared graphically as shown in Fig. 2 and 3 and statistically as shown in Table 2. As it can be seen in Fig. 2 and 3, the curves are superimposing and it is difficult to identify visually how each model performs. Yet, it is clear that the curves generally show similar trend over months for both rainfall and evapotranspiration.

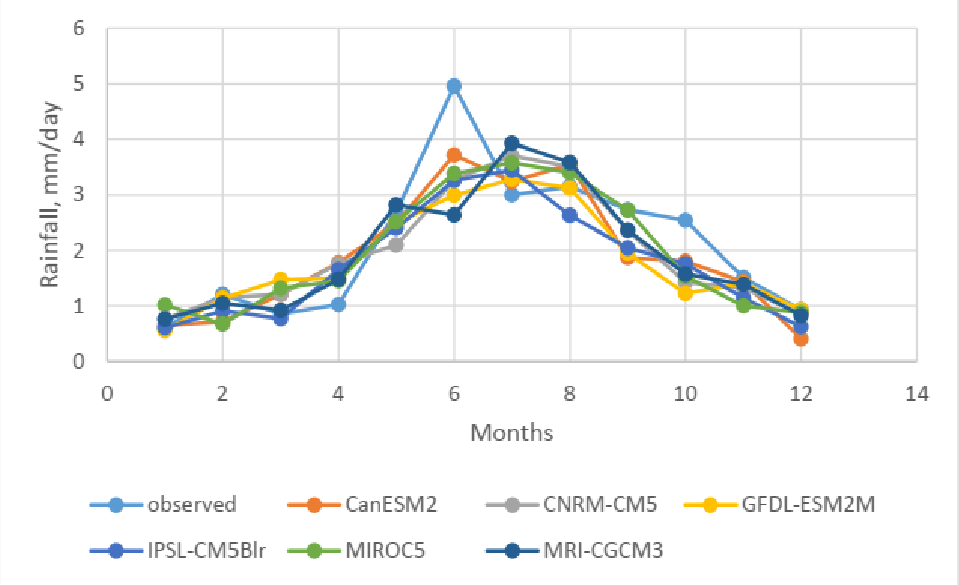

Fig. 2. Comparison of projected and observed rainfall (2000-2005)

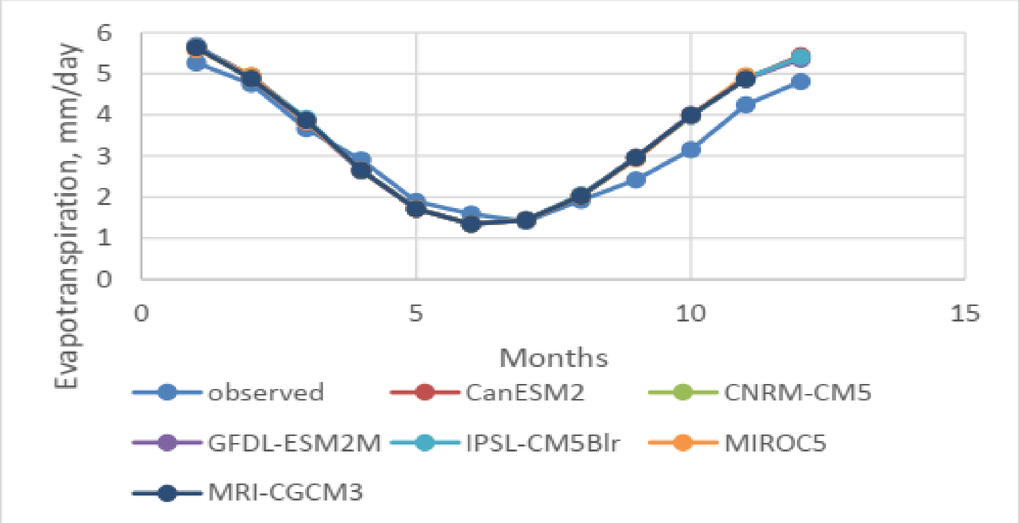

Fig. 3. Comparison of projected and observed evapotranspiration (2000-2005)

To identify precisely how each model performs, the statistical comparisons employing the concept of sum of square error were used to compare the monthly average observed and projected rainfall and evapotranspiration for each climate model. The sum of square errors for respective climate model is summarized in Table 2. The result indicates that sum of square error (SSE) for rainfall is lowest for CanESM2 and highest for MRI-CGCM3 whereas sum of square error (SSE) for evapotranspiration is the highest for CanESM2 while CNNRM-CM5, MRI-CGCM3, and MIROC5 have shown nearly the same SSE. These indicate that rainfall projected by CanESM2 and evapotranspiration projected by CNNRM-CM5, CNNRM-CM5, MRI-CGCM3, and MIROC5 are relatively accurate to simulate the observed median climate values for the period 2000-2005. It can be noticed that the differences in SSE across the models for evapotranspiration are not large. Similarly, the differences in SSE across the models for rainfall are not significant except for CanESM2 and MRI-CGCM3. Additionally, the SSE values in Table 2 also show that rainfall is generally less reliably projected by the models than evapotranspiration indicated by higher SSE for rainfall projections. Suppiah et al. [14] also found large variations in rainfall projections by different climate models.

3.2 Performance of Hydrological Models

After several attempts of calibration and validation, the best possible combination of NashSutcliffe efficiency (NSE), Coefficient of Efficiency for Calibration (Ec), and Coefficient of Efficiency Validation (Ev) for respective model were identified as shown in Table 3.

Table 2. Statistical comparison by sum of square error (SSE)

Climate models	**Sum of square error (SSE)-mm/day**	
	Rainfall	**Evapotranspiration**
CanESM2	4.30	2.18
CNNRM-CM5	5.96	2.04
GFDL-ESM2M	6.95	2.10
IOSL-CM5BIr	5.26	2.15
MRIOC5	5.03	2.09
MRI-CGCM3	7.82	2.06

As it can be seen in the Table 3, the hydrological models SIMHYD and SMAR performed poorly while AWBM and Sacramento showed comparable performance. The correlation efficiency and NSE value of Sacramento for calibration are higher than that of AWBM, but for both, correlation efficiency lies between 0.8 ≤ E ≤ 0.93. However, the performance of Sacramento for validation is significantly lower than that of AWBM. For validation, the Correlation efficiency for AWBM lies between 0.8 ≤ E ≤ 0.93 while for Sacramento the correlation efficiency lies between 0.6 ≤ Ev≤ 0.8. This means, AWBM has better consistency for different set of data than Sacramento.

Based on criteria by Ladson [16] shown in Table 4, the performance by AWBM is good while performance by Sacramento is satisfactory. Therefore, the AWBM and the calibration parameters (shown in Table 5) found for the AWBM were used for simulations of runoff for base and future periods in the impact assseement. These parameters can be used for other studies for a reasonable period beyond which catchment characteristics and its response would change due to change in land use and cover.

Table 3. Performance of hydrological models

Models	Calibration		Validations	
	NSE	**EC**	**NSE**	**EV**
AWBM	0.75	0.87	0.64	0.84
Sacramento	0.83	0.92	0.44	0.75
SIMHYD	-0.04	0.59	0.009	0.46
SMAR	-0.04	0.59	0.009	0.46

Table 4. Hydrological model performance classes [16]

Classification	Coefficient of efficiency (EC) for calibration	Coefficient of efficiency (Ev) for validation
Excellent	Ec ≥ 0.93	Ev ≥ 0.93
Good	0.8≤ Ec<0.93	0.8≤ Ev<0.93
satisfactory	0.7≤ Ec<0.8	0.6≤ Ec<0.8
Passable	0.6≤ Ec< 0.7	0.3≤ Ec< 0.7
Poor	Ec< 0.93	Ev< 0.93

3.3 Impact of Warming on Climate Variables and Runoff

The impacts of warming for evapotranspiration, rainfall, and runoff have been estimated. Due to differences in the climate and hydrological models, time frame, watershed characteristics, and scale of projects in different studies, the estimated percentage changes might vary across studies. This makes direct comparisons of the results of this study with other studies difficult. However, the results are compared with previous studies in general sense.

3.3.1 Impacts on potential evapotranspiration

Based on the projected annual evapotranspiration from the two climate models (CanESM2 and MRI-CGCM3) for base and future periods, the estimated percentage changes in potential annual evapotranspiration by 2030s (2026-2035) relative to base period (1990 - 2005) are given in Table 6. As shown in the table, for intermediate emission scenario (RCP4.5), the average annual evapotranspiration is expected to change in range of 1.58 to 2.28 %, 1.56 to 2.52%, and 1.47 to 2.25 % across the climate models for corresponding 10th, 50th, and 99th percentiles of annual values. Whereas for high emissions scenario (RCP8.5), the changes for the same period are expected to be in range of 2.63 to 4.27 %, 1.98 to 4.35 %, and 1.91 to 4.52 % across climate models for corresponding 10th, 50th, and 99th percentiles of annual rainfall. Projections by both climate models, CanESM2 and MRI-CGCM3, in this study show increase in average annual potential evapotranspiration for all percentiles and emission scenarios. According to CSIRO and BOM [17], by 2030 annual evapotranspiration would change by 0, 3, and 6.5 % for intermediate emission scenario and by 0, 3, and 3% for high emission scenarios, for corresponding 10th, 50th, and 99th percentiles in Adelaide and Mount lofty range natural resource management region. The projections in this study are in agreement with results by CSIRO and BOM [17].

Table 5. AWBM calibration parameters

Parameters	Description	Calibration value
A1	partial area of smallest store	0.134
A2	partial area of middle store	0.433
BF1	Base flow index	0.420
C1	Surface storgae capcity of smallest store	7.1
C2	Surface storgae capcity of middle store	131.8
C3	Surface storgae capcity of large store	474.5
KB	Base flow recession constant	1
KS	Surface runoff recession constant	0.51

To summarize, by 2030s, the average annual potential evapotranspiration is expected to rise relative to the base period (1990-2005) under both climate models and emission scenarios. It can be seen in the above tables that the rates of changes for high-emission scenario are generally higher than for intermediate emission scenario. Additionally, it can be noticed that the percentage changes for CanESM2 are consistently higher than that of MRI-CGCM3. Averaged percentage changes across climate models show rise in a range of 1.9 to 2.0 % and 3.2 to 3.5 % across percentiles for the intermediate and high emission scenario, respectively.

3.3.2 Impacts on annual average rainfall

Based on the projected annual rainfall from two climate models (CanESM2 and MRI-CGCM3) for base and future period, the estimated percentage changes in annual rainfall by 2030s (2026-2035) relative to base period (1986 - 2005) are given in Table 7. As shown in the Table 7, for intermediate emission scenario (RCP 4.5), the average annual rainfall is expected to change in range of -1.16 to -6.34 %, -1.1 to -8.95 %, and -6.81 to 1.57 % across the climate models for corresponding 10th,50th,and 99th percentiles of annual rainfall. Whereas for high emissions scenario (RCP8.5), the changes for the same period are expected to be in range of -9.43 to -7.87 %, -6.82 to -13.44%, and -13.44 to -11.58% for the corresponding 10th, 50th, and 99th percentiles of annual rainfall.

Projections by CSIRO and BOM [17] for the Adelaide and Mount range natural resource management region indicate that by 2030, the annual rainfall is expected to change by -15, -4.5, and 0 % for intermediate emission scenarios and by -15,-4.5, and 0 % for the high emission scenario, for the corresponding 10th, 50th, and 99th percentiles of annual rainfall. Whereas Charles and Fu [9] projected a decline in annual rainfall by 4.9 % and 5.4% for intermediate and high emission scenario, respectively. On the other hand, CSIRO projected a decline ranging 1 to 10% for the region corresponding to the increase in atmospheric carbon dioxide to 420 – 480 ppm (RCP2.6) [18]. It can be noted that most of the projections in this study are in agreement with the previous projections in publications mentioned above.

To summarize, average annual rainfall is expected to decline by 2030 for all cases emission scenarios and percentiles except for projection by MRI-CGCM3 at 99th percentile under intermediate emission scenario. It can be seen that, similar to evapotranspiration, the rates of changes are generally higher for high emission scenario than for intermediate emission scenario. Additionally, it can be noticed that the percentage changes for CanESM2 are consistently higher than that of MRI-CGCM3 model. The averaged percentage change across climate models, the decline in average annual rainfall may range 2.62 to 5.03 % and 8.17 to 10.13% across percentiles under intermediate and high emission scenario, respectively.

Table 6. Percentage changes of average annual potential evapotranspiration

Gobal climate models	**Intermediate emission scenario (RCP4.5)**			**High emisssion scenario (RCP8.5)**		
	10 th percentile	**50 th percentile**	**99 th percentile**	**10 th percentile**	**50 th percentile**	**99 th percentile**
CanESM2	2.28	2.52	2.25	4.27	4.35	4.52
MRI-CGM3	1.58	1.56	1.47	2.63	1.98	1.91
Average	1.9	2.0	1.9	3.5	3.2	3.2

Table 7. Percentage change in average annual rainfall

Gobal climate models	**Intermediate emission scenario (RCP4.5)**			**High emisssion scenario (RCP8.5)**		
	10 th percentile	**50 th percentile**	**99 th percentile**	**10 th percentile**	**50 th percentile**	**99 th percentile**
CanESM2	-6.34	-8.95	-6.81	-9.43	-13.44	-11.58
MRI-CGM3	-1.16	-1.10	1.57	-7.87	-6.82	-4.75
Average	-3.75	-5.03	-2.62	-8.65	-10.13	-8.17

Table 8. Percentage changes in average annual runoff

Gobal climate models	Intermediate emission scenario (RCP4.5)			High emisssion scenario (RCP8.5)		
	10 th percentile	50 th percentile	99 th percentile	10 th percentile	50 th percentile	99 th percentile
CanESM2	20.92	9.7	-8.81	-10.62	-16.63	-13.05
MRI-CGM3	-9.98	-2.26	1.36	-23.98	-23.66	-21.21
Average	5.47	3.72	5.08	-17.3	-20.15	-17.13

3.3.3 Impact on annual average streamflow

Based on the simulated runoff for projected daily rainfall and evapotranspiration from respective climate models for base and future periods, the estimated percentagechanges in annual runoff by 2030s (2026-2035) relative to the base period (1986 - 2005) are given in Table 8. As shown in the table, for intermediate emission scenario (RCP 4.5), the average annual runoff from the catchment is expected to change in range of -9.98 to 20.9 %, -2.26 to 9.7 %, and 1.36 to 8.81 % for the corresponding 10th, 50th, and 99th percentile of annual rainfall.

It can be noted that despite decline in annual rainfall and increase in annual evapotranspiration at higher rate for CanESM2, the annual runoff or response of the catchment showed rise especially at intermediate emission scenario. A number of studies in South Australia have projected decline in mean annual runoff for several catchments under both intermediate and high emission scenarios [2,4]. Another study projected that runoff in the Eastern mount Lofty Ranges would decline by 3 to 52% with various climate models by 2030 [19].

Thus, the simulated flow for climate projection by MRI-CGCM3 is in agreement with the previous findings explained above whereas result for CanESM2 shows contradictions for intermediate emission scenario.

To summarize, percentage change in average annual runoff for 2030 (2026-2035) relative to base period (1990- 2005) would possibly increase or decrease for intermediate emission scenario while it is expected to decrease consistently for high emission scenario. There is wider variability among simulated annual flow across the climate models for intermediate emission scenario. Averaged percentage changes across climate models show rise in average annual runoff in range from 3.72 to 5.47 % for intermediate scenario and decline in range from 17.13 to 20.15 % across percentiles for high emission scenario.

The interpretation of the simulated runoff for different percentiles are based on the practical impacts associated with each percentiles. According to Westra *et al.* [2], mean or median annual flow (50th percentile), low annual flow (10th percentile flow), and maximum annual flow (99 percentile) can be used to explain impacts on water resources availability, drought, and flooding conditions, respectively. Accordingly, the annual low flow (worst case) show possibilities of drought for projection by MRI-CGCM3 under intermediate emission scenario and for both climate models under high emission scenario. Whereas for others cases, the low flow would increase. With respect to median flow, it is expected to decline for all cases except for projections by CanESM2 under intermediate emission scenario. These would have severe implications for water resource availability for competing water users. As to maximum annual flow, it would increase under intermediate emission scenario where as it is expected to decline under high emission scenarios at indicated rates. Thus, there would be higher possibility flooding conditions under intermediate emission scenarios than that of high emission scenario.

4. CONCLUSION AND RECOMMENDATIONS

The following conclusions and recommendations are forwarded

- The climate model, CanESM2**,** has shown best performance in simulating monthly average observed daily rainfall (2000-2005) while CNNRM-CM5, MRI-CGCM3, and MIROC5 have shown similar higher performance in simulating monthly average observed daily evapotranspiration (2000-2005). None of the models showed consistently highest performance for both rainfall and evapotranspiration.
- Among the four hydrological models in RRL, calibration and validation resulted in ‘Good’ performance for AWBM model and

'satisfactory' performance for Sacramento. The other models, SIMHYD and SMAR, perform very poorly for the catchment and its hydrological conditions in the period 2000-2010. Therefore, it is recommended to use AWBM and the corresponding calibration parameters for simulation of runoff for the watershed for reasonable period of time until significant changes in hydrological and watershed characteristics happen.

- By 2030s, the average annual potential evapotranspiration is expected to rise relative to the base period (1990-2005) for both climate models (CanESM2 and MRI-CGCM3) under both emission scenarios. Averaged percentage changes across climate models show rise in average annual evapotranspiration in range from 1.9 to 2.0 % and from 3.2 to 3.5% across percentiles for intermediate and high emission scenario, respectively. The average annual rainfall is expected to decline for all emission scenarios and percentiles except for projection by MRI-CGCM3 at 99th percentile for intermediate emission scenario. Averaged percentage changes across climate models show decline in average annual rainfall in range from 2.62 to 5.03 % and from 8.17 to 10.13 % across percentiles for intermediate and high emission scenario, respectively.
- Average annual runoff for 2030s (2026-2035) would possibly increase (CanESM2) or decrease (MRI-CGCM3) relative to base period (1990-2005) for intermediate emission scenario while it is expected to decrease consistently for high emission scenario for both climate models. Averaged percentage changes across climate models show rise in average annual runoff in range from 3.72 to 5.47 % for intermediate scenario and decline in range from 17.13 to 20.15 % across percentiles for high emission scenario.

Thus, on average, annual runoff would slightly rise for intermediate emission scenario for all percentiles indicating no challenges in water availability, drought, and flooding conditions at annual time scale. Whereas at high emission scenario, there would be significant decline in annual runoff, indicating remarkable challenges in water availability, and risk of drought at annual time scale. Analysis at seasonal time scale might be needed to understand the pattern of the changes in runoff but for reservoir catchment such as Myponga, the analysis at annual time scale is sufficient. Thus, appropriate adaptation and mitigation measures should be identified and applied at national, state, and local administrative level to minimize possible negative impacts and utilize the possible opportunities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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