MSSRF

ADAPTATION TO CLIMATE CHANGE
An integrated science-stakeholder-policy approach to develop adaptation framework for water and agriculture sectors in Andhra Pradesh and Tamil Nadu states of India

Climate and Hydrology Scenarios for the ClimaAdapt programme regions in Tamil nadu and Andhra Pradesh states in India

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A. Introduction

The impact of climate change is likely to have serious influences on agriculture and water sectors and eventually on the food security and livelihoods of a large section of the rural population in developing countries (IPCC AR4, 2007). "ClimaAdapt - Adaptation to climate change: An integrated science-stakeholder-policy approach to develop Adaptation framework for Water and Agriculture sectors in Tamil Nadu and Andhra pradesh states in India" is undertaken in two river basins.

The overall goal of the ClimaAdapt program is to improve the adaptive capacity of the agriculture and water sectors in the states of Andhra Pradesh and Tamil Nadu through development of appropriate adaptation measures and providing inputs to climate and sector plans. The main objective is to implement selected climate change adaptation measures at a systems level, develop methodologies for upscaling, build capacity of the relevant agencies, including farmers' networks and women Self Help Groups (SHGs) to address climate change impacts. The inputs to the state climate and sectoral adaptation plans (agriculture and water sectors) will be given through a consultative process involving all relevant stakeholders (including state government and their respective agencies, institutions, departments, and non-government organizations, where appropriate).

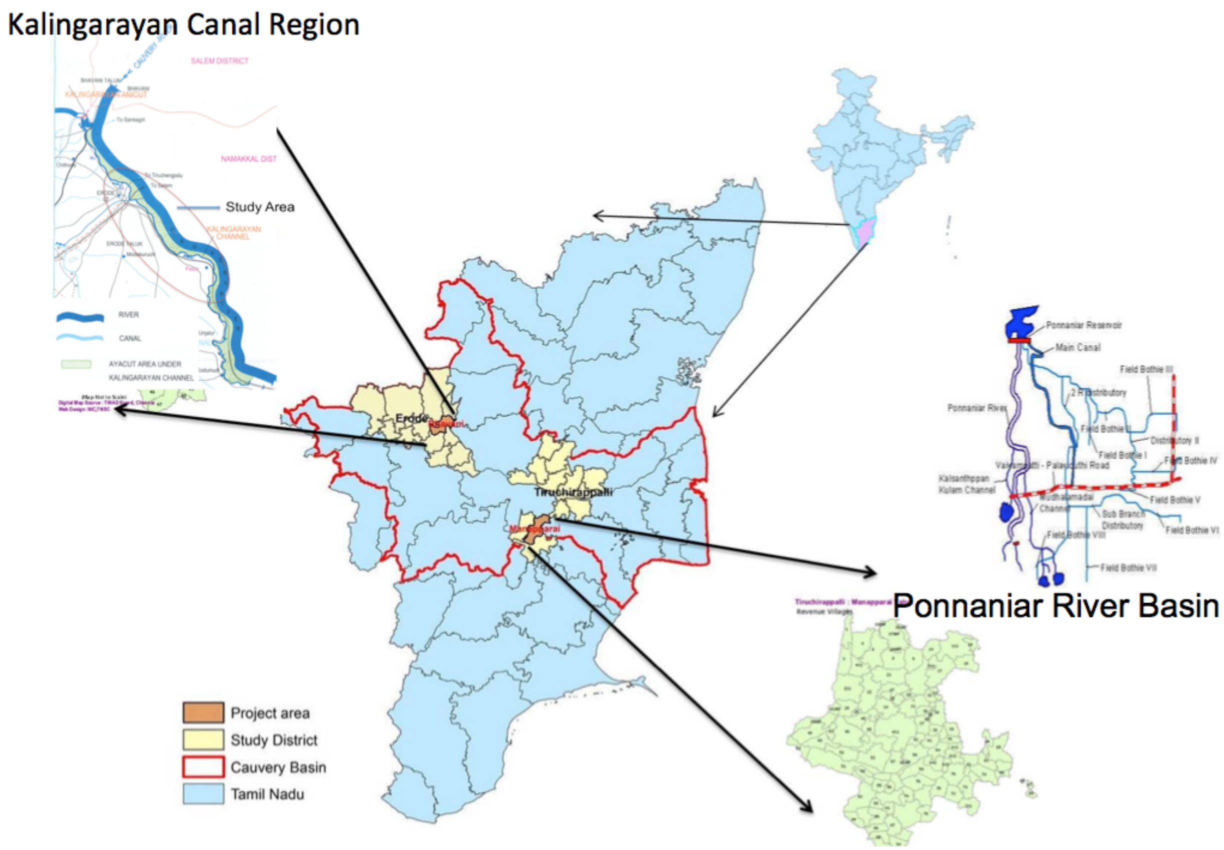
The first and foremost need of the project is developing climate and hydrological scenarios for the ClimaAdapt programme regions based on which appropriate adaptation technologies will be identified and upscaled. Prior to ClimaAdapt programme, ClimaRice project was in operation in Cauvery and Krishna River Basins and climate scenarios for the current and future were developed by International Pacific Research Centre (IPRC), Hawaii, who was one of the project partners. Tamil Nadu Agricultural University (TNAU), Coimbatore and International Water Management Institute (IWMI, Hyderabad in coordination with Indian Institute of Technology (Madras), Chennai developed hydrological scenarios. In the current study, these scenarios were extracted for the ClimaAdapt programme regions and presented for the impact assessment and development of adaptation strategies for managing the changing climate.

B. Study Region

B1. Tamil Nadu

The ClimaAdapt project aims to upscale various adaptation strategies in two basins viz. Kalingarayan canal basin at Erode district and Ponnaniar reservoir basin at Thiruchirapalli district, Tamil Nadu, India (Figure 1).

Figure 1. ClimaAdapt project locations in Tamil Nadu



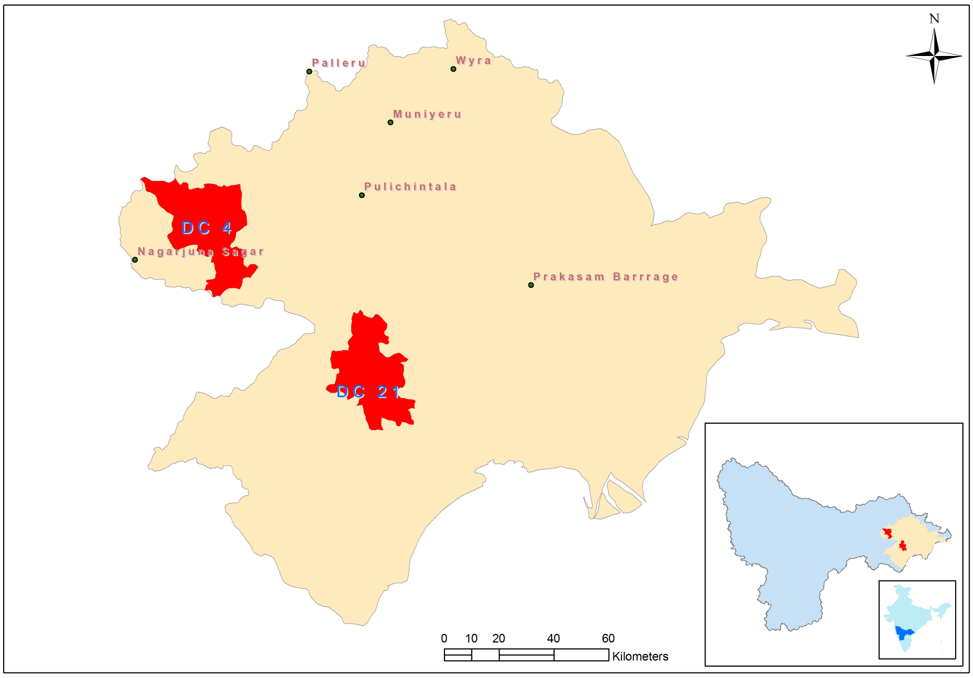
Kalingarayan basin has an ayacut area of 15748 acres. In the ClimaAdapt project, 2100 acres in the mid region of Kalingarayan canal was chosen where the farmers are practicing mainly rice based cropping system. Major problems identified in this region are: (i) low water use efficiency (<25% in the present condition) (ii) water and soil pollution, (iii) High labour shortage.

Ponnaniar reservoir is located in between Sommalai hills and Perumal malai hills. Capacity of the reservoir is 120 MCft of water and supplies irrigation water to 5 villages covering an area of 2101 acres. More than 70% of the cultivable area is under rice crop. A major problem identified in this region is water scarcity.

B2. Andhra Pradesh

In Andhra Pradesh, the ClimaAdapt project is in operation at two locations viz., Left canal (DC4) and Right canal of Nagarjuna Sagar (DC 21). Both the areas are dominated by rice based cropping system. The studty area are presented in Figure 2.

Figure 2. ClimaAdapt project locations in Andhra Pradesh



C. Current Climate of the study region

C.1. Tamil Nadu

C.1.1. Kalingarayan Basin

The climate of kalingarayan basin is dry throughout the year except during the monsoon seasons and experiences mean temperature ranging from 23.8 to 30.6° C. Generally, the area receives rainfall that is lesser than the state average. This region is widely benefited by the two monsoons *viz.,* North East monsoon (47%) and South West Monsoon (31%). Rainfall received during different seasons in the study region of Kalingarayan basin are presented in Table 1.

Table 1. Seasonal rainfall (mm) of kalingarayan basin

Season	Months	Normal rainfall (mm)
Summer	February – May	154.1
South West Monsoon	June – September	213.1
North East Monsoon	October – January	323.5
Annual Rainfall		**711.4**

C.1.2. Ponnaniar Basin

This region experiences a moderate climate with the mean temperature ranging from 26.7 to 32.7° C. The average rainfall received is 850.6 mm per year with maximum rainfall during the North-East monsoon season and also a fair amount of rainfall during summer

Table 2. Seasonal rainfall (mm) of Ponnaniar basin

Season	Months	Normal rainfall (mm)
Summer	February – May	167.0
South West Monsoon	June – September	288.5
North East Monsoon	October – January	395.1
Annual Rainfall		850.6

C.2. Andhra Pradesh

Rainfall received in different seasons in Krishna basin are presented in table.4.

Table 3. Seasonal rainfall (mm) in Krishna Basin

Season	Months	DC 4 - Normal rainfall (mm)	DC 21 - Normal rainfall (mm)
Summer	February – May	52.3	70.8
South West Monsoon	June – September	483.9	623.1
North East Monsoon	October – January	137.9	265.7
Annual Rainfall		674.1	959.6

DC 4: The climate is dry throughout the year except during the South west monsoon season. This region receices 484 mm of rainfall in South west monsoon season alone. During North east monsoon 138 mm of rainfall is received. The annual average rainfall is 674 mm.

DC. 21: This region of Krishnabasin receives an annual rainfall of 959.6 mm. Major share of rainfall is received during South west monsoon.

D. Development of Future Climate Scenarios

D.1. The Purpose of Climate Scenarios

A climate scenario is a plausible representation of future climate that has been constructed for the use of investigating the potential impacts of climate change. Climate scenarios often make use of climate projections based on the greenhouse gas emission scenarios and aerosol concentrations in the atmosphere and combining them with observed climate data. The science of climate scenario development acts as an important connection between the climatologists and scientists dealing with impact assessment, development of adaptation and mitigation strategies which is important for vulnerability assessment.

D.2. Data sources and Climate models

D.2.1. Data Sources

A baseline period is needed to define the observed climate with which climate change information is usually combined to create a climate scenario. When using climate model results for scenario construction, the baseline also serves as the reference period from which the modelled future change in climate is calculated. Data for the base line was obtained from the India meteorological Department for the period of 30 years from 1976 – 2005 and used in the current study.

D.2.2. Climate Models

The climatic data needed for this study was developed by the International Pacific Research Centre (IPRC), Hawaii. Climate simulations made using the Global Circulation Model (GCM) GFDL (Geophysical Fluid Dynamics Laboratory), at a coarse resolution was spatially downscaled using the IPRC – Regional Circulation Model (RegCM) with lateral and boundary conditions taken from GFDL coupled model integrations. The daily meteorological parameters such as precipitation, maximum temperature, minimum temperature and solar radiation for grid points with a grid space of 0.25^0 by 0.25^0 (~25km × 25km) spatially spread across study regions of ClimaAdapt project in Tamil Nadu and Andhra Pradesh were extracted from the IPRC RegCM model outputs for the timelines viz., (i) 1981 – 2000 : Baseline, (ii) 2021 – 2050: Mid century based on Y1B scenario with doubling of CO_2 by mid-century, and (iii) 2081-2100: End scenario based on A1B scenario with doubling of CO_2 by end-century.

Uncertainties will remain inherent in predicting future climate change, however, some uncertainties are likely to be narrowed by considering a range of climate model outputs. The cascade of uncertainties in future climate predictions includes: unknown future emissions of greenhouse gases and aerosols, the conversion of emissions to atmospheric concentrations and to radiative forcing of the climate, modelling the response of the climate system to forcing, and methods for regionalising GCM results (IPCC, AR3, 2001).

Climate models at different spatial scales and levels of complexity provide the major source of information for constructing scenarios. GCMs and a hierarchy of simple models produce information at the global scale. Future climate scenarios derived from 16 Global Climate Models at a resolution of 50 x 50 km is available for the whole globe from www.climatewizard.org. To reduce the uncertainty, ensemble all 16 different Global Climate

Model outputs for A1b (Balanced emission scenario) with 60 % probability was extracted for the study region of Tamil Nadu and Andhra Pradesh. As we take the output from 16 different models, the regional bias as well as model parameters bias are corrected, error reduced and 60% probability level would give us the most likely condition of the future climate.

D.3. Results of Future climate projection

D.3.1. Kalingarayan basin

A. Changes in the precipitation pattern due to climate change

Climate simulations made using the Global Circulation Model (GCM) of GFDL and also the 16 model ensemble at 60% probability for Mid and End Century for Kalingarayan basin is presented in table 4.

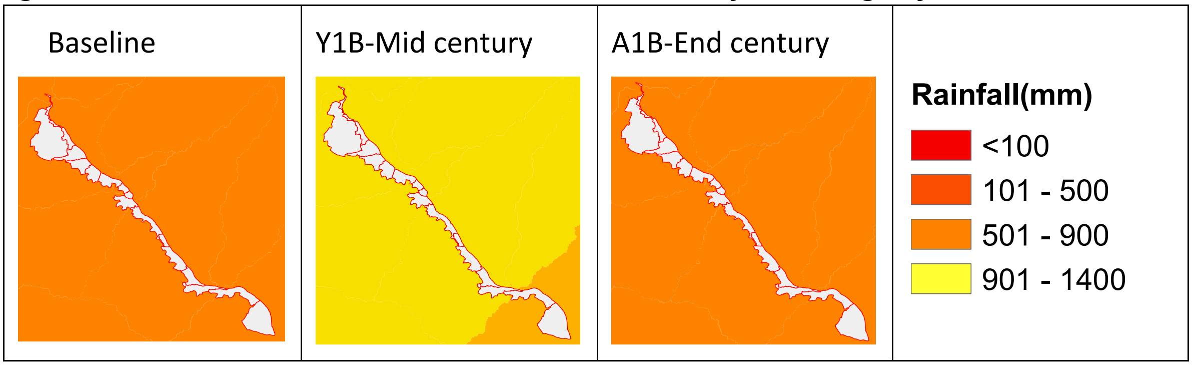
Table 4. Seasonal rainfall prediction for Kalingarayan basin

Seasons	Measured Rainfall in mm	Baseline rainfall in mm -GFDL Model	Expected changes (%) in rainfall – GFDL Model		Expected changes (%) in rainfall - 16 model ensemble at 60% probability	
			Mid Century	End Century	Mid Century	End Century
Summer	166.64	116.58	151.0	37.8	-2.17	-13.5
SWM	217.19	334.81	49.2	19.1	14.2	19.1
NEM	327.33	187.5	91.8	27.1	0.5	-0.8
Annual	711.16	638.9	97.3	28.0	4.2	1.7

a. Annual precipitation

Observed mean annual precipitation in Kalingarayan basin is 711 mm. The GFDL baseline rainfall predicted is 639 mm. The annual rainfall bias in the baseline is -10.16%. The GFDL model under predicts the current rainfall condition. The quantam of annual rainfall as per GFDL model in different time periods are presented in figure 3.

Figure 3. Annual Rainfall for Baseline, Mid and End century for Kalingarayan basin – GFDL



Annual precipitation is expected to be increased in the Y1B-mid century compared to baseline. The rainfall is expected to be 97 % higher than the current quantity in the mid-century in kalingarayan basin as per GFDL- Y1B scenario.

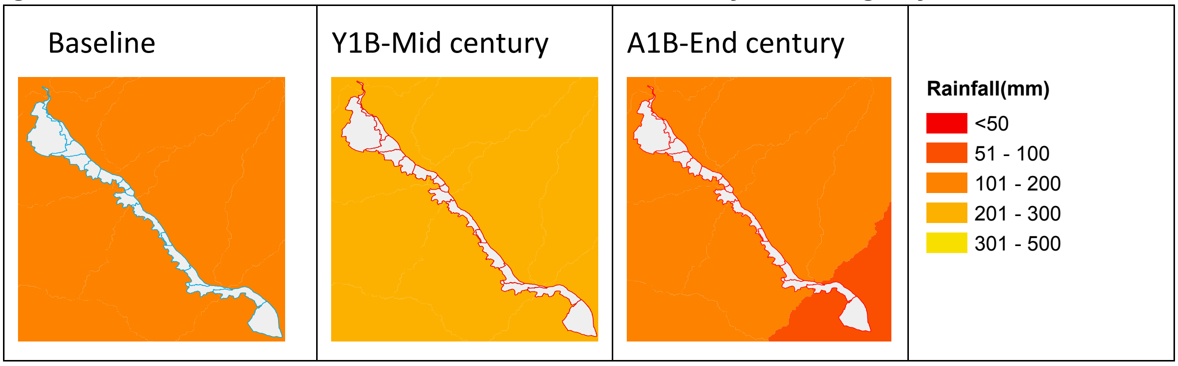
In the A1B-end century, the precipitation would again go down compared to Y1B-mid century, however, it would be around 28% higher than the current quantity as per A1B – scenario of GFDL model.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that 4.2 % increase in rainfall in the mid century and 1.7% increase in the end century compared to current conditions.

b. Summer season precipitation

The quantam of rainfall during summer season (Febuary to May) as per GFDL model in different time periods are presented in figure 4

Figure 4. Summer rainfall for Baseline, Mid and End century for Kalingarayan basin – GFDL



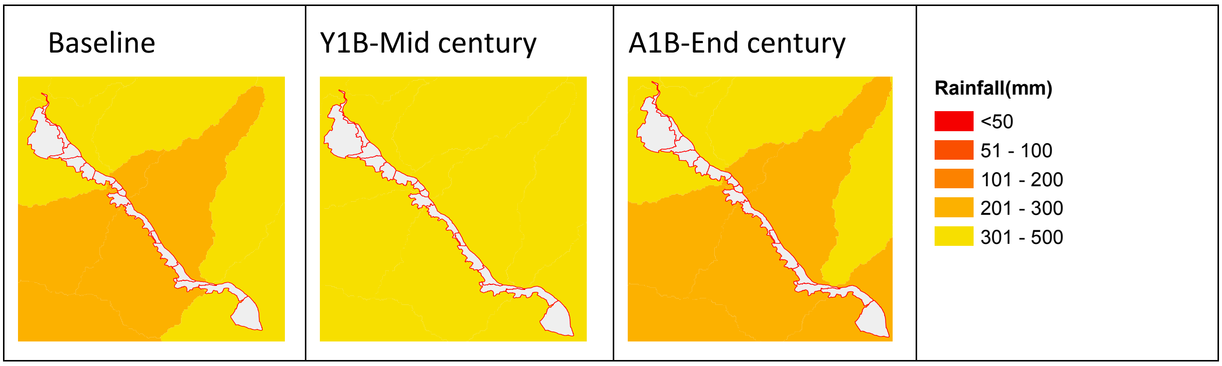
In general, during summer season, 166 mm rainfall is received in kalingarayan basin. The GFDL model predictions indicate that there is a possibility for getting 151% more rainfall compared to current conditions in the Y1B-mid-century. Again in the A1B-end of the century, 38 % increase in rainfall than the current conditions are expected during the summer season.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the summer season rainfall is expected to decrease by 2.17% in the mid century and by 13.5 % in the end century compared to current conditions.

c. South west monsoon (SWM) season precipitation

The quantam of rainfall during South west monsoon season (June to September) as per GFDL model in different time periods are presented in figure 5.

Figure 5. SWM rainfall for Baseline, Mid and End century for Kalingarayan basin – GFDL



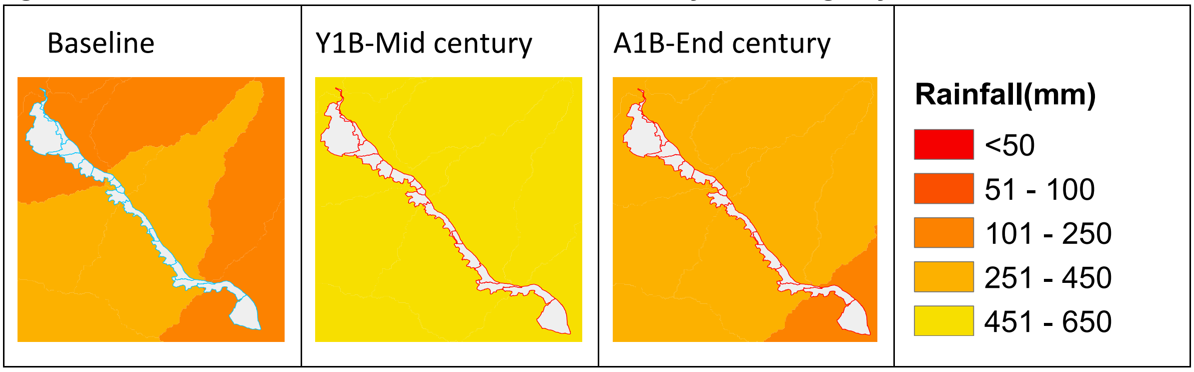
During SWM, in Kalingarayan basin area, 217 mm of rainfall is normally received under current climate condition. In Y1B-mid-century of GFDL model, rainfall quantity is expected to increase by 49% and in the A1B-end-century, it is expected to increase by 19%.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 14.2% in the mid century and by 19.1 % in the end century compared to current conditions.

d. North East monsoon (NEM) season precipitation

The quantam of rainfall during North east monsoon season (October to January) as per GFDL model in different time periods are presented in figure 6.

Figure 6. NEM rainfall for Baseline, Mid and End century for Kalingarayan basin – GFDL



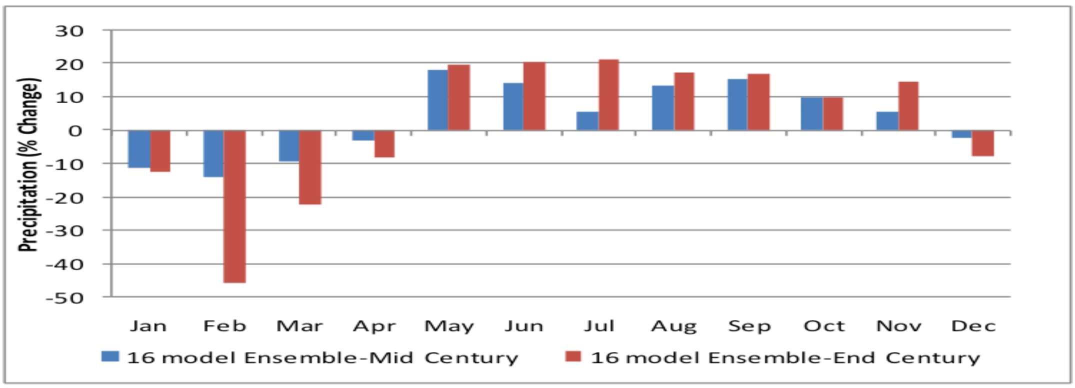
During North east monsoon, Rainfall is projected to be increased to two fold in the Y1B-mid-century and there would be a decrease in rainfall quantity in the A1B-end-century compared to Y1B-mid-century.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the NEM season rainfall is not expected to change in the mid and end century compared to current conditions.

e. Finalisation of mid and end century rainfall for Kalingarayan basin

From the GFDL model outputs, more exterme rainfall events are expected. In the mid century during summer and south west monsoon season the rainfall expected to increase by more than 200% and 100% respectively. However, most of the GCM model results does not agree with this outcome. Hence, the results from the 16 model ensemble at 60% probability for Mid and End Century was considered for the development of future rainfall (Figure 7).

Figure 7. Expected changes in rainfall (%) during mid and end century in Kalingarayan basin



The rainfall in the mid century is expected to increase in the monsoon months starting from May through November in the order of 5 to 18 %. In contrast the rainfall is expected to decrease from December through April during the mid century.

The same trend in rainfall is expected in the end century also with different magnitude. Rainfall is expected to increase by 20% during May, June and July , by 15% during August, September and November and by 10% during October. In the rest of the month starting from December to April rainfall is expected to decrease from 10-45%.

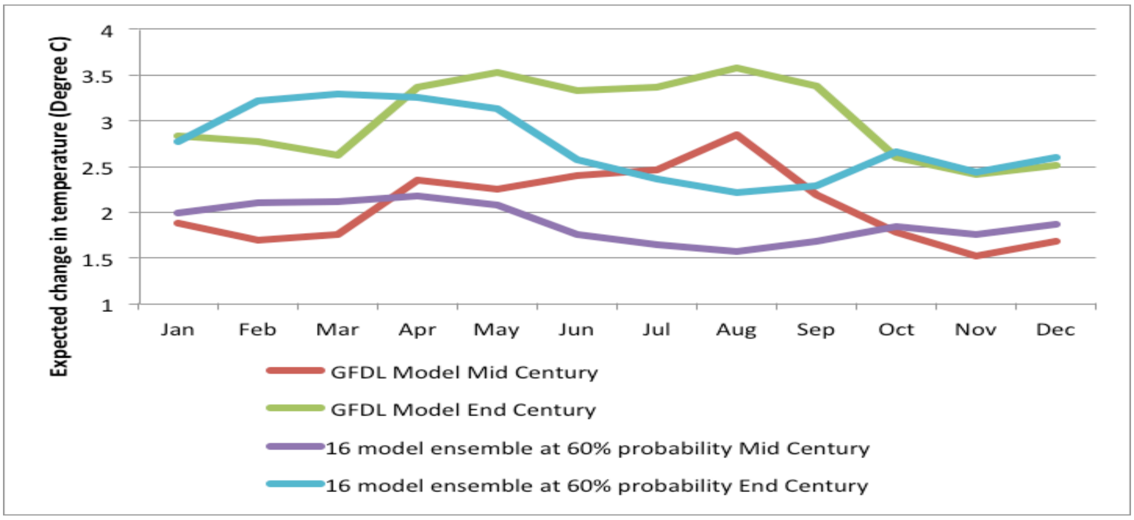
f. Finalisation of mid and end century temperature for Kalingarayan basin

Temperature changes expected in Kalingarayan basin is presented in table 5 and figure 8.

Table 5. Temperature changes expected (^{0}C) in Kalingarayan basin

Month	Mean Temperature (^{0}C)	Changes expected in Mean Temperature (^{0}C) – GFDL Model		Changes expected in Mean Temperature (^{0}C)- 16 model ensemble at 60% probability	
	Current	Mid Century	End Century	Mid Century	End Century
Jan	23.83	1.87	2.83	1.98	2.77
Feb	26.20	1.69	2.77	2.10	3.22
Mar	26.41	1.75	2.62	2.11	3.29
Apr	30.46	2.35	3.36	2.17	3.25
May	30.56	2.24	3.52	2.07	3.13
Jun	28.94	2.39	3.32	1.75	2.57
Jul	27.49	2.45	3.36	1.64	2.36
Aug	27.34	2.84	3.57	1.56	2.21
Sep	27.07	2.18	3.37	1.68	2.29
Oct	25.99	1.77	2.59	1.84	2.66
Nov	24.27	1.52	2.40	1.75	2.43
Dec	23.26	1.68	2.51	1.86	2.60
Mean		2.06	3.02	1.87	2.73

Figure 8. Temperature changes expected (^{0}C) in Kalingarayan basin



Temperature is expected to steadily increase and by mid and end century as per GFDL model, a mean increase of 2.06 ^{0}C and 3.02 ^{0}C respectively. As per 16 model ensemble at 60% probability, an increase of 1.87 ^{0}C and 2.73 ^{0}C is expected for mid and end century respectively.

D.3.2. Ponnaniyar basin

A. Changes in the precipitation pattern due to climate change

Climate simulations made using the Global Circulation Model (GCM) of GFDL and also the 16 model ensemble at 60% probability for Mid and End Century for Ponnaniyar basin is presented in table 6.

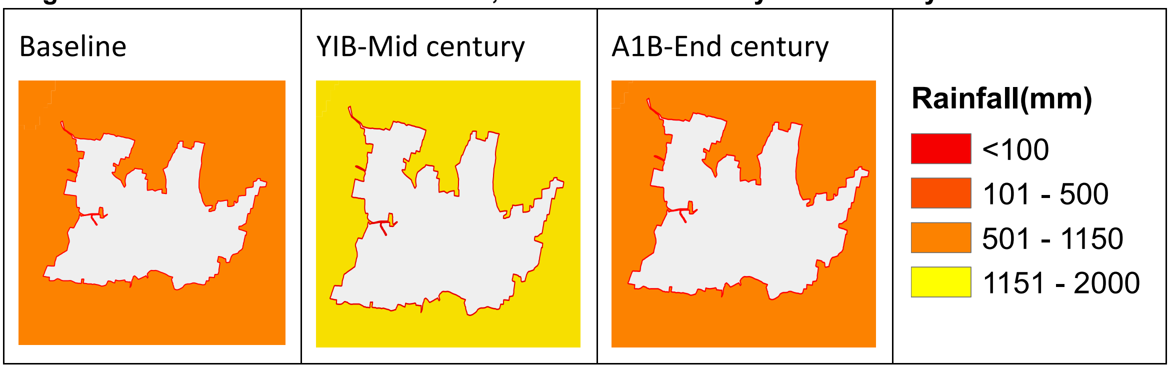
Table 6. Seasonal rainfall prediction for Ponnaniyar basin

Month	Measured Rainfall in mm	Baseline rainfall in mm -GFDL Model	Expected changes (%) in rainfall – GFDL Model		Expected changes (%) in rainfall - 16 model ensemble at 60% probability	
			Mid Century	End Century	Mid Century	End Century
Summer	167.00	99.92	195.83	80.02	-2.11	-14.23
SWM	288.47	203.73	112.45	14.80	12.24	19.16
NEM	395.10	285.53	46.85	20.59	0.43	1.08
Annual	850.57	589.18	118.38	38.47	3.52	2.00

a. Annual precipitation

Observed mean annual precipitation in Ponnaniyar basin is 850 mm. The GFDL baseline rainfall predicted is 589 mm. The annual rainfall bias in the baseline is -30.7%. The GFDL model under predicts the current rainfall condition. The quantam of annual rainfall as per GFDL model in different time periods are presented in figure 9.

Figure 9. Annual Rainfall for Baseline, Mid and End century for Ponnaniyar basin – GFDL



Annual precipitation is expected to be increased in the Y1B-mid century compared to baseline. The rainfall is expected to be 118 % compared to current quantity in the mid-century in Ponnaniyar basin as per GFDL- Y1B scenario.

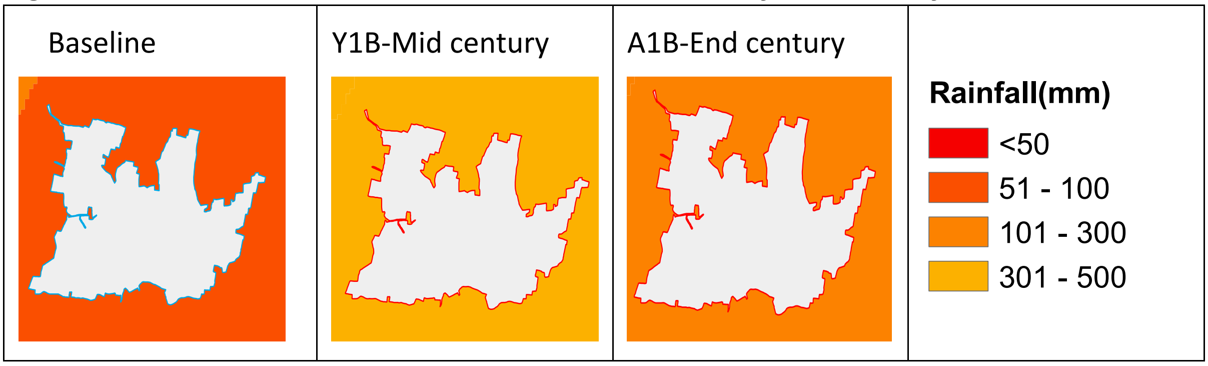
In the A1B-end century, the precipitation would again go down compared to Y1B-mid century, however, it would be around 38% higher than the current quantity as per A1B – scenario of GFDL model.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that 3.5 % increase in rainfall in the mid century and 2 % increase in the end century compared to current conditions.

b. Summer season precipitation

The quantam of rainfall during summer season (Febuary to May) as per GFDL model in different time periods are presented in figure 10.

Figure 10. Summer rainfall for Baseline, Mid and End century for Ponnaniyar basin – GFDL



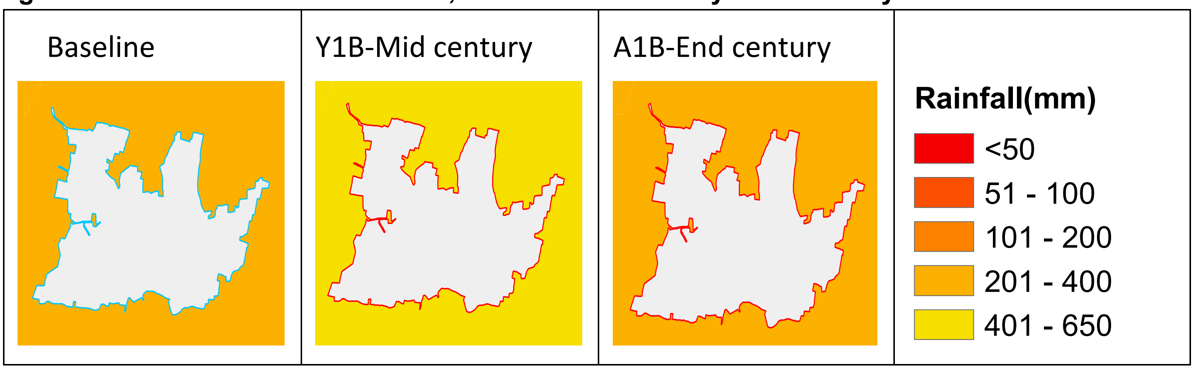
In general, during summer season, 167 mm rainfall is received in Ponnaniyar basin. The GFDL model predictions indicate that there is a possibility for getting 195% more rainfall compared to current conditions in the Y1B-mid-century. Again in the A1B-end of the century, 80 % higher rainfall than the current conditions are expected during the summer season.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the summer season rainfall is expected to decrease by 2.11% in the mid century and by 14.23 % in the end century compared to current conditions.

c. South west monsoon (SWM) season precipitation

The quantam of rainfall during South west monsoon season (June to September) as per GFDL model in different time periods are presented in figure 11.

Figure 11. SWM rainfall for Baseline, Mid and End century for Ponnaniyar basin – GFDL



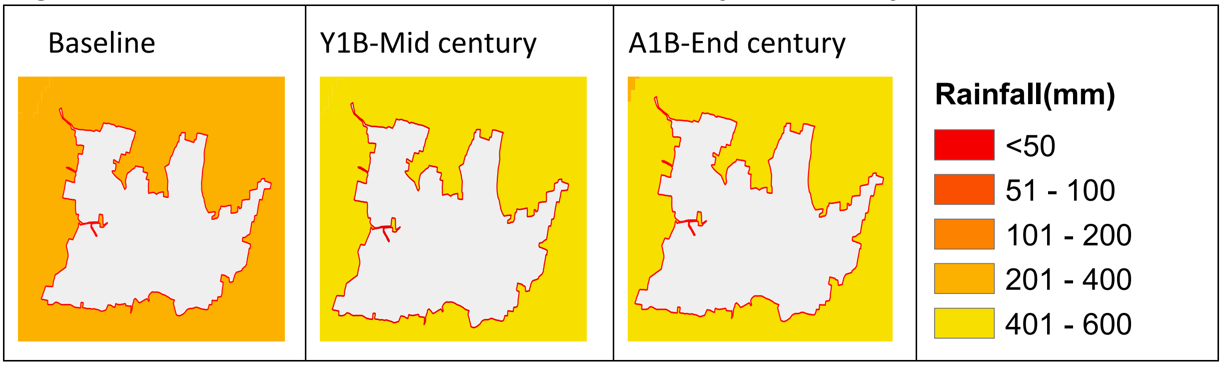
During SWM, in Ponnaniyar basin area, 288 mm of rainfall is normally received under current climate condition. In Y1B-mid-century of GFDL model, rainfall quantity is expected to increase by 112% and in the A1B-end-century, it is expected to increase by 14%.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 12.2% in the mid century and by 19.1 % in the end century compared to current conditions.

d. North East monsoon (NEM) season precipitation

The quantam of rainfall during North east monsoon season (October to January) as per GFDL model in different time periods are presented in figure 12.

Figure 12. NEM rainfall for Baseline, Mid and End century for Ponnaniyar basin – GFDL



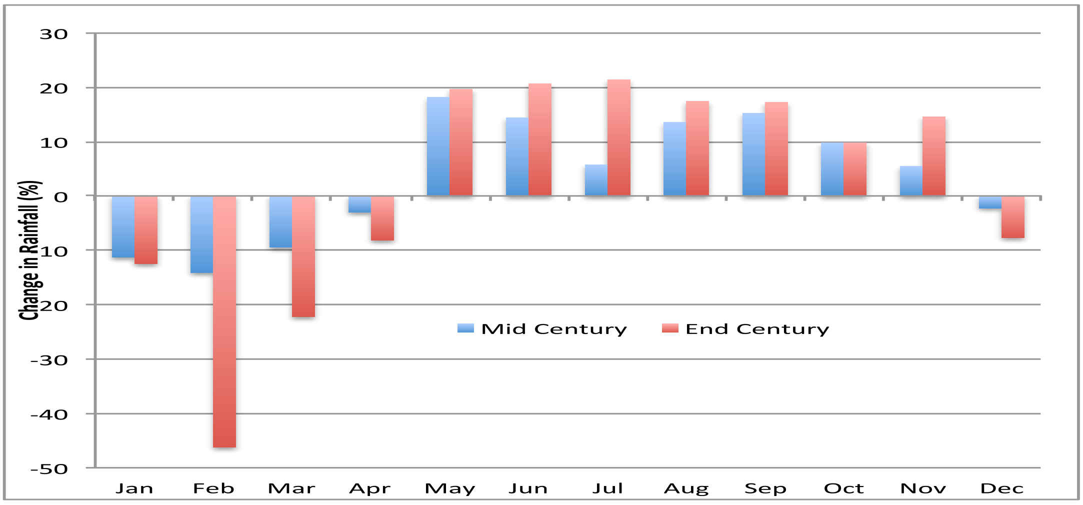
As per GFDL model, during North east monsoon, Rainfall is projected to be increased by 47 % in the Y1B-mid-century and by 20.6 % in the A1B –end century compared to current rainfall.

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the NEM season rainfall is not expected to change in the mid century and a slight increase (1.08 %) in the end century compared to current conditions.

e. Finalisation of mid and end century rainfall for Ponnaniyar basin

The results from the 16 model ensemble at 60% probability for Mid and End Century was considered for the development of future climate of Ponnaniyar basin.

Figure 13. Expected changes in rainfall (%) during mid and end century in *Ponnaniyar* basin



The rainfall in the mid century is expected to increase in the monsoon months starting from May through November in the order of 6 to 18 %. In contrast the rainfall is expected to decrease from December through April during the mid century.

The same trend in rainfall is expected in the end century also with different magnitude. Rainfall is expected to increase by around 20% during May, June and July , by 17% during

August, September and November and by 10% during October. In the rest of the month starting from December to April rainfall is expected to decrease from 8-47%.

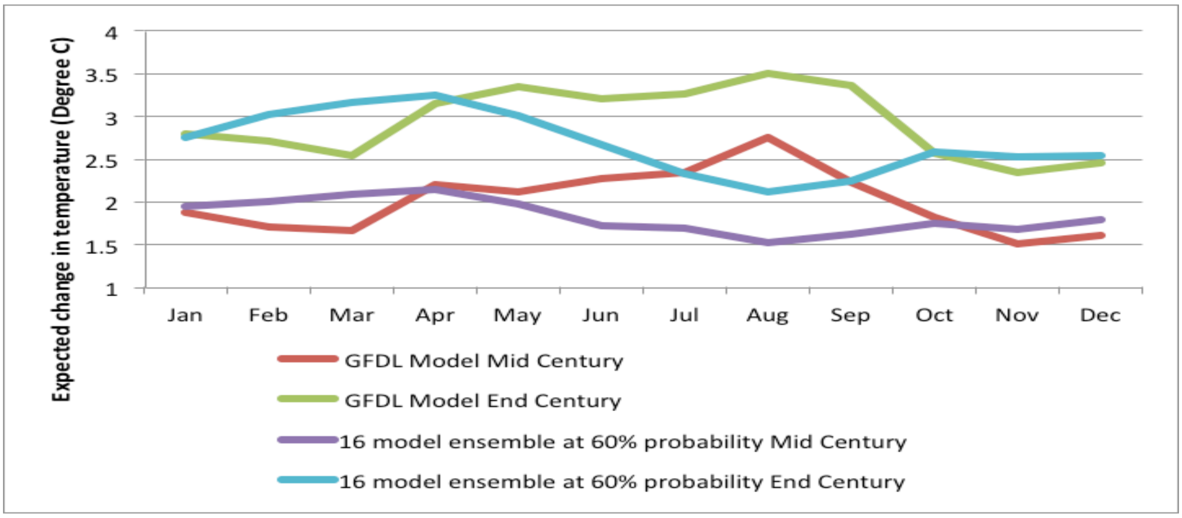
f. Finalisation of mid and end century temperature for Ponnaniyar basin

Temperature changes expected in Ponnaniyar basin is presented in table 7 and figure 14.

Table 7. Temperature changes expected (^{0}C) in Ponnaniyar basin

Month	Mean Temperature (^{0}C)	Changes expected in Mean Temperature (^{0}C) – GFDL Model		Changes expected in Mean Temperature (^{0}C)- 16 model ensemble at 60% probability	
	Current	Mid Century	End Century	Mid Century	End Century
Jan	27.69	1.87	2.80	1.94	2.75
Feb	29.43	1.70	2.71	2.00	3.02
Mar	31.83	1.66	2.54	2.08	3.17
Apr	32.71	2.20	3.14	2.14	3.25
May	32.50	2.11	3.34	1.97	3.01
Jun	32.00	2.27	3.21	1.71	2.67
Jul	31.16	2.34	3.26	1.69	2.33
Aug	30.51	2.75	3.50	1.52	2.12
Sep	28.87	2.22	3.36	1.61	2.24
Oct	27.65	1.82	2.57	1.75	2.58
Nov	26.77	1.50	2.34	1.68	2.53
Dec	26.81	1.61	2.45	1.79	2.55
mean		2.00	2.93	1.82	2.69

Figure 14. Temperature changes expected (^{0}C) in ponnaniyar basin



Temperature is expected to steadily increase and by mid and end century as per GFDL model, a mean increase of 2.0 ^{0}C and 2.9 ^{0}C respectively. As per 16 model ensemble at 60% probability, an increase of 1.82 ^{0}C and 2.69 ^{0}C is expected for mid and end century respectively.

D.3.3. Krishna basin

A. Changes in the precipitation pattern due to climate change

Climate simulations made using the Global Circulation Model (GCM) of GFDL and also the 16 model ensemble at 60% probability for Mid and End Century for Krishna basin is presented in table 8 (DC 4) and Table 9 (DC 21).

Table 8. Seasonal rainfall prediction for Krishna basin – DC4

Seasons	Measured Rainfall in mm	Baseline rainfall in mm -GFDL Model	Expected changes (%) in rainfall – GFDL Model		Expected changes (%) in rainfall - 16 model ensemble at 60% probability	
			Mid Century	End Century	Mid Century	End Century
Summer	52.30	152.50	61.33	72.13	-7.32	-11.32
SWM	483.90	474.00	225.83	175.50	14.69	14.09
NEM	137.94	63.60	59.68	45.20	13.64	5.95
Annual	674.14	690.10	115.61	97.61	7.00	2.91

Table 9. Seasonal rainfall prediction for Krishna basin – DC21

Seasons	Measured Rainfall in mm	Baseline rainfall in mm -GFDL Model	Expected changes (%) in rainfall – GFDL Model		Expected changes (%) in rainfall - 16 model ensemble at 60% probability	
			Mid Century	End Century	Mid Century	End Century
Summer	70.80	128.20	58.20	145.68	-8.15	-13.31
SWM	623.10	441.40	216.75	158.33	15.20	17.01
NEM	265.70	81.50	61.53	116.08	8.47	13.38
Annual	959.60	651.10	112.16	140.03	5.17	5.69

a. Annual precipitation

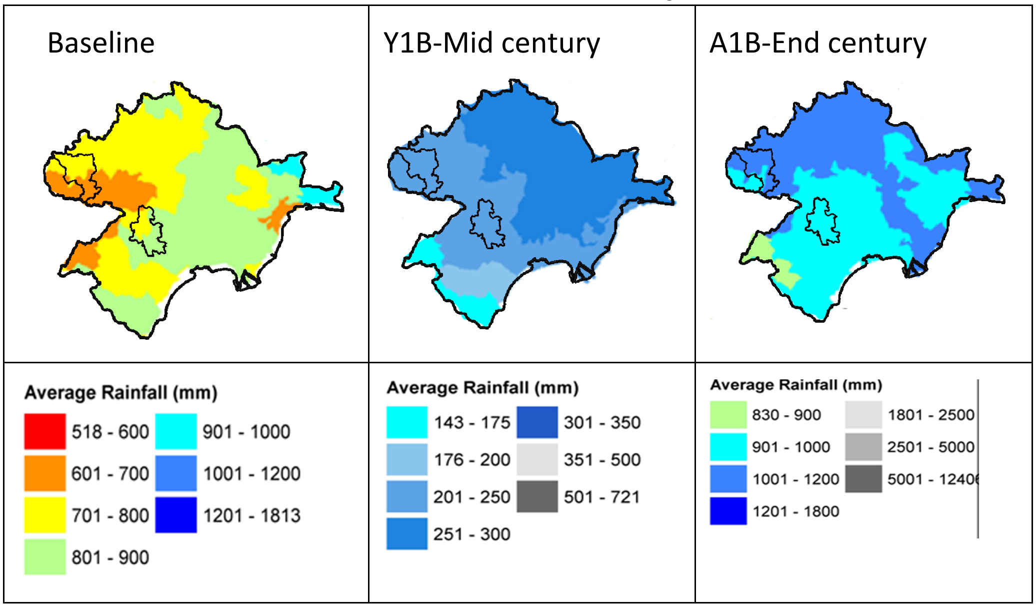
Observed mean annual precipitation in DC No.4 in Krishna basin is 674 mm. The GFDL baseline rainfall predicted is 690 mm. The annual rainfall bias in the baseline is 2.37%. The GFDL model almost correctly predicts the current rainfall condition for DC4 of Krishna Basin.

Observed mean annual precipitation in DC No.21-Krishna basin is 959 mm. The GFDL baseline rainfall predicted is 651 mm. The annual rainfall bias in the baseline is -32.14%. The GFDL model under predicts the current rainfall condition.

The quantam of annual rainfall as per GFDL model in different time periods for Krishna basin are presented in figure 15.

DC 4: Annual precipitation is expected to be increased in the Y1B-mid century compared to baseline. The rainfall is expected to be 115 % compared to current quantity in the mid-century in as per GFDL- Y1B scenario. In the A1B-end century, the precipitation would again go down compared to Y1B-mid century, however, it would be around 97% higher than the current quantity as per A1B – scenario of GFDL model. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that 7 % increase in rainfall in the mid century and 3 % increase in the end century compared to current conditions.

Figure 15. Annual Rainfall for Baseline, Mid and End century for Krishna basin – GFDL

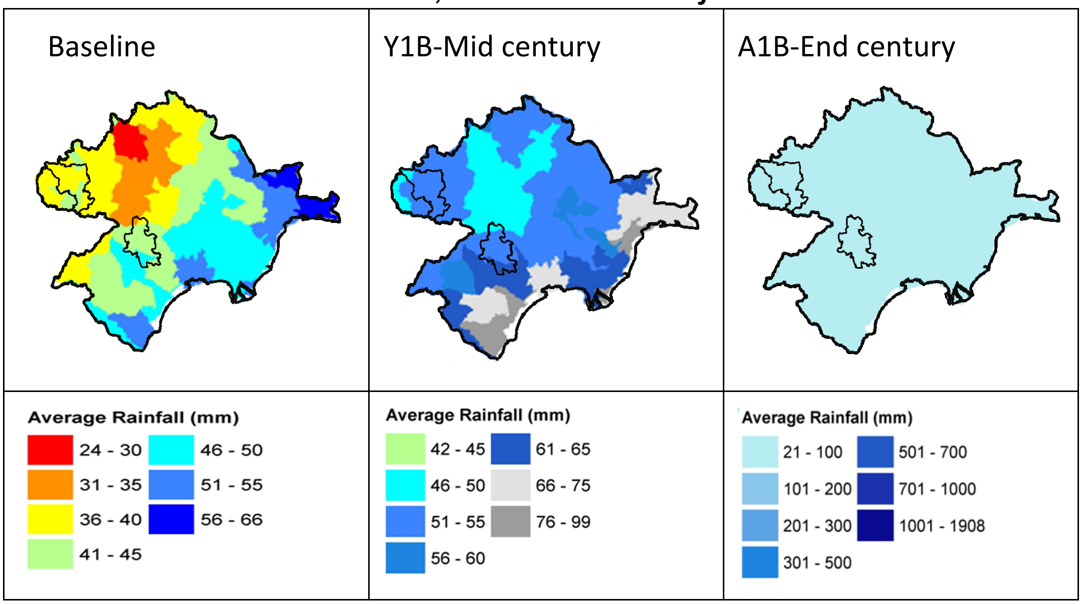


DC 21: Annual precipitation is expected to be increased in the Y1B-mid century compared to baseline. The rainfall is expected to be 112 % higher than the current quantity in the mid-century in as per GFDL- Y1B scenario. In the A1B-end century, it would be around 140 % higher than the current quantity as per A1B – scenario of GFDL model. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that 5.17 % increase in rainfall in the mid century and 5.69 % increase in the end century compared to current conditions.

b. Summer season precipitation

The quantam of rainfall during summer season (Febuary to May) as per GFDL model in different time periods are presented in figure 16.

Figure 16. Summer rainfall for Baseline, Mid and End century for Krishna basin – GFDL



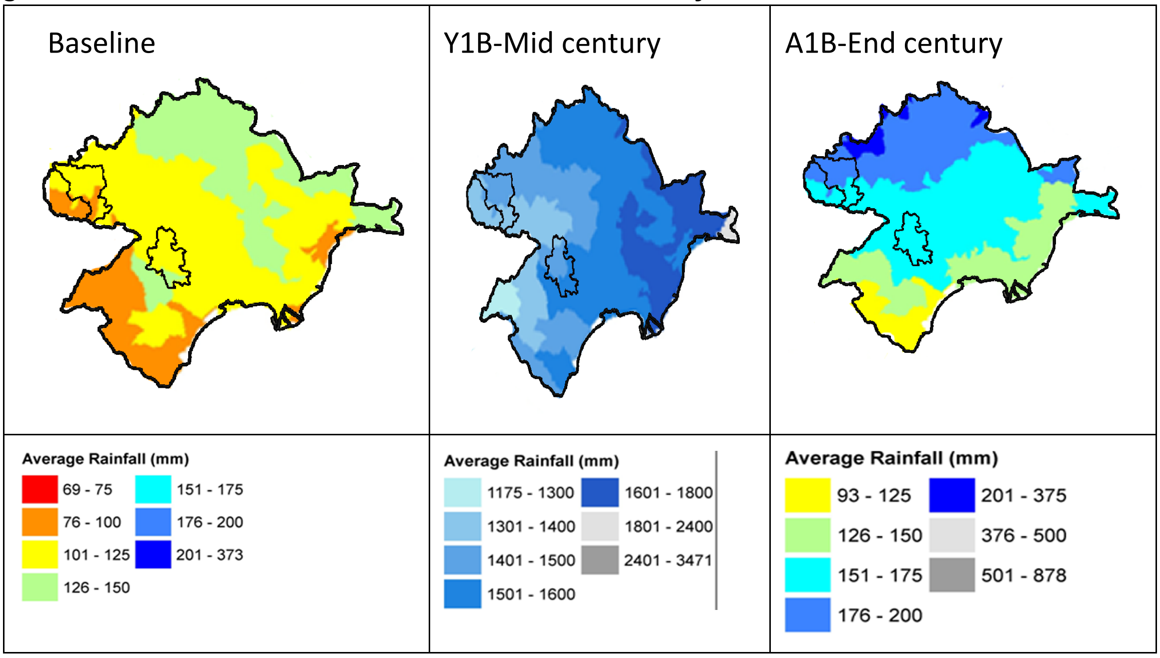
DC 4: In general, during summer season, 52 mm rainfall is received in DC No.4. The GFDL model predictions indicate that there is a possibility for getting 161% of the rainfall compared to current conditions in the Y1B-mid-century. Again in the A1B-end of the century, 172 % of the rainfall of current conditions are expected during the summer season. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the summer season rainfall is expected to decrease by 7.32% in the mid century and by 11.32 % in the end century compared to current conditions.

DC 21: In general, during summer season, 70 mm rainfall is received in DC No.21-Krishna basin. The GFDL model predictions indicate that there is a possibility for getting 158 % of the rainfall compared to current conditions in the Y1B-mid-century. Again in the A1B-end of the century, 245 % of the rainfall of current conditions is expected during the summer season. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the summer season rainfall is expected to decrease by 8.15% in the mid century and by 13.31 % in the end century compared to current conditions.

c. South west monsoon (SWM) season precipitation

The quantam of rainfall during South west monsoon season (June to September) as per GFDL model in different time periods for Krishna basin are presented in figure 5.

Figure 17. SWM rainfall for Baseline, Mid and End century for Krishna basin – GFDL



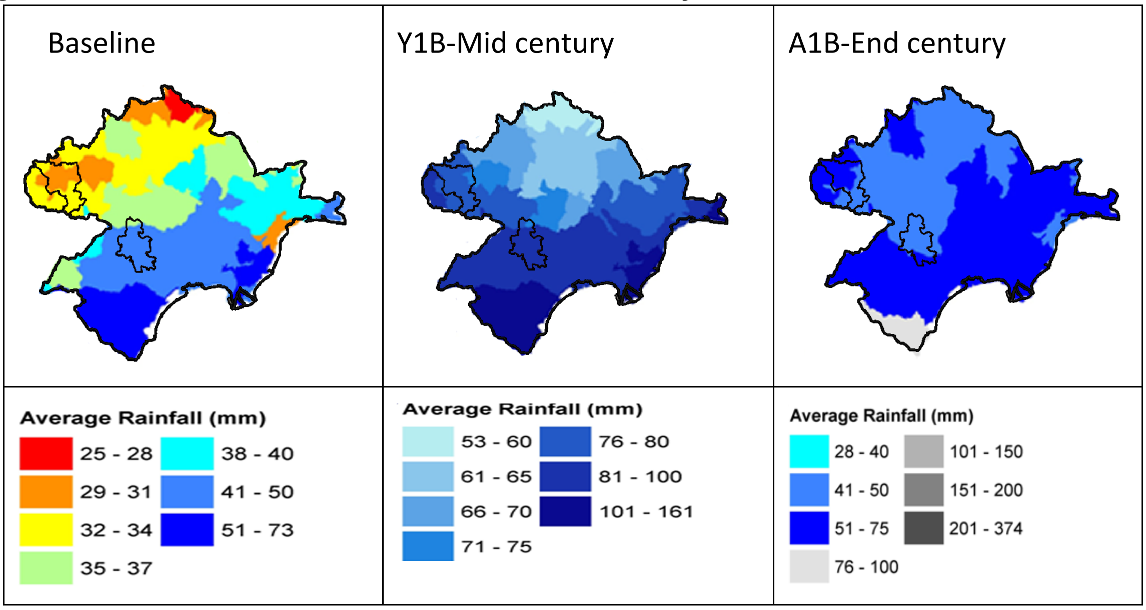
DC No.4 : During SWM, 483 mm of rainfall is normally received under current climate condition. In Y1B-mid-century of GFDL model, rainfall quantity is expected to increase by 225% and in the A1B-end-century, it is expected to increase by 175%. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 14.69 % in the mid century and by 14.01 % in the end century compared to current conditions.

DC No.21 : During SWM, in DC No.21-Krishna basin area, 623 mm of rainfall is normally received under current climate condition. In Y1B-mid-century of GFDL model, rainfall quantity is expected to increase by 316 % and in the A1B-end-century, it is expected to increase by 158 %. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 15.20 % in the mid century and by 17.01 % in the end century compared to current conditions.

d. North East monsoon (NEM) season precipitation

The quantum of rainfall during North east monsoon season (October to January) as per GFDL model in different time periods are presented in figure 18.

Figure 18. NEM rainfall for Baseline, Mid and End century for Krishna basin – GFDL



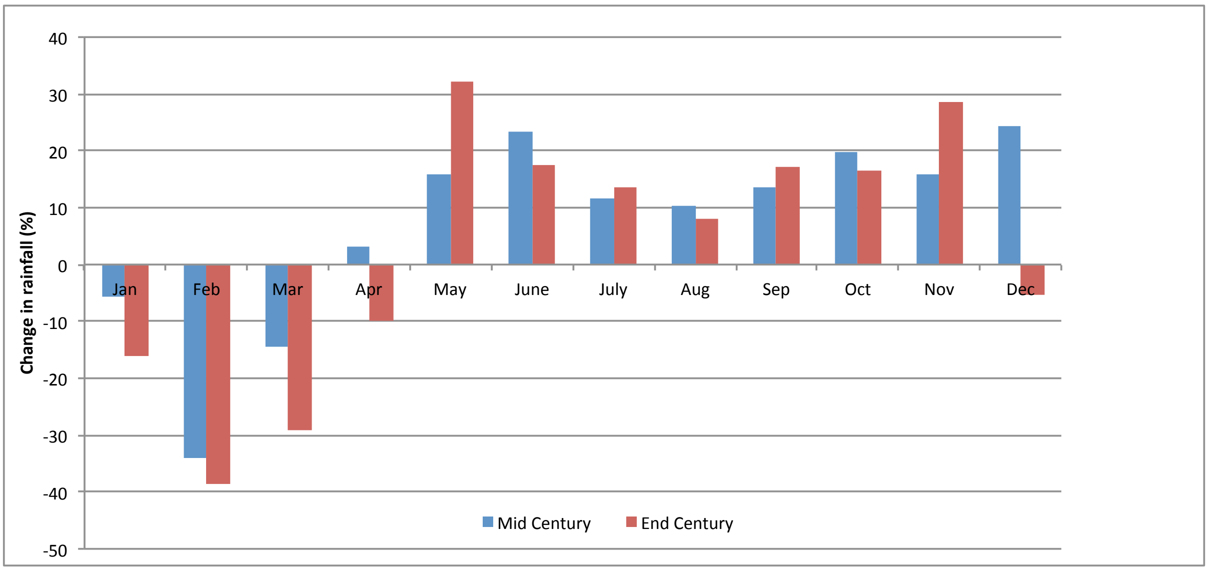
DC No.4 : During north east monsoon, Rainfall is projected to be increased by 59 % in the Y1B-mid-century and there would be a decrease in rainfall quantity in the A1B-end-century compared to Y1B-mid-century. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 13.64 % in the mid century and by 5.95 % in the end century compared to current conditions.

DC No.21 : During north east monsoon, Rainfall is projected to be increased by 61 % in the Y1B-mid-century and there would be a decrease in rainfall quantity in the A1B-end-century compared to Y1B-mid-century. Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability indicated that the SWM season rainfall is expected to increase by 8.47 % in the mid century and by 13.38 % in the end century compared to current conditions.

e. Finalisation of mid and end century rainfall for Krishna basin

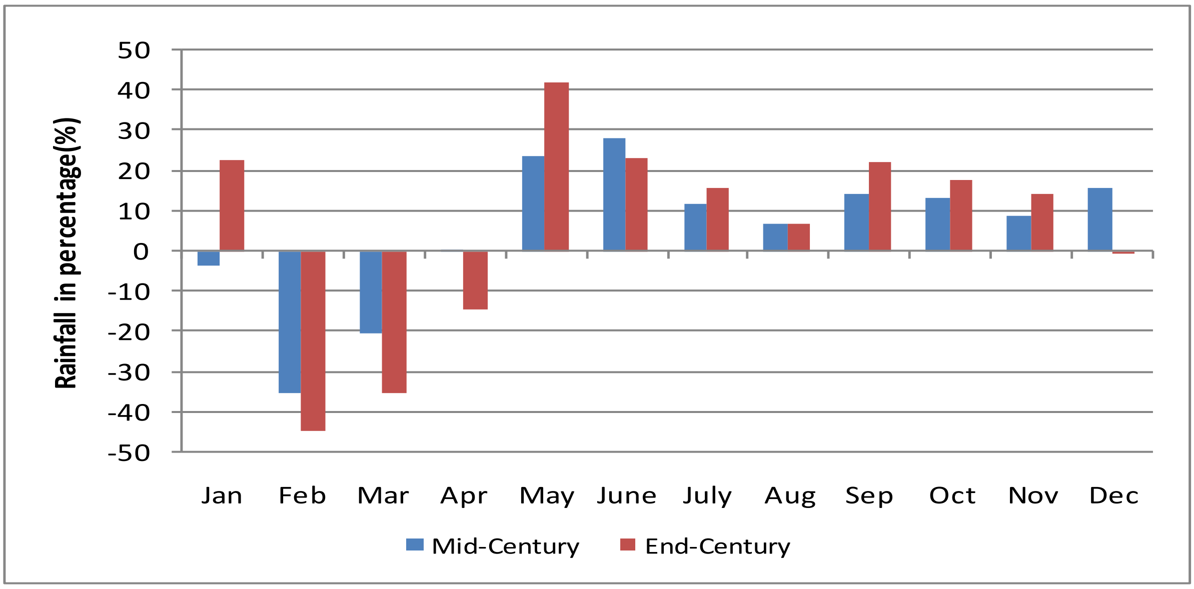
The 16 model ensemble at 60% probability for Mid and End Century was considered for the development of future climate. The results of DC 4 is presented in Figure 19 and DC21 in Figure 20.

Figure 19. Expected changes in rainfall (%) during mid and end century in DC4 Krishna basin



The rainfall in the mid century is expected to increase in the monsoon months starting from May through December in the order of 10.5 to 23 %. In contrast the rainfall is expected to decrease from January through April during the mid century. The same trend in rainfall is expected in the end century also with different magnitude. Rainfall is expected to increase from May to November to the range of 9-33 %. In the rest of the month starting from December to April rainfall is expected to decrease from 5-39%.

Figure 20. Expected changes in rainfall (%) during mid and end century in DC 21 Krishna basin



The rainfall in the mid century is expected to increase in the monsoon months starting from May through December in the order of 7 to 28 %. In contrast the rainfall is expected to decrease from January through April during the mid century. The same trend in rainfall is expected in the end century also with different magnitude. Rainfall is expected to increase from May to November to the range of 7-41 %. In the rest of the month starting from December to April rainfall is expected to decrease from 2-43%.

E. Development of Future Hydrological Scenario

Climate change is likely to have profound effects on the hydrological cycle through altered precipitation, evapotranspiration, and soil moisture patterns. According to the IPCC (2007), an increase in the average global temperature is very likely to lead to change in precipitation during the 21st century, although changes in precipitation will vary from region to region. Most of the hydrological models predict lesser water availability in the river basins for agriculture due to climate change in the coming decades (Ragab and Prudghomme, 2002). Hence, understanding the hydrology and modelling different hydrological processes within a river basin is important for assessing the environmental influence on river basin hydrology.

The hydrological response to climate change in terms of Potential evapotranspiration, Soil water content and water yield is estimated and analysed for Base line scenario i.e., current condition, Y1B scenario in MiDCentury & A1B scenario in EnDCentury. The hydrological scenarios were also developed using the future climate data derived from 16 GCM model ensemble at 60% probability for Mid and End Century.

E.1. *Climate change and Potential Evapotranspiration (PET)*

E.1.1. Kalingarayan and Ponnaniyar basins

Potential evapotranspiration is a good indicator for water requirement of the crop. As per GFDL model annual PET at Kalingarayan and Ponnaniyar basins are expected to increase in Y1B – mid century and A1B-end century (Table 10 and 11).

Table 10. Climate change and PET (mm) – Kalingarayan basin

Months	Current	GFDL-Mid Century	GFDL-End Century	16 model ensemble-Mid Century	16 model ensemble-End Century
Jan	104.51	132.39	118.15	121.24	129.16
Feb	109.18	123.65	125.8	112.8	119.8
Mar	150.41	183.19	164.56	168.08	177.66
Apr	162.47	195.55	165.67	180.22	190.35
May	155.69	212.18	187.7	196.12	206.65
Jun	136.98	175.51	155.74	163.66	171.68
Jul	145.12	158.95	146.37	149.15	155.92
Aug	155.54	172.97	144.65	163.32	170.09
Sep	138.31	152.42	136.22	143.44	149.99
Oct	137.1	157.56	133.55	146.45	154.08
Nov	154.42	157.94	132.94	147.3	154.91
Dec	155.59	152.5	128.56	141.04	149.17
Annual	1705.3	1974.81	1739.91	1832.82	1929.46

In Kalingarayan basin, the PET is expected to increase by 15.8 % in the mid century and by 2.0 % in the end century compared to current conditions as per GFDL model. The projected increase in PET is higher at Ponnaniyar basin compared to Kalingarayan and as per Y1B-mid and A1B- end century PET would increase by 25.1% and 16.2% respectively.

Table 11. Climate change and PET (mm) – Ponnaniyar basin

	Current	GFDL-Mid Century	GFDL-End Century	16 GCM ensemble-Mid Century	16 GCM ensemble-End Century
Jan	112.82	131.64	120.65	119.12	128.31
Feb	115.22	122.33	112.19	127.36	118.84
Mar	153.14	184.86	170.05	167.21	179.67
Apr	167.82	204.47	188.35	174.63	198.85
May	151.37	246.87	228.44	208.70	240.36
Jun	152.86	203.19	188.73	170.82	197.94
Jul	174.33	191.25	179.43	170.39	187.92
Aug	180.23	210.07	198.57	164.45	206.78
Sep	149.46	169.88	160.03	152.42	167.03
Oct	138.42	161.12	150.02	138.16	157.44
Nov	160.69	158.60	147.37	127.97	154.76
Dec	159.59	148.42	137.39	125.00	145.07
Annual	1815.95	2132.7	1981.22	1846.23	2082.97

Ensemble 16 different Global Climate Model outputs for A1b (Balanced emission scenario) with 60 % probability also indicated that the annual PET in Kalingarayan basin is expected to increase by 7.5 % in the mid century and by 13.1 % in the end century compared to current conditions. The increase is expected at Ponnaiyar basin by 8.3 and 22.1% in Y1B-mid and A1B-end century respectively.

Table 12. Seasonal changes expected in PET (%) in kalingarayan and Ponnaiyar basins

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai
Summer	23.7	29.1	11.4	19.0	13.8	15.4	20.2	25.6
SWM	14.6	17.9	1.2	10.6	7.6	0.2	12.5	15.6
NEM	8.8	4.9	-7.0	-2.8	0.8	-10.7	6.5	2.5
Annual	15.8	17.4	2.0	9.1	7.5	1.7	13.1	14.7

The Potential Evapo transpiration is expected to increase in all the seasons in mid and end century compared to current conditions exept in the NEM season end century.

The 16 GCM ensemble results indicate that during mid century in Kalingarayan basin 7.5 % increase in PET is expected while in Ponnaniyar, it is only 1.7 %. The reason might be higher water availability in kalingarayan basin compared to Ponnaniyar basin.

E.1.2. Krishna River basin

The seasonal changes expected in PET in the mid and end century for the two study regions of Krishna basin are presented in Table 12.

Potential Evapo Transpiration is expected to increase in both the study regions. As per GFDL model scenario, mid century would have 16.5 % higher PET compared to current condtions, while, in the end century, it would slightly get decreased. In contrast, PET is expected to increase gradually with time and would go up by 11.5 and 13.3 % from the current conditions in DC4 and DC21 of Krishna basin respcetively.

Table 13. Seasonal changes expected in PET (%) in Krishna Basin

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	DC 4	DC 21	DC 4	DC 21	DC 4	DC 21	DC 4	DC 21
Summer	28.7	32.3	21.4	23.4	18.2	18.5	20.6	24.2
SWM	9.1	7.7	6.2	7.3	3.3	3.2	5.5	6.2
NEM	11.8	9.5	13.0	15.3	6.8	7.7	8.5	9.5
Annual	16.5	16.5	13.5	15.3	9.4	9.8	11.5	13.3

E.2. *Climate change and Soil Water*

E.2.1. Kalingarayan and Ponnaniyar basins

Soil water storage as per GFDL model at Kalingarayan and Ponnaniyar basins are presented in Table 14 and 15.

Table 14. Climate change and Soil Water (mm) – Kalingarayan basin

Months	Current	GFDL-Mid Century	GFDL-End Century	16 model ensemble-Mid Century	16 model ensemble-End Century
Jan	49.35	61.04	54.25	48.59	49.96
Feb	53.66	58.27	52.81	49.6	56.96
Mar	35.89	52.46	42.54	30.12	41.68
Apr	19.21	30.66	20.08	18.94	19.8
May	30.11	31.59	30.17	31.06	26
Jun	46.92	52.43	43.6	47.12	40.17
Jul	55.09	63.05	45.03	56.79	51.74
Aug	62.13	64.28	55.16	62.83	59.75
Sep	60.29	73.79	64.56	60.93	58.06
Oct	60.31	74.6	68.08	60.54	59.48
Nov	51.57	63.8	60.21	51.86	50.99
Dec	49.96	63.32	54.54	50.02	50.19

Table 15. Climate change and Soil water (mm) – Ponnaniyar basin

Months	Current	GFDL-Mid Century	GFDL-End Century	16 model ensemble-Mid Century	16 model ensemble-End Century
Jan	43.43	61.17	50.52	43.14	45.07
Feb	50.91	53.40	43.62	44.74	54.44
Mar	29.82	48.10	36.27	24.89	34.82
Apr	12.46	33.50	21.34	12.32	13.98
May	14.01	28.12	19.56	15.2	12.25
Jun	23.18	50.20	33.42	24.83	18.38
Jul	45.08	58.97	40.46	48.77	42.69
Aug	52.93	59.59	50.13	54.74	49.72
Sep	60.41	70.94	60.61	61.07	58.73
Oct	56.72	81.12	66.94	57.21	55.69
Nov	48.21	69.29	56.29	48.96	47.9
Dec	46.87	66.04	54.63	46.97	46.94

Table 16. Seasonal changes expected in Soil water storage (%) in kalingarayan and Ponnaniyar basins

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai
Summer	24.6	52.2	4.8	12.7	-6.6	-9.4	4.0	7.7
SWM	13.0	32.0	-7.2	1.7	1.4	4.3	-6.6	-6.7
NEM	24.4	42.2	12.3	17.0	-0.1	0.5	-0.3	0.2
Annual	20.0	40.6	2.9	10.3	-1.1	-0.2	-1.7	-0.7

As per GFDL scenario, the soil water storage is expected to increase in both the study regions of Tamil Nadu. During Mid- century, it is expected to be increase by 20 % in Kalingarayan basin and by 40.6 % in Ponnaniyar basin.

Ensemble of 16 GCM scenario indicate not much change in soil water storage due to changing climate. A very slight decrease up to 1.7% is expected in the future time periods.

E.2.2. Krishna River basins

Changes expected in Krishna basin with reference to soil moisture storage is presented in Table 17.

Table 17. Seasonal changes expected in Soil water storage (%) in Krishna basins

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	DC 4	DC 21	DC 4	DC 21	DC 4	DC 21	DC 4	DC 21
Summer	18.5	16.8	4.8	7.8	0.4	-1.4	1.0	-1.5
SWM	8.5	10.2	5.3	2.4	2.2	6.5	0.7	-3.2
NEM	1.5	5.8	12.3	14.5	-0.1	0.5	1.8	-1.5
Annual	9.5	7.5	8.2	0.8	1.9	1.2	1.5	-2.1

As per GFDL scenario, the soil water storage is expected to increase in both the study regions of Krishna basin. During Mid- century, it is expected to be increase by 9.5 % in DC 4 and by 7.56 % in DC 21.

Ensemble of 16 GCM scenario indicate not much change in soil water storage due to changing climate. A very slight decrease up to 2.1% is expected in the end century time period in DC 21.

E.3. *Climate change and Water yield*

Impact of climate change on water yield in presented in this section.

E.3.1. Kalingarayan and Ponnaniyar basins

Table 18. Climate change and Water yield (mm) – Kalingarayan basin

	Current	GFDL-Mid Century	GFDL-End Century	16 model ensemble-Mid Century	16 model ensemble-End Century
Jan	9.57	20.26	10.26	9.19	8.35
Feb	8.96	21.56	10.00	6.18	3.75

Mar	5.48	18.90	11.50	4.06	2.37
Apr	3.29	31.67	5.14	2.22	1.23
May	4.77	25.41	6.74	5.95	6.35
Jun	12.45	26.89	12.92	20.12	19.81
Jul	20.70	36.21	17.92	25.79	30.87
Aug	29.76	35.09	19.83	36.74	39.73
Sep	32.89	66.73	51.95	41.65	44.39
Oct	58.52	107.56	60.79	67.73	69.47
Nov	26.10	65.57	44.31	29.76	30.78
Dec	14.16	40.18	21.79	15.51	15.83

Table 19. Climate change and Water yield (mm) – Ponnaniyar basin

	Current	GFDL-Mid Century	GFDL-End Century	16 model ensemble-Mid Century	16 model ensemble-End Century
Jan	7.89	26.94	8.53	7.55	7.38
Feb	11.39	28.17	2.63	8.48	4.39
Mar	4.43	22.83	3.22	3.14	1.64
Apr	4.95	29.42	11.76	3.78	2.67
May	2.59	18.32	4.05	2.82	2.62
Jun	3.22	16.95	18.51	4.18	4.60
Jul	14.84	17.28	15.07	17.51	23.45
Aug	9.32	17.41	12.81	12.11	14.63
Sep	19.41	39.06	26.06	26.73	29.32
Oct	49.07	104.88	44.46	57.77	58.90
Nov	22.20	77.31	28.69	25.17	26.69
Dec	14.21	51.38	18.27	15.25	15.36

Table 20. Seasonal changes expected in water yield (%) in kalingarayan and Ponnaiyar basins

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai	Kalinga	Ponnai
Summer	333.5	322.7	48.4	-7.3	-18.2	-22.0	-39.1	-51.5
SWM	72.2	93.8	7.1	54.8	29.7	29.4	40.7	53.9
NEM	115.6	179.0	26.6	7.0	12.8	13.2	14.8	16.0
Annual	118.9	175.2	20.5	18.7	16.9	12.8	20.4	17.2

As per GFDL model – Y1B scenario, the water yield is expected to increase by 119 % and 175% in the Kalingarayan and Ponnaniyar basins respectively in the mid century than the current levels. In the end century (A1B scenario), it is expected to increase by 20.5 and 18.7 % respectively for Kalingarayan and Ponnaniyar basins compared to current conditions.

The water availability was assessed in terms of average flow hydrographs and flow duration curves. The flow duration curve for Kalingarayan and ponnaniyar basin shows the range of flow in each scenario.

E.3.2. Krshina basin

Table 21. Climate change and Water yield (mm) – Krishna Basin

Seasons	Expected changes (%) in rainfall – GFDL Model				Expected changes (%) in rainfall - 16 model ensemble at 60% probability			
	Mid Century		End Century		Mid Century		End Century	
	DC4	DC 21	DC4	DC 21	DC4	DC 21	DC4	DC 21
Summer	385.5	333.0	65.2	55.8	-5.2	-3.3	-8.3	-11.2
SWM	130.4	165.8	86.7	81.2	17.6	15.8	15.3	14.4
NEM	85.2	96.5	22.5	27.4	11.8	6.6	6.3	10.1
Annual	200.4	198.4	58.1	54.8	8.1	6.4	4.4	4.4

Water yield is expected to increase in both the study regions of Krishna basin in the future changing climatic conditions. As per GFDL model, in the mid century (Y1B), the water yield would is expected to increase by 200.4 % in DC 4 and by 198.4 % in DC21. In end-century (A1B), it is expected to increase by 58.1 and 54.8 % in DC4 and DC21 respectively.

As per 16 GCM ensemble model prediction, there would be an increase in water yield by 6-8 % in the mid century and 4.4 % in the end century in Krishna basin.

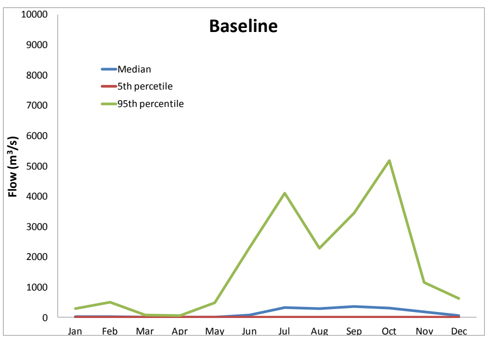
E.4. Water availability

E.4.1. Kalingarayan and ponnaniyar

The water availability was assessed in terms of average flow hydrographs (Figure 21).

Figure 21. Variability in monthly flow Baseline Hydrographs - Kalingarayan and ponnaniyar basins

Kalingarayan



Ponnaniyar

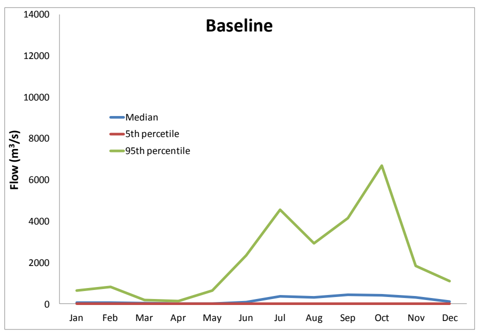
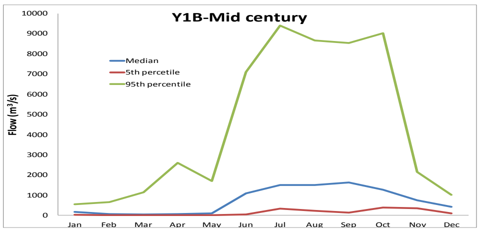
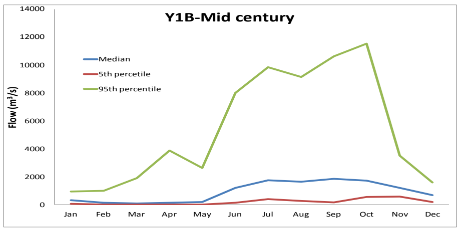
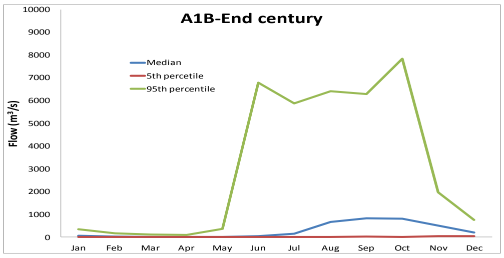


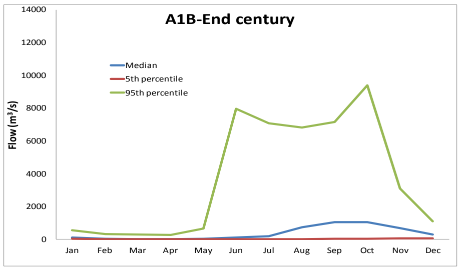
Figure 22. Variability in monthly flow Hydrographs simulated for future - Kalingarayan and ponnaniyar basins – GFDL model

Kalingarayan - GFDL	Ponnaniyar - GFDL





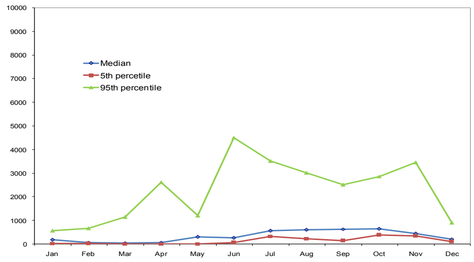


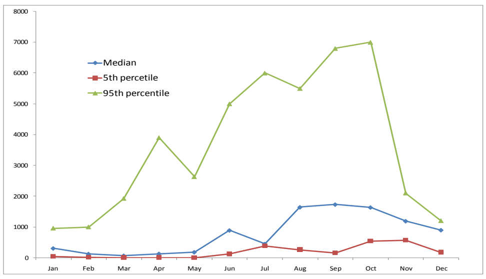


The flow hydrographs indicate that more inflows could be expected with both the climate change scenarios when compared to the baseline. Further, the flow hydrographs indicate that the flood magnitudes could be higher.

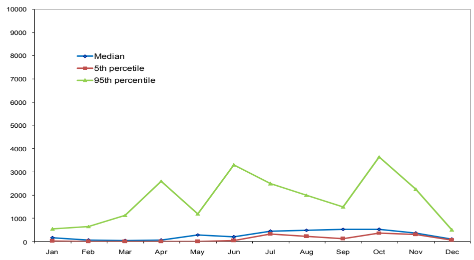
Figure 23. Variability in monthly flow Hydrographs simulated for future - Kalingarayan and ponnaniyar basins – 16 GCM ensemble

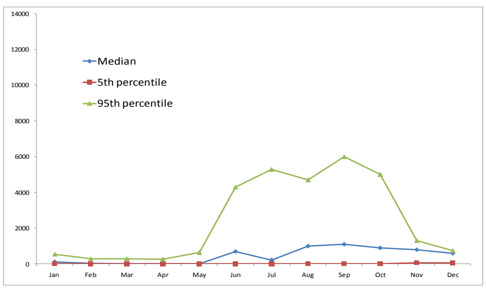
Kalingarayan - 16 GCM ensemble – Mid Century (A1B)	Ponnaniyar - 16 GCM ensemble - Mid Century (A1B)





Kalingarayan - 16 GCM ensemble – End Century (A1B)	Ponnaniyar - 16 GCM ensemble - End Century (A1B)



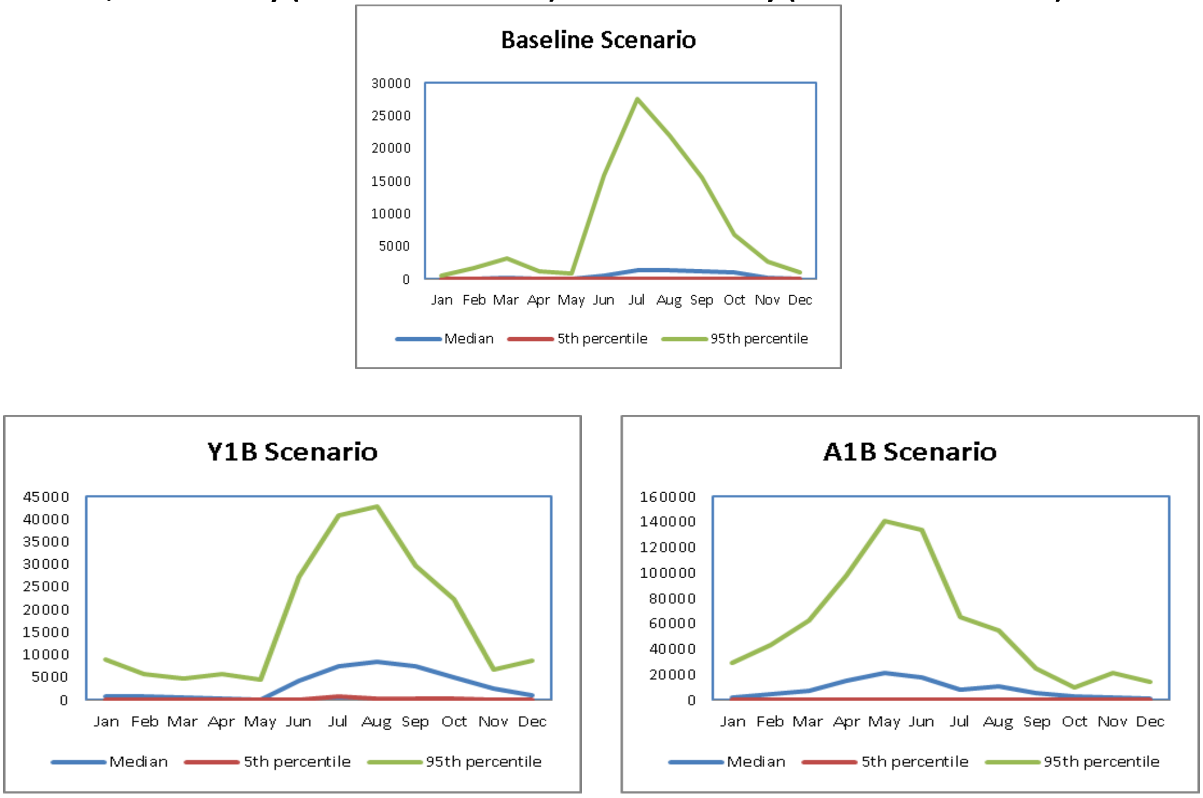


As per 16 GEM ensemble, The high flows will be much higher in the end century followed by mid century than the baseline.

E.4.2. Krishna Basin

The water availability was assessed for Krishna basin in terms of average flow hydrographs (Figure 24).

Figure 24. Variability in monthly flow Baseline Hydrographs – Nagarjunasagar reservoir - Baseline, Mid century (GFDL-Y1B Scenario) and End century (GFDL- A1B Scenario)



As per GFDL model out, flood like situation is expected in the study region. However, the ensemble model results indicate there would be increase in water avialbility but in shorter intervals with flood like situation. It is also expected that there would be intermittent droughts and long dry spells within the growing season in the future times.

F. Summary

Impact of climate change is likely to have serious influences on agriculture and water sectors and eventually on the food security and livelihoods of a large section of the rural population in developing countries. To improve the adaptive capacity of the agriculture and water sectors in the states of Andhra Pradesh and Tamil Nadu, ClimaAdapt Programme (Adaptation to climate change: An integrated science-stakeholder-policy approach to develop Adaptation framework for Water and Agriculture sectors in Tamil Nadu and Andhra pradesh states in India) is undertaken in selected pockets of Krishna (Left canal (DC4) and right canal of Nagarjuna Sagar (DC 21) in Andhra Pradesh) and Cauvery (Kalingarayan canal basin at Erode district and Ponnaniar reservoir basin at Thiruchirapalli district, Tamil Nadu) river basins.

The first and foremost need of the project is developing climate and hydrological scenarios for identifying and upscaling appropriate adaptation technologies. From ClimaRice (a feeder project to ClimaAdapt), climate scenarios for the current and future were developed by International Pacific Research Centre (IPRC), Hawaii. Tamil Nadu Agricultural University (TNAU), Coimbatore and International Water Management institute (IWMI), Hyderabad in coordination with Indian institute of Technology (Madras), Chennai developed the hydrological scenarios. In the current study, these scenarios were extracted for the ClimaAdapt programme regions and presented for the impact assessment and development of adaptation strategies for managing the changing climate.

Current Climate: The climate of Kalingarayan basin is dry throughout the year except during the monsoon seasons with mean temperature ranging from 23.8 to 30.6 °C. and mean annual precipitation of 711 mm. Ponnaiyar basin experiences a moderate climate with the mean temperature ranging from 26.7 to 32.7° C and mean annual rainfall of 850 mm. In both the locations, maximum rainfall is received during the North-East monsoon season.

In Andhra Pradesh study regios (DC 4 and DC 21 of Nagarjunasagar river basin), except during the South west monsoon season, climate is dry throughout the year. DC 4 receices 484 mm of rainfall in South west monsoon season and 138 mm during North east monsoon season. The annula average rainfall is 674 mm. DC. 21 has an annual average rainfall of 959.6 mm with major share received during South west monsson.

Future Climate Scenario: Data for the base line was obtained from the India meteorological Department for the period of 30 years from 1976 – 2005 and used in the current study. The climatic data needed for this study was developed by IPRC, Hawaii using the GFDL (Geophysical Fluid Dynamics Laboratory) Global Circulation Model (GCM) at a coarse resolution, spatially downscaled using the IPRC – Regional Circulation Model (RegCM).

The daily meteorological parameters such as precipitation, maximum temperature, minimum temperature and solar radiation for grid points with a grid space of 0.25^0 by 0.25^0 (~25km × 25km) spatially spread across study regions of ClimaAdapt project in Tamil Nadu and Andhra Pradesh were extracted for the timelines viz., (i) 1981 – 2000 : Baseline, (ii) 2021 – 2050: Mid century based on Y1B scenario with doubling of CO_2 by mid-century, and (iii) 2081-2100: End scenario based on A1B scenario with doubling of CO_2 by end-century.

Uncertainties will remain inherent in predicting future climate change, however, some uncertainties are likely to be narrowed by considering a range of climate model outputs. To reduce the uncertainty, ensemble of 16 different Global Climate Model outputs for A1b

(Balanced emission scenario) with 60 % probability was extracted for the study region of Tamil Nadu and Andhra Pradesh from www.climatewizard.org.

From the GFDL model outputs, more exterme rainfall events are expected. During mid-century summer and south west monsoon season, the rainfall expected to increase by more than 200% and 100% respectively. However, most of the GCM model results does not agree with this outcome. Hence, the results from the 16 model ensemble at 60% probability for Mid and End Century was considered. As we take the output from 16 different models, the regional bias as well as model parameters bias are corrected, error reduced and 60% probability level would give us the most likely condition of the future climate.

In **Kalingarayan basin**, rainfall in the mid century is expected to increase in the monsoon months starting from May through November in the order of 5 to 18 %. The same trend is expected in the end century with different magnitude. Rainfall is expected to increase by 20% during May, June and July , by 15% during August, September and November and by 10% during October during end century. Rainfall is expected to decrease from December through April from 10-45% in both the time periods. Temperature is expected to steadily increase and by mid and end century (2.06 ^{0}C and 3.02 ^{0}C) respectively as per GFDL model, and as per 16 model ensemble, an increase of 1.87 ^{0}C and 2.73 ^{0}C is expected for mid and end century respectively.

In **Ponnaniyar basin**, 16 Global Climate Model ensemble outputs for A1b (Balanced emission scenario) indicated 3.5 % and 2 % increase in rainfall in the mid and end century compared to current conditions. The summer season rainfall is expected to decrease by 2.11% and 14.23 % in the mid and end century, while, SWM rainfall is expected to increase by 12.2% and 19.1 % in the mid and end century compared to current conditions. NEM season rainfall is not expected to change in the mid century but for a slight increase (1.08 %) in the end century compared to current conditions. Temperature is expected to increase by 2.0 ^{0}C and 2.9 ^{0}C as per GFDL model, and by 1.82 ^{0}C and 2.69 ^{0}C as per 16 GCM ensemble during mid and end century respectively from the current levels.

In **DC 4** of Nagarjunasagar basin, rainfall in the mid century is expected to increase in the monsoon months starting from May through December in the order of 10.5 to 23 %. In contrast the rainfall is expected to decrease from January through April during the mid century. The same trend in rainfall is expected in the end century also with different magnitude. Rainfall is expected to increase from May to November to the range of 9 to 33 %. In the rest of the month starting from December to April rainfall is expected to decrease from 5-39%.

In **DC 21** of Nagarjunasagar basin, rainfall in the mid century is expected to increase in the monsoon months starting from May through December in the order of 7 to 28 %. The same trend in rainfall is expected in the end century and expected to increase in the range of 7-41 %. In the rest of the month starting from December to April rainfall is expected to decrease from 2-43%.

Hydrological scenario : Climate change is likely to have profound effects on the hydrological cycle through altered precipitation, evapotranspiration, and soil moisture patterns. The hydrological response to climate change in terms of Potential evapotranspiration, Soil water content and water yield is estimated and analysed for Base line scenario i.e., current condition, Y1B scenario in MiDCentury & A1B scenario in EnDCentury. The hydrological scenarios were also developed using the future climate data derived from 16 GCM model ensemble at 60% probability for Mid and End Century.

Potential evapotranspiration is a good indicator for water requirement of the crop. In Kalingarayan basin, the PET is expected to increase by 7.5 % in the mid century and by 13.1 % in the end century compared to current conditions as per 16 GCM ensemble. In ponnaniyar basin, the PET is expected to increase by 1.7 % in the mid century and by 14.7 % in the end century.

Potential Evapo Transpiration is expected to increase gradually with time in both the study regions of Krishna basin. PET would go up by 11.5 and 13.3 % from the current conditions in DC4 and DC21 of Krishna basin during mid and end century respcetively.

Soil water storage expected to increase in both the study regions of Tamil Nadu. During Mid century, it is expected to increase by 20 % in Kalingarayan basin and by 40.6 % in Ponnaniyar basin. However, ensemble of 16 GCM scenario indicate not much change in soil water storage due to changing climate. A very slight decrease up to 1.7% is expected in the future time periods.

As per GFDL scenario, the soil water storage is expected to increase in Krishna basin. During Mid- century, it is expected to increase by 9.5 % in DC 4 and by 7.56 % in DC 21. Ensemble of 16 GCM scenario indicate not much change in soil water storage and a decrease up to 2.1% is expected in the end century time period in DC 21.

Water Yield: As per GFDL model – Y1B scenario, the water yield is expected to increase by 119 % and 175% in the Kalingarayan and Ponnaniyar basins respectively in the mid century than the current levels. In the end century (A1B scenario), it is expected to increase by 20.5 and 18.7 % respectively for Kalingarayan and Ponnaniyar basins compared to current conditions.

In Krishna basin, water yield is expected to increase in both the study regions in the future changing climatic conditions. As per GFDL model, in the mid century (Y1B), the water yield would is expected to increase by 200.4 % in DC 4 and by 198.4 % in DC21. In end-century (A1B), it is expected to increase by 58.1 and 54.8 % in DC4 and DC21 respectively. As per 16 GCM ensemble model prediction, there would be an increase in water yield only by 6-8 % in the mid century and 4.4 % in the end century in Krishna basin. Increase in water yield would lead to more run off and would create problems of soil erosion and losing of top productive soil.

Water Availability: The water availability was assessed in terms of average flow hydrographs and flow duration curves. The flow hydrographs and flow duration curve indicate that more inflows could be expected with both the climate change scenarios when compared to the baseline. Further, the flow hydrographs indicate that the flood magnitudes could be higher. As per 16 GEM ensemble, The high flows will be much higher in the end century followed by mid century than the baseline.

As per GFDL model out, flood like situation is expected in the study region. However, the ensemble model results indicate there would be increase in water avialbility but in shorter intervals with flood like situation. It is also expected that there would be intermittent droughts and long dry spells within the growing season in the future times.

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