NILE BASIN INITIATIVE
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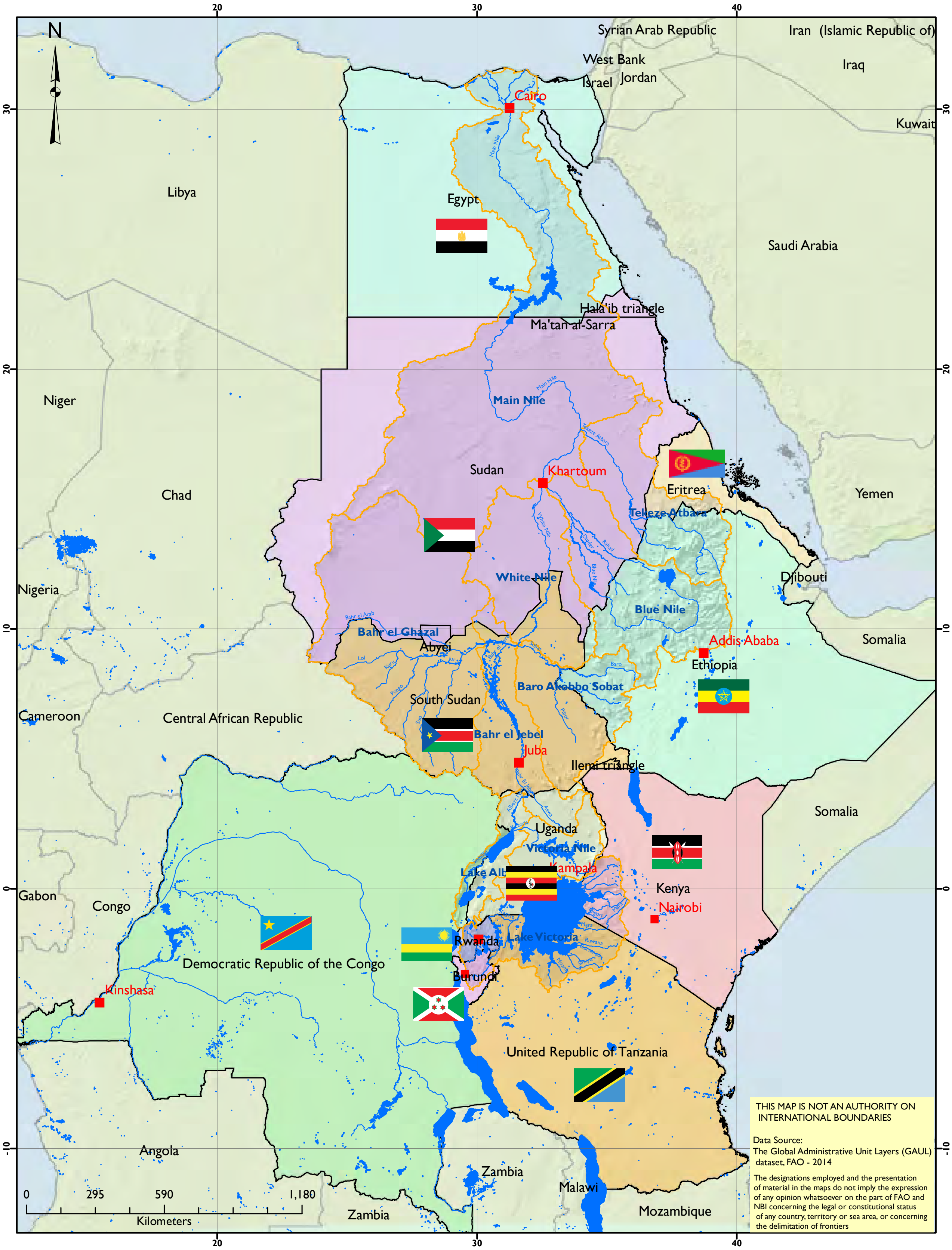
WHAT DOES A GLOBAL AVERAGE TEMPERATURE RISE OF 1.5 AND 2 DEGREE MEAN FOR THE NILE BASIN?

CLIMATE CHANGE PROJECTIONS: KENYA

NBI MEMBER STATES



* Eritrea participates as an observer

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1. Introduction

Africa is one of the most vulnerable regions to weather and climate change impacts as indicated by the IPCC report in 2007 and 2014, and yet has a low adaptive capacity. Several studies assessed how climate change will impact the flow at the Nile, and found that, there is a wide disparity in predictions of future Nile flow scenarios. A study in 1998 by Yates supports previous findings that changes in precipitation and to a lesser extent temperature over the Nile basin could have serious consequences on regional water resources throughout this large African basin. The 2*CO_2 GCM scenarios gave a wide range of changes both in total water yield at Aswan and regional hydrologic changes throughout the basin. Five of six GCMs showed increased flows at Aswan, with increases as much as 137% (UKMO). Only one GCM (GFDL) showed a decline in annual discharge at Aswan (-15%). Five of six GCMs predict increased precipitation in equatorial Africa. With some GCM scenarios predicting large increases in Nile discharge, there will be a need to increase flood protection. He estimated 6% increase of the Nile at Aswan Dam. Another study by Kim in 2007 expected that in a 100-year time series analysis using the outcomes of the six general circulation models showed that precipitation changes for the 2050s (2040 through 2069) can be -7% to 28% with a mean increase of about 11%.

Rogelj and Knutti in 2016 pointed out that further investigation is required by the geoscience community to address in what way the unclear risks and impacts for 1.5 °C differ from those for 2 °C, which can then contribute to the climate policy discussions, it will help each country about the state of knowledge of what may happen in their region. In particular, there is a need to understand the geographical distribution of these risks: in what regions and in what ways is the differential impact of 2.0 over 1.5 degrees is small or big. Assessments of these differential risks can contribute to discussions about the costs of adaptation to overcome impacts experienced beyond 1.5 degrees, and mechanisms for loss and damage for impacts that cannot be avoided.

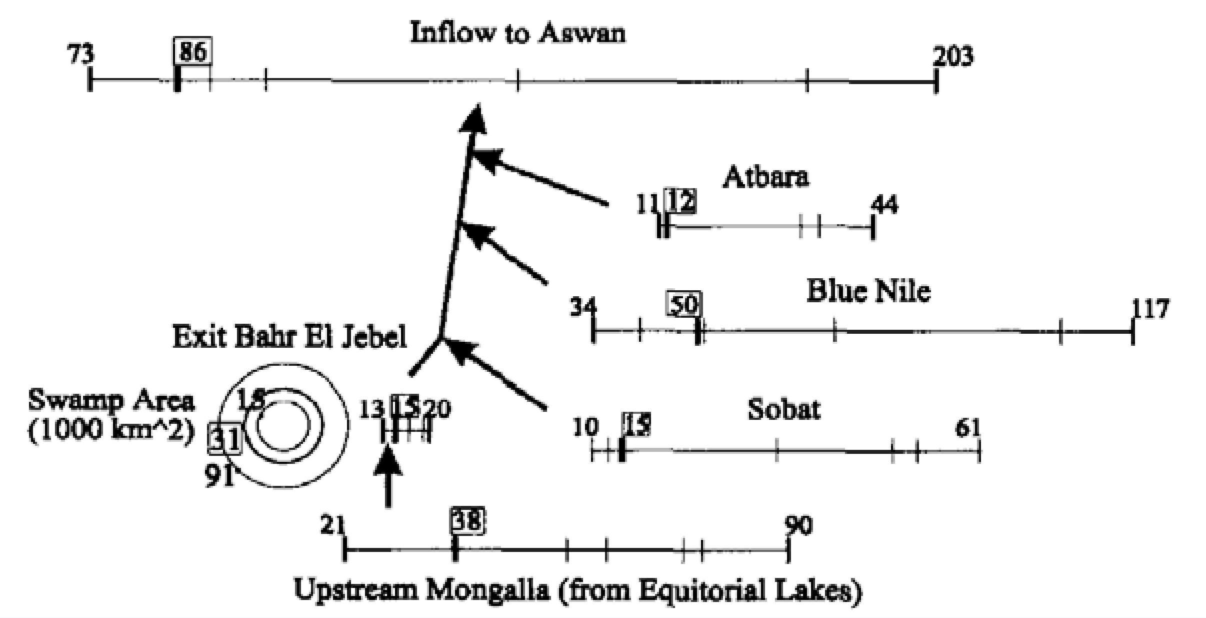

Figure 1: Graphical representation of range of discharges (in BCM) for major points along Nile (Two numbers on ends of each line represent extreme discharges of six GCM scenarios, whereas boxed number is historic average; additional tick marks on each line are remaining GCM scenarios, which indicates range of climate change induced flows of Nile Basin (Yates et al.1998b).

1.1 Rationale

Climate change could bring about dramatic changes in the water resources of the Nile basin, which need a great effort from the water management and planners in managing current and developing future water resources projects.

The extensive literature review revealed that there is no common agreement among all the GCMs and there is a level of uncertainty in the projected rainfall and flow over the Nile Basin. The previous analysis didn't investigate whether the used models were dry or wet. In addition, it used a limited number of ensemble members.

The NBI-Sec is intended to do a series of studies in order to answer different scientific questions involving future climate change for rainfall and temperature, water resources, extreme events, agriculture, land cover change, and seasonal prediction applications

1.2 Scope

This bulletin presents an analysis of historical and projected temperature and rainfall changes in Kenya at 1.5 and 2.0 degrees global warming. Using data from the CMIP5 multi-model archive, the study:

- Determined the historical spatial trend of the rainfall and temperature.
- Determined the timing of global mean warming of 1.5 and 2.0 degrees over pre-industrial temperatures;
- Rank the models from the wettest to driest, and from the coldest to hottest for each country to illustrate which one is wet and which is dry.
- Calculated changes in mean annual spatial temperature and precipitation changes at these times over Kenya.

2. Data and methods

The global observational gridded TS3.22 dataset from the University of East Anglia's Climatic Research Unit (CRU) was used to examine and map observed seasonal (JJA and DJF) and trends in temperature and precipitation. Monthly values were used at a resolution of 0.5 degrees longitude by 0.5 degrees latitude, from 1963 to 2012. The Mann-kendall test was used to calculate the P-value significance above 95%.

A suite of CMIP5 models for the RCP8.5 were downloaded and used in this study. This included GCMs for which there were multiple ensembles. In total 35 GCMs were considered and provided 81 ensemble members (some GCMs has multiple members of the same model) for temperature analysis and 78 for rainfall (Figure 1). The timing of each Global Warming Level (GWL; in this case 1.5 and 2.0 degrees over preindustrial) in each model simulation was determined as follows: (i) calculate a 40-year pre-industrial global mean temperature, for the period 1861-1900; these dates were chosen to incorporate the maximum number of models, as some only have data starting in 1861; (ii) identify the first year at which the 31-year running mean of global temperature exceeds 1.5 and 2.0 degrees over the pre-industrial global mean temperature. National area-averaged temperature and rainfall changes relative to pre-industrial at the time of 1.5 and 2.0 GWL were then calculated using the 31-year mean centered on the time of GWL.

3. Results

3.1 Timing of 1.5 and 2 degree significant warming levels

The mean time of 1.5 and 2.0 GWL across the 81 members of the RCP8.5 is 2024 and 2038 respectively (Figure 1). However, there is considerable variability amongst the GCMs. Models with higher transient climate sensitivity reach the GWLs sooner, while those with lower sensitivity pass the GWL later. For example, the BNUESM, is the first to reach 1.5 and 2.0 GWL at 2008 and 2022, respectively; in contrast, INMCM4 is the last to reach these GWLs, at 2043 and 2057.

The median time delay between 1.5 and 2.0 GWLs is 14 years, with a range of 11 to 22. There is, however, no correlation between the speed at which models reach 1.5 degrees and time they take to warm a further 0.5 degrees. Nonetheless, at the rates of climate forcing associated with RCP8.5, the time between these two GWLs is very short. This implies that under current rates of emissions increases, there will be very little time to react to the progressive impacts of climate change in countries as warming moves from the 1.5 to the 2.0 GWL and beyond.

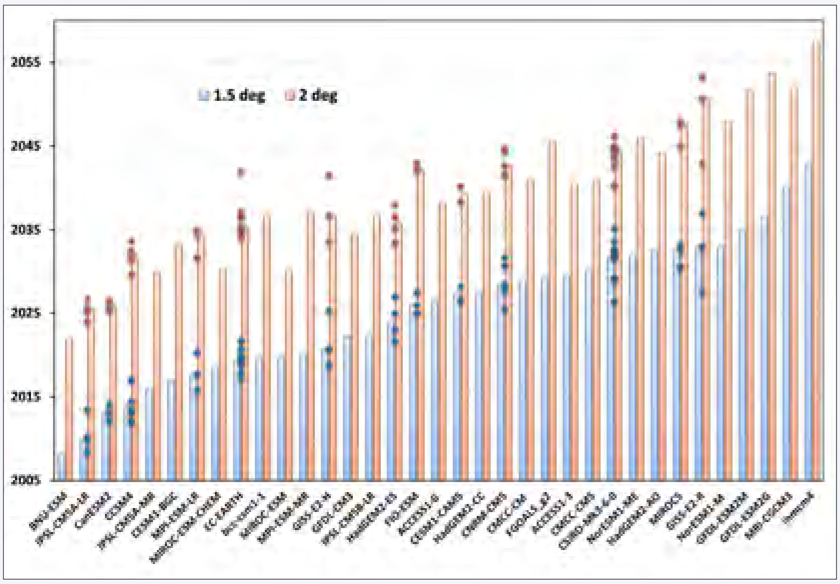

Figure 2: The timing of global warming of 1.5 °C and 2.0 °C in each ensemble member, some GCMs has multiple members of the same model.

3.2 Historical rainfall over Kenya:

The historical trend of the rainfall over Kenya showed a small (insignificant) trend of drying with higher significant drying trend over the north region.

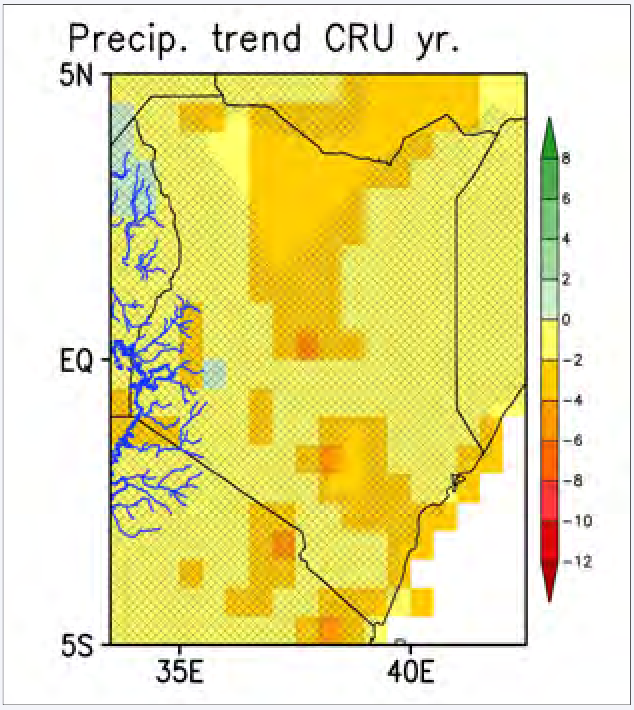

Figure 3: The monotonic slope in precipitation (mm) between 1963 and 2012 at each grid cell, according to a linear trend per decade for Jan. to Dec. Hatching indicates areas where the trend is not statistically significant at the 95% level. Data taken from the CRU TS3.22 datasets.

3.3 Historical temperature over Kenya:

The historical trend of the temperature over Kenya showed a significant warming trend over the entire country. The east part showed the lowest significant increasing trend and increased gradually to the west.

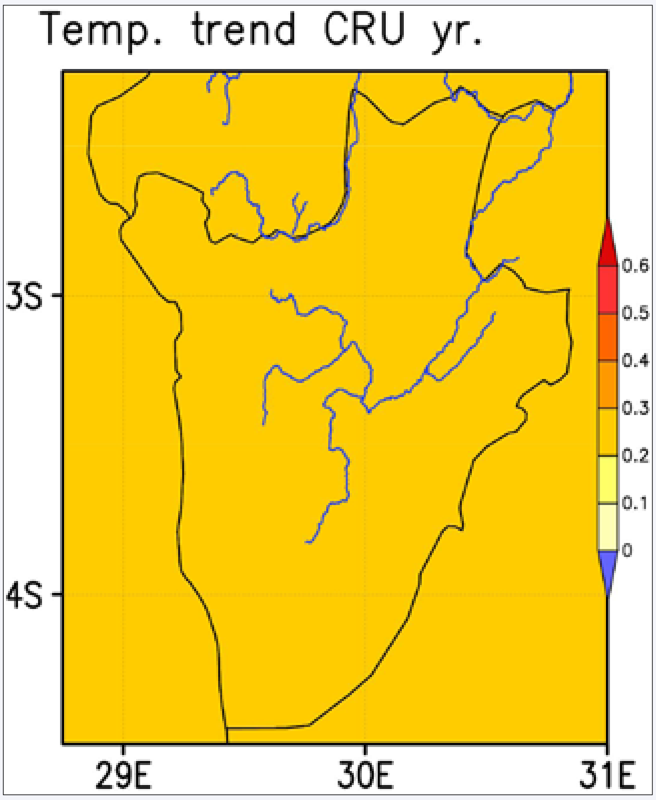

Figure 4: The monotonic slope in precipitation (mm) between 1963 and 2012 at each grid cell, according to a linear trend per decade for Jan. to Dec. Hatching indicates areas where the trend is not statistically significant at the 95% level. Data taken from the CRU TS3.22 datasets.

3.4 The rank of all GCMs for temperature and rainfall

It is always advised when using any GCM to force a hydrological model, not to use only one GCM. Several ensemble members should be used. The tables below showed the rank of all the GCMs from wettest to driest for the rainfall, and from hottest to coldest for the temperature.

Table 1: Rank of the GCMs from wettest to driest over Kenya.

No	Model	pre	No	Model	pre	No	Model	pre
1	MIROC-ESM	221	27	MRI-CGCM3	61.8	53	CSIRO-Mk3-6-0	-0.384
2	MIROC-ESM-CHEM	186	28	CSIRO-Mk3-6-0	57.4	54	EC-EARTH	-2.04
3	CanESM2	185	29	CSIRO-Mk3-6-0	52.8	55	MPI-ESM-MR	-3.37
4	CanESM2	178	30	IPSL-CM5A-LR	47.2	56	CSIRO-Mk3-6-0	-5.84
5	CESM1-CAM5	178	31	MIROC5	45.2	57	EC-EARTH	-6.32
6	CanESM2	174	32	FGOALS_g2	43.9	58	CNRM-CM5	-9.97
7	IPSL-CM5A-LR	167	33	BNU-ESM	33.7	59	HadGEM2-ES	-11.5
8	CanESM2	155	34	NorESM1-M	32.3	60	HadGEM2-AO	-14.5
9	CESM1-CAM5	125	35	CSIRO-Mk3-6-0	30.4	61	MIROC5	-14.5
10	CanESM2	119	36	ACCESS1-3	28.9	62	ACCESS1-0	-18.2
11	CESM1-CAM5	119	37	inmcm4	28.7	63	GISS-E2-R	-18.6
12	IPSL-CM5A-LR	119	38	bcc-csm1-1	28.5	64	CNRM-CM5	-18.8
13	CCSM4	108	39	MPI-ESM-LR	26.4	65	HadGEM2-ES	-19.4
14	IPSL-CM5A-MR	105	40	CNRM-CM5	24.6	66	MIROC5	-20
15	CCSM4	98.8	41	HadGEM2-CC	24.6	67	GISS-E2-H	-22.1
16	CESM1-BGC	96	42	GFDL-CM3	15.7	68	CNRM-CM5	-25.3
17	FIO-ESM	93.5	43	CNRM-CM5	15.6	69	MPI-ESM-LR	-27.5
18	CCSM4	92.7	44	EC-EARTH	14.3	70	FIO-ESM	-29.5
19	IPSL-CM5A-LR	92	45	GFDL-ESM2M	14.2	71	IPSL-CM5B-LR	-39.7
20	CCSM4	85.3	46	MPI-ESM-LR	10.5	72	GFDL-ESM2G	-40.3
21	NorESM1-ME	82.2	47	CSIRO-Mk3-6-0	8.41	73	GISS-E2-H	-53.5
22	CSIRO-Mk3-6-0	81.1	48	CSIRO-Mk3-6-0	6.86	74	GISS-E2-R	-57.5
23	CCSM4	77.5	49	EC-EARTH	3.69	75	GISS-E2-H	-57.8
24	FIO-ESM	75.2	50	GISS-E2-R	3.56	76	CMCC-CMS	-58.9
25	CSIRO-Mk3-6-0	71.7	51	CMCC-CM	2.16	77	HadGEM2-ES	-60.9
26	CCSM4	62.9	52	CSIRO-Mk3-6-0	1.67	78	HadGEM2-ES	-62.4

Table 2: Rank of the GCMs from hottest to coldest over Kenya.

No	Model	tmp	No	Model	tmp	No	Model	tmp
1	GFDL-ESM2G	2.17	28	EC-EARTH	1.73	55	bcc-csm1-1	1.5
2	CMCC-CMS	2.15	29	MIROC5	1.73	56	CNRM-CM5	1.5
3	IPSL-CM5A-LR	1.97	30	MIROC5	1.73	57	FIO-ESM	1.5
4	IPSL-CM5A-LR	1.96	31	EC-EARTH	1.72	58	GISS-E2-H	1.5
5	IPSL-CM5A-LR	1.94	32	FIO-ESM	1.72	59	CanESM2	1.48
6	IPSL-CM5A-MR	1.9	33	inmcm4	1.72	60	CanESM2	1.46
7	CSIRO-Mk3-6-0	1.89	34	EC-EARTH	1.7	61	CNRM-CM5	1.45
8	CMCC-CM	1.87	35	GISS-E2-R	1.68	62	FIO-ESM	1.44
9	GFDL-ESM2M	1.87	36	EC-EARTH	1.67	63	CCSM4	1.43
10	CSIRO-Mk3-6-0	1.85	37	EC-EARTH	1.66	64	CCSM4	1.43
11	IPSL-CM5A-LR	1.85	38	GISS-E2-R	1.65	65	CNRM-CM5	1.42
12	HadGEM2-ES	1.84	39	EC-EARTH	1.63	66	HadGEM2-CC	1.41
13	ACCESS1-0	1.82	40	FGOALS_g2	1.63	67	NorESM1-ME	1.4
14	MPI-ESM-LR	1.81	41	HadGEM2-ES	1.63	68	CCSM4	1.37
15	CSIRO-Mk3-6-0	1.8	42	ACCESS1-3	1.61	69	CCSM4	1.36
16	GISS-E2-R	1.78	43	CanESM2	1.6	70	CanESM2	1.35
17	MPI-ESM-LR	1.78	44	GISS-E2-H	1.6	71	CESM1-BGC	1.34
18	CSIRO-Mk3-6-0	1.77	45	HadGEM2-ES	1.6	72	MRI-CGCM3	1.34
19	CSIRO-Mk3-6-0	1.77	46	CSIRO-Mk3-6-0	1.59	73	CCSM4	1.33
20	EC-EARTH	1.77	47	CSIRO-Mk3-6-0	1.59	74	CCSM4	1.32
21	MPI-ESM-LR	1.77	48	CanESM2	1.58	75	GFDL-CM3	1.3
22	MPI-ESM-MR	1.77	49	HadGEM2-ES	1.58	76	HadGEM2-AO	1.3
23	CSIRO-Mk3-6-0	1.75	50	NorESM1-M	1.58	77	MIROC-ESM-CHEM	1.27
24	IPSL-CM5B-LR	1.75	51	GISS-E2-H	1.56	78	BNU-ESM	1.19
25	MIROC5	1.75	52	EC-EARTH	1.54	79	MIROC-ESM	1.05
26	CSIRO-Mk3-6-0	1.74	53	CNRM-CM5	1.52	80	CESM1-CAM5	1.01
27	CSIRO-Mk3-6-0	1.73	54	CNRM-CM5	1.51	81	CESM1-CAM5	0.853

3.5 Projected rainfall by using 78 CMIP5 GCMs at 2 °C and 1.5 °C over Kenya:

A mean of 78 GCMs were used to show the projection over Kenya at global warming level of 2 and 1.5 °C during 2038 and 2024. The east part of Kenya projected little rainfall increase. The west part of Kenya and the source of the White Nile showed the highest projected amount of rainfall especially around the equator.

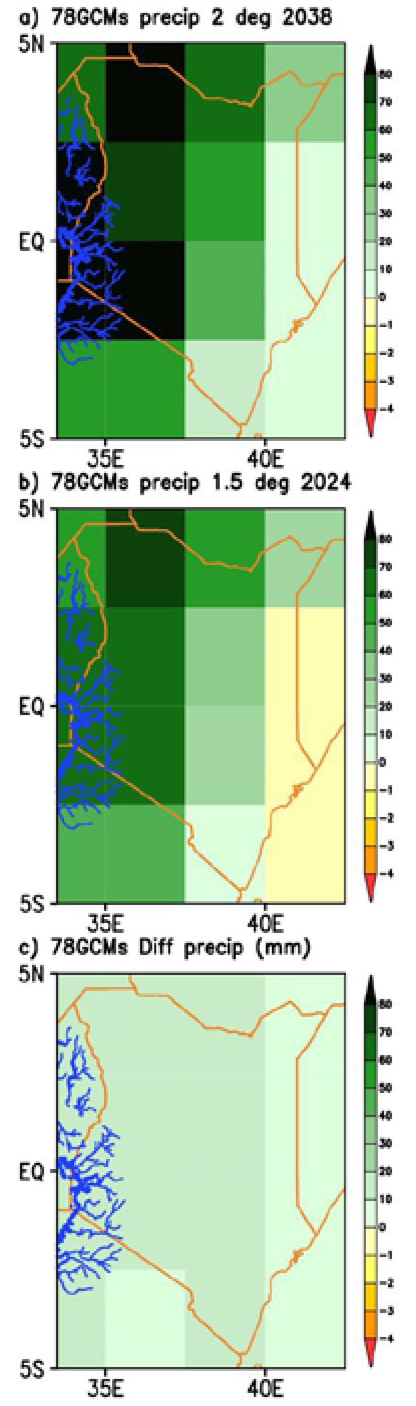

Figure 5: Projected spatial annual rainfall change for Kenya, at the time of global warming of 2°C, 1.5 °C, and the difference. Data are average from 78 CMIP5 climate model simulations under the RCP8.5 forcing scenario.

3.6 Projected temperature by using 78 CMIP5 GCMs at 2 °C and 1.5 °C over Kenya:

A mean of 81 GCMs were used to show the projection of temperature over Kenya at the global mean temperature of 2 and 1.5 °C during 2038 and 2024. The temperature projected to be same like the global mean temperature in many regions of Kenya. The south-east was projected to be even lower than the global mean temperature at 2038.

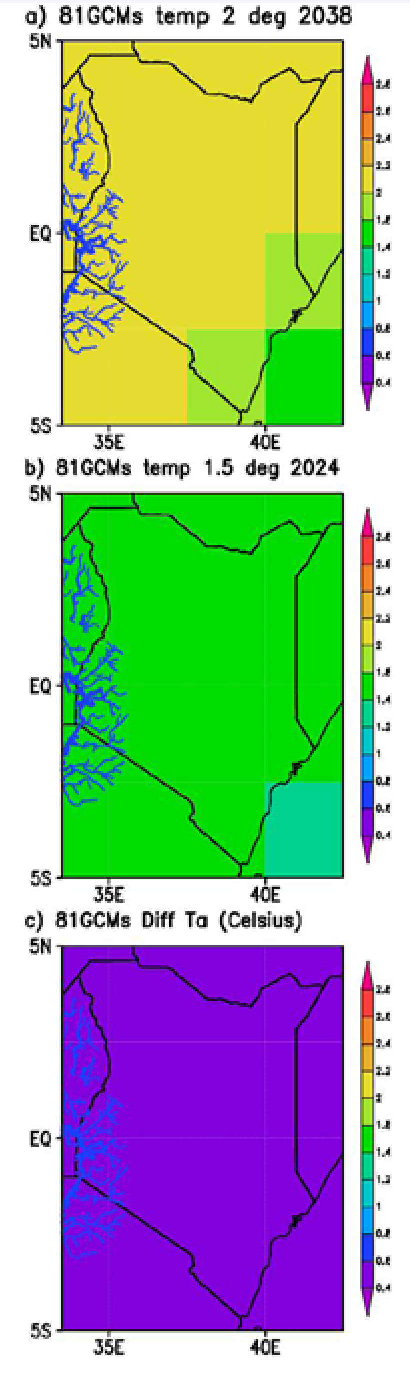

Figure 6: Projected spatial annual temperature change for Kenya, at the time of global warming of 2°C, 1.5 °C, and the difference. Data are average from 81 CMIP5 climate model simulations under the RCP8.5 forcing scenario.

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