Assessment of Global Reanalysis Precipitation Datasets for Hydrological Applications in Kenya

Maureen Wanzala, Hannah Cloke, Andrea Ficchi, Liz Stephens, Heou Badjana, David Lavers

Email: **maureen.wanzala@welthungerhilfe.de**

@_Maureen_AW

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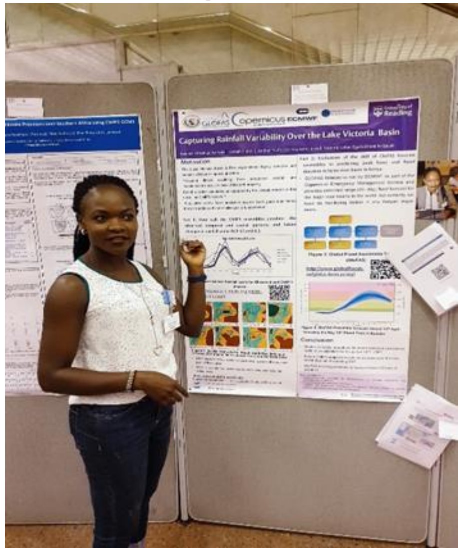
Introduction

- Meteorologist, hydro-meteorologist and climate scientist.
- Provide research, monitoring, and analysis of fast (floods and tropical storms) and slow (droughts) onset weather and climate hazards to support to country offices and RBs to enhance preparedness and Anticipatory Humanitarian Actions ahead of and during hazards.
- Science communications, working with broader scientific community and humanitarian agencies



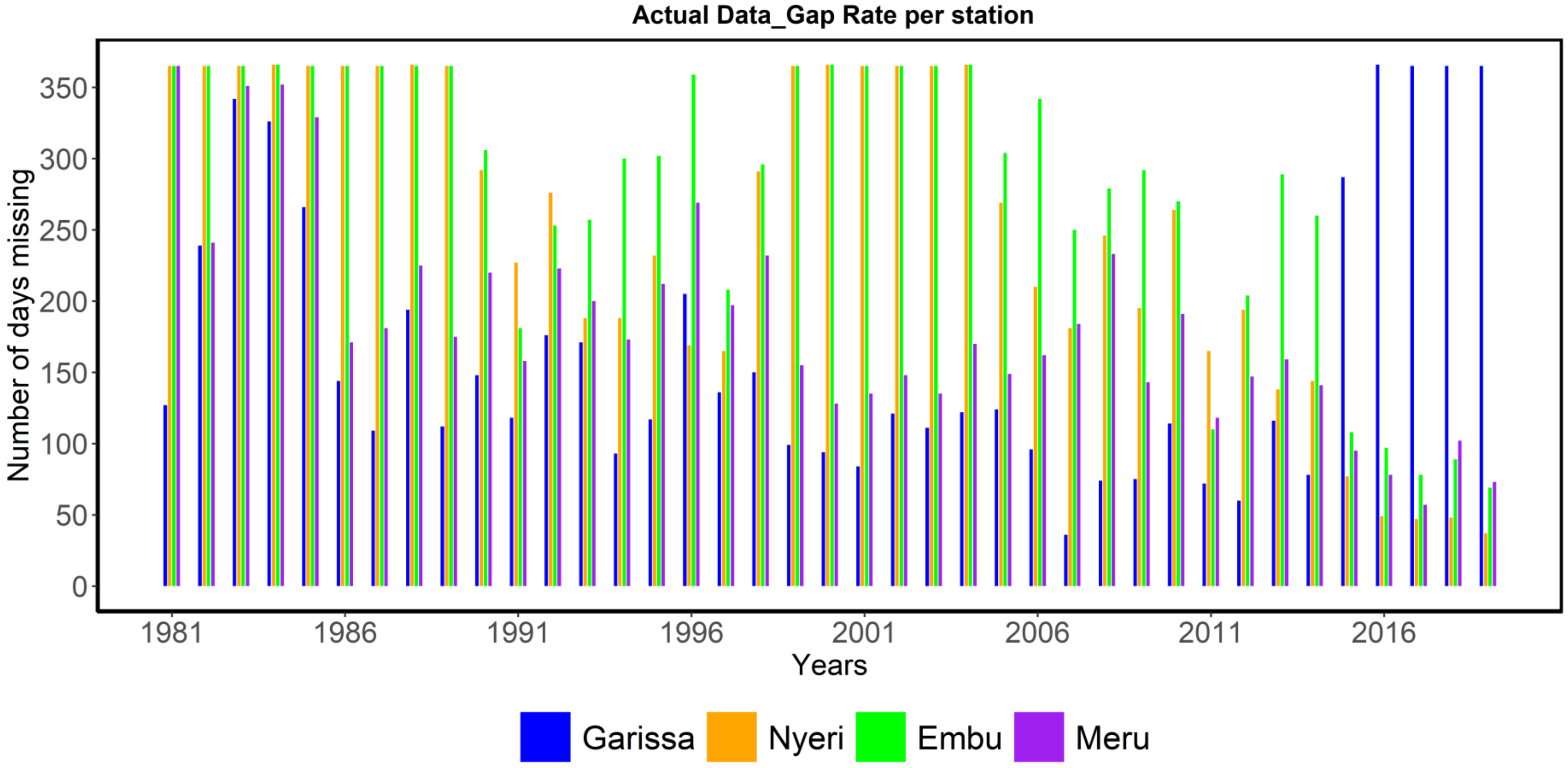
Email: **maureen.wanzala@welthungerhilfe@de**

@_Maureen_AW

Background

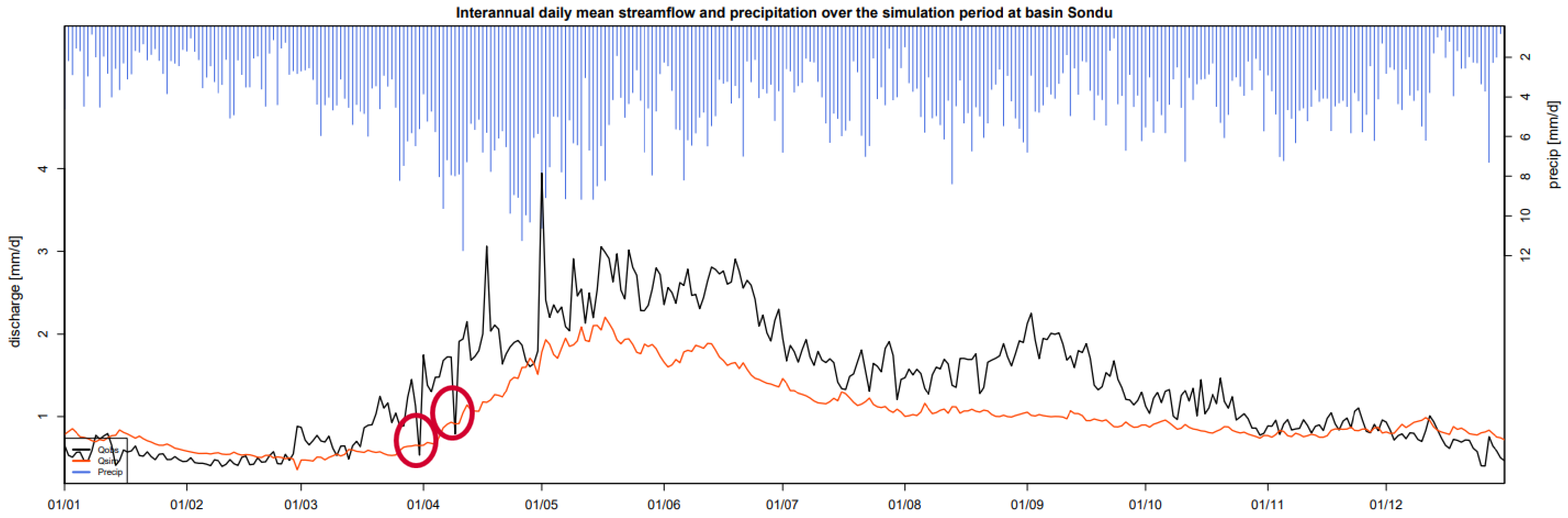
Reanalysis vary in **quality** and are used as substitutes to observations in data scarce regions:-

- Ground validation is key but very challenging, in sparse rainfall gauge networks regions



Background

- Validation process uses ground proxies which fail to capture the real-time evolution and magnitude of events (e.g., floods and droughts)



Background

- Thus, the need to assess the impact on the river discharge on a catchment-by-catchment basis due to the stark differences between the river basins

- **Objective:** To assess different **reanalysis datasets** and identify which are the most suitable in **simulating streamflow** when coupling both the **performance statistics** and **sensitivity analysis**

Research Questions

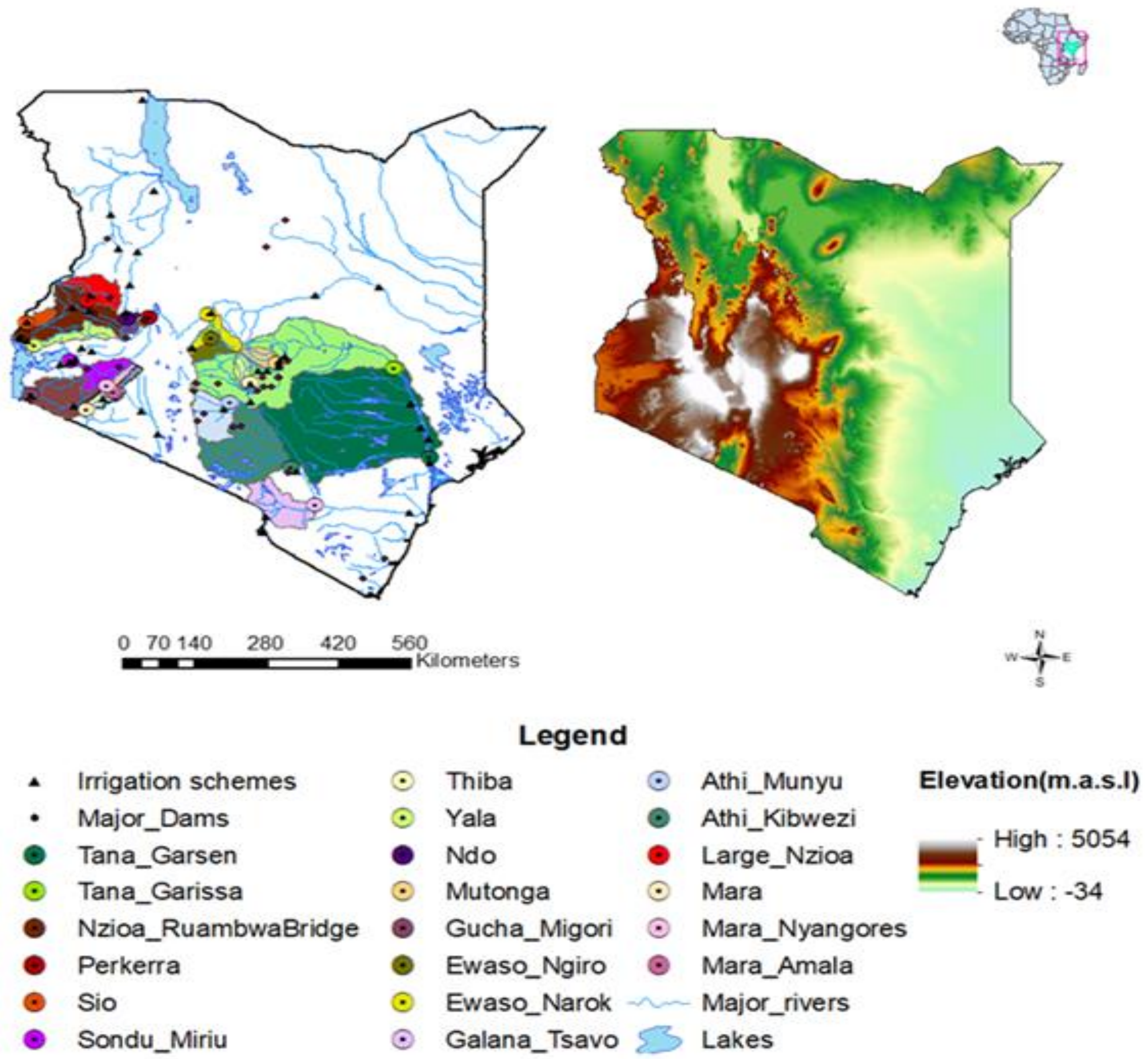
- How well do the precipitation datasets compare in terms of temporal dynamics at the basin scale? Which product is the most accurate compared to observations?

- How well do precipitation datasets compare in terms of spatial patterns? Which product shows consistency in spatial heterogeneity compared to observations?

- How does the general hydrological model performance vary with different datasets?

- How does the sensitivity of a rainfall runoff model (GR4J) vary with alternative rainfall forcing?

Study Area



Study catchments, with the location of the outlet river gages used in this study and the main irrigation schemes and major dams across Kenya (left) and topography of Kenya (right)

- Kenya lies astride of the equator at longitude 34°E–42°E and Latitude 5°S–5°N and along the quasi-meridional western edge of the Indian Ocean at the eastern side of Africa

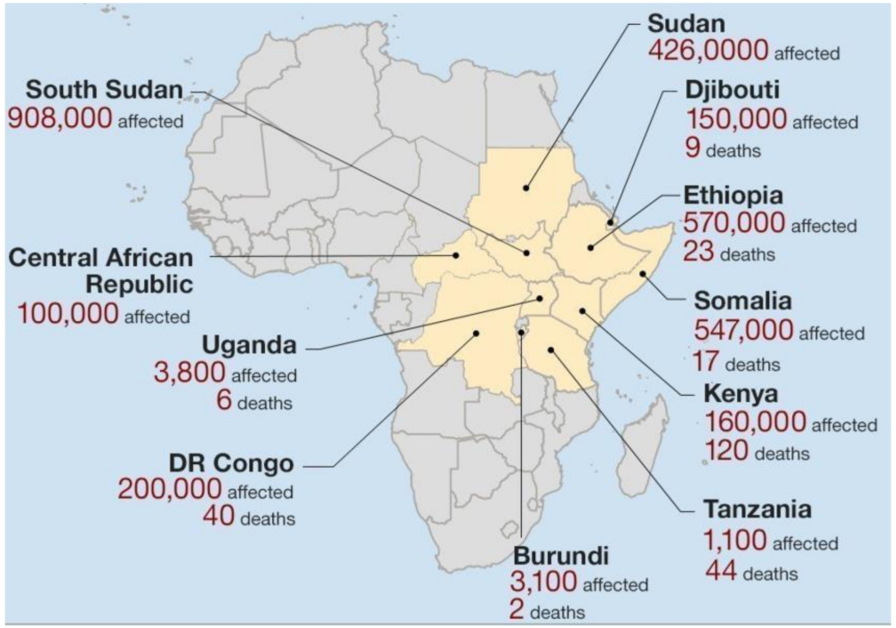
- The study is undertaken in **19 Kenyan catchments** with good and satisfactory streamflow data records

Why Kenya in Particular

- Flood occurs annually during the rainy seasons (March-May “**long rains**” and Oct-Dec “**short rains**”)

- Flooding in EA is remarkable in terms of **duration, scale, and severity**. By late **May, the 2021** floods had killed more people than COVID-19.

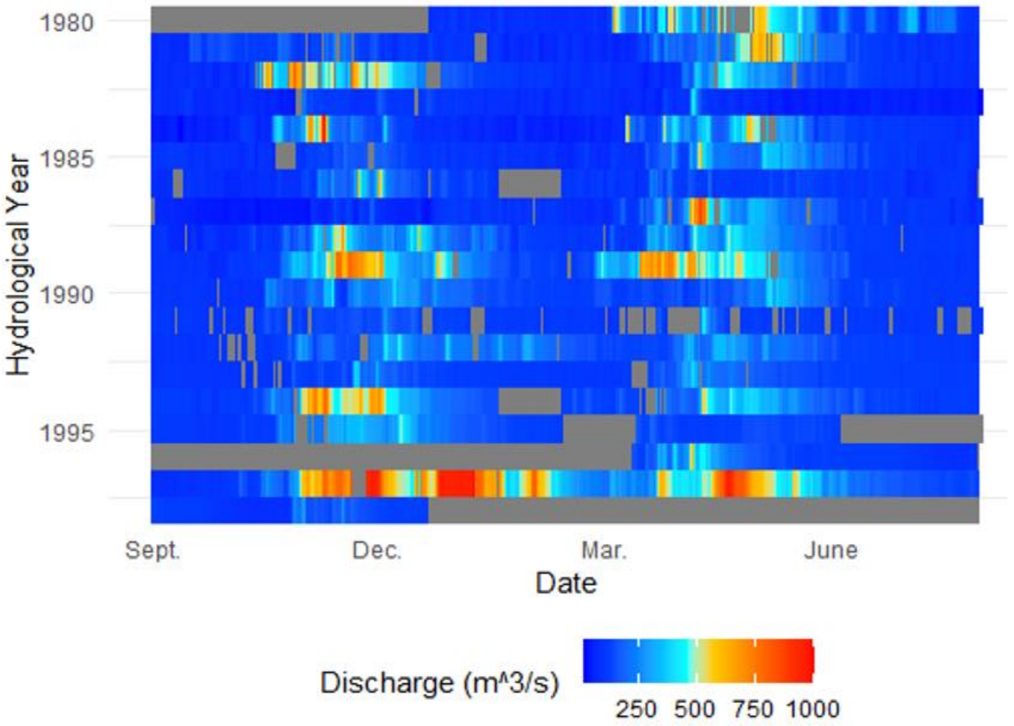
https://medium.com/@icpac/recurring-floods-in-eastern-africa-amidst-projections-of-frequent-and-extreme-climatic-events-for-30d20d0d6f76



Source: OCHA

Flood Risk in Kenya

- Kenya is among the highest climate risk countries in the world (Global Climate Risk Index, 2019)
- The common climate and weather extremes are particularly droughts and floods (Eckstein et al., 2019)
- Major flood events occur roughly every two years on average (Emergency Events Database (EM-DAT)
- The typical population of people affected per event is approximated to be 70,000 (Parry et al., 2012)
- Between 1964 - 2019, Kenya recorded 18 major flood events, with 1961, 1997–1998, 2002, 2003, 2006,2010, 2012, and 2018 recording particularly high impact flood events, and declared national disasters



- High discharge occur during the wet seasons
- There is a large annual variation in river discharges

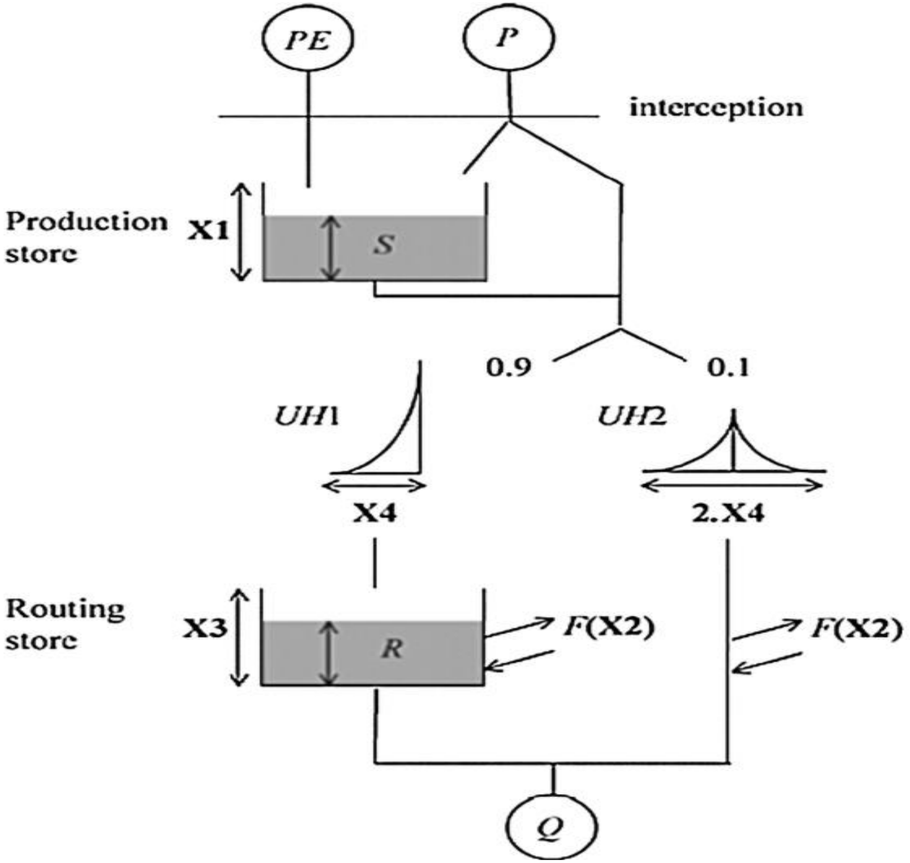
Data and Methods

- Reanalysis datasets (ERA 5, ERA-Interim, NCEP/NCAR-CFSR, and JRA-55), and CHIRPS, as well as observed river discharge data for the period 1981-2016

- Using a lumped bucket-style hydrological model (**GR4J**, Perrin et al. 2003), we assess the **model performance** via the **KGE criterion and parameter uncertainty** via Sobol's Sensitivity Analysis

- Performance metrics: Correlation Coeffient (CC), Root Mean Square Error (RMSE),BIAS, Kling Gupta Efficiency (KGE), Sobol Total Sensitivity Index(TSI), Model Suitability Index(MSI) were computed from the calibration and validation using GR4J model

GR4J Hydrological Model



- **GR4J**: daily continuous lumped, conceptual model based on neutralisation for interception, a soil moisture accounting (SMA) store (production), an excess rainfall and routing store & unit hydrographs (Perrin et al., 2003).

- 4 parameters to calibrate: maximum capacity of the production store (X1, mm), groundwater exchange coefficient (X2, mm/day), maximum capacity of the non-linear routing store (X3, mm); and time base of the unit hydrograph (X4, days)

GR4J Parameters

Parameter	Description	Typical Value
X1	Capacity of the production store (mm)	**(0, 1000)**
X2	Groundwater exchange coefficient(mm)	**(-5, 5)**
X3	Capacity of the nonlinear routing store (mm)	**(0, 300)**
X4	Unit hydrograph time base (day)	(0.5, 5)

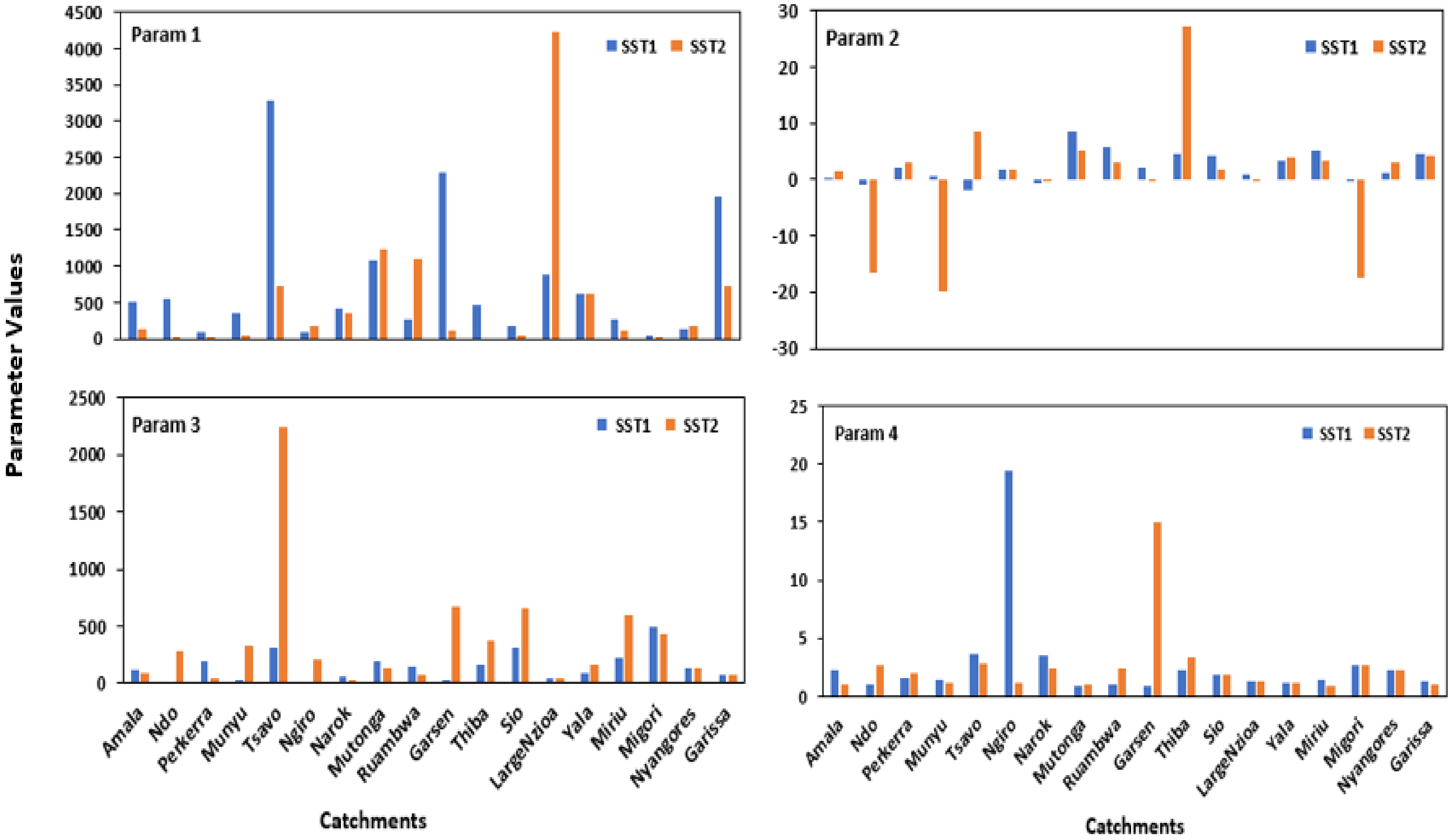
GR4J Calibration Strategy

- GR4J conceptual rainfall-runoff model was calibrated to determine appropriate parameter values
- Parameters were calibrated to the Kling-Gupta Efficiency (KGE)((Gupta et al, 2009)) objective function
- 36 years of streamflow data for the catchments were used
- Split-sample validation testing (Klemes, 1986) was used to test model skill beyond the calibration period.

Split Sample Test (SST)

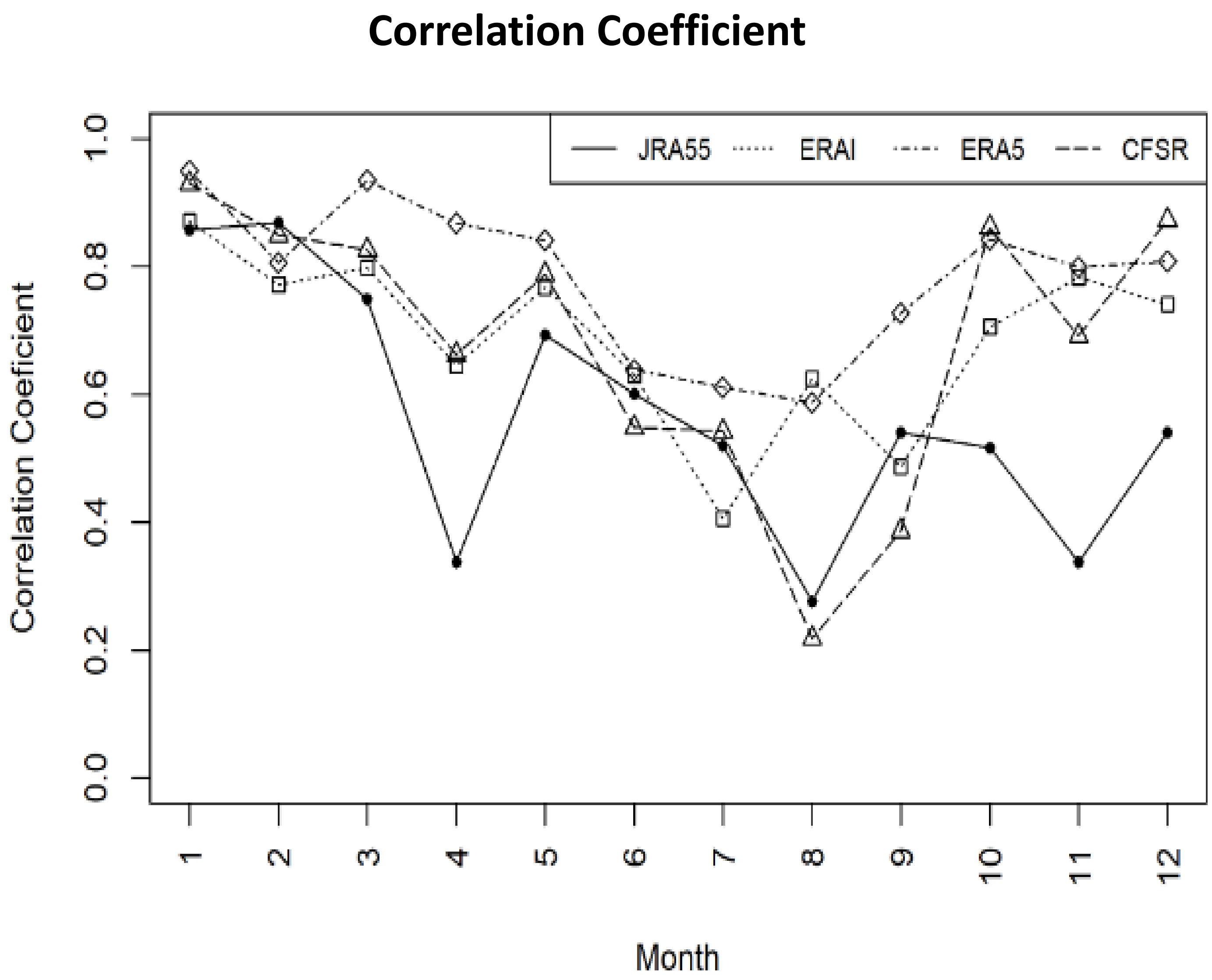
Y1 to Y4 (1981-1983) **Model spin up**	**Y5 to Y15 (1984 – 1999)** **SST1**	**Y16 to Y36 (2001 – 2016)** **SST2**

GR4J Calibrated Parameters



Parameter	Description	Typical Value
X1	Capacity of the production store (mm)	(0, 1000)
X2	Groundwater exchange coefficient (mm/day)	(-5, 5)
X3	Capacity of the nonlinear routing store (mm)	(0, 300)
X4	Unit hydrograph time base (day)	(0.5, 5)

Performance Statistics

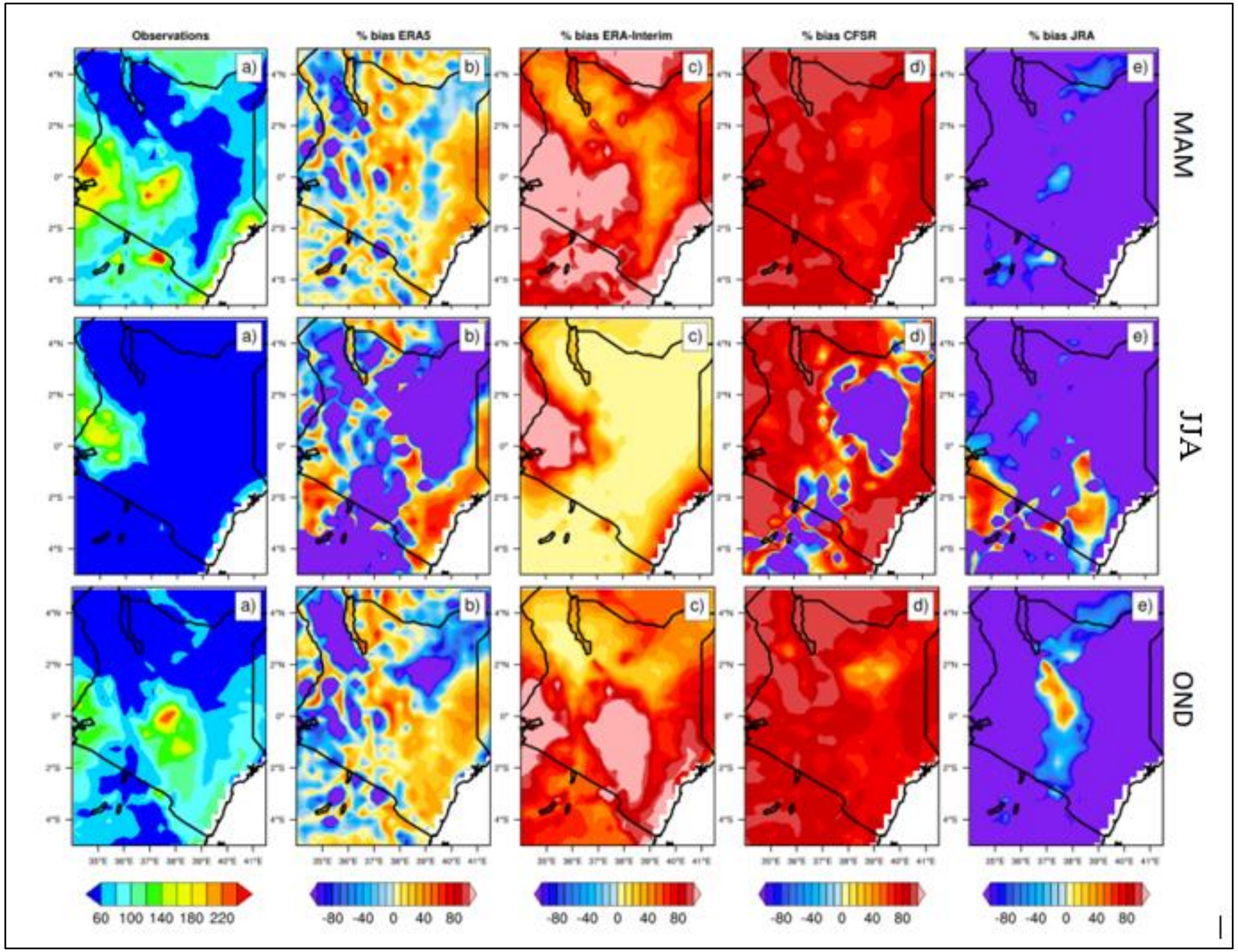


- ERA5 has higher correlation coefficients (0.88) than JRA55, ERAI & CFSR in comparison to observations on monthly timesteps

- Same performance is observed on the seasonal scale (not shown)

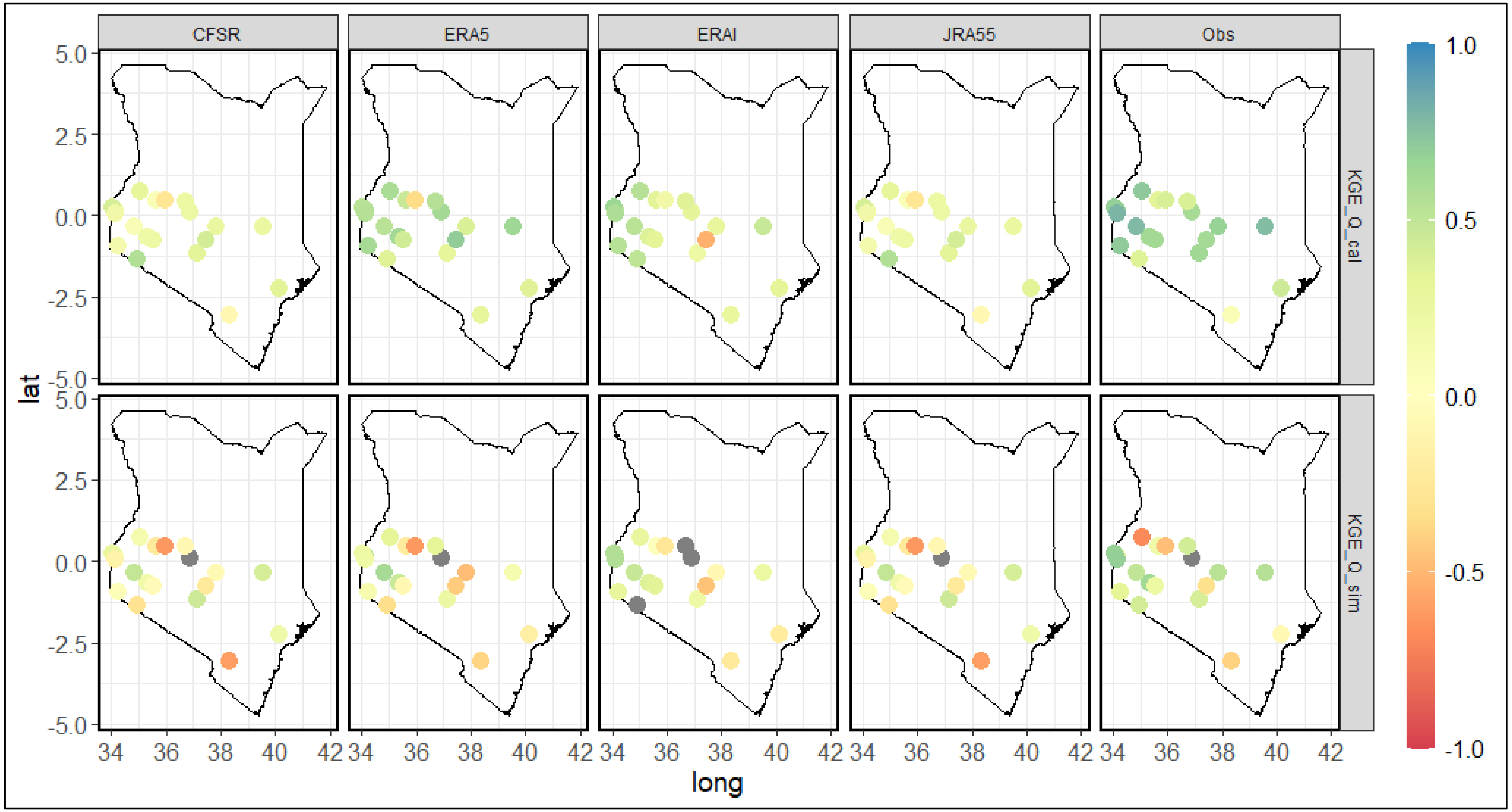
Performance Statistics

Wet extreme rainy days



Seasonal observed precipitation (mm) and mean bias (%) of the extreme rainy days at 95th percentile in the four reanalysis products for 1981–2016 period

- The observed extreme precipitation varies between 60mm and 240mm across western, central highlands and coastal catchments for the rainy seasons (MAM and OND), whereas in the dry season (JJA) varied between 100mm and 160mm across the western catchments only, and less than 60mm in other regions.
- CFSR and ERAI show a positive bias for extreme precipitation across most parts of the country in all the three seasons, whereas JRA55 has an enhanced negative bias in most parts of the country.
- ERA5 has a positive bias in MAM and OND in most parts of the country with some patches of negative bias in the western and central highlands catchments.
- ERA5 outperforms other reanalysis products as it captures the wet extremes over the regions in which observations show enhanced precipitation in the respective seasons.



Source:- Wanzala et al., 2022

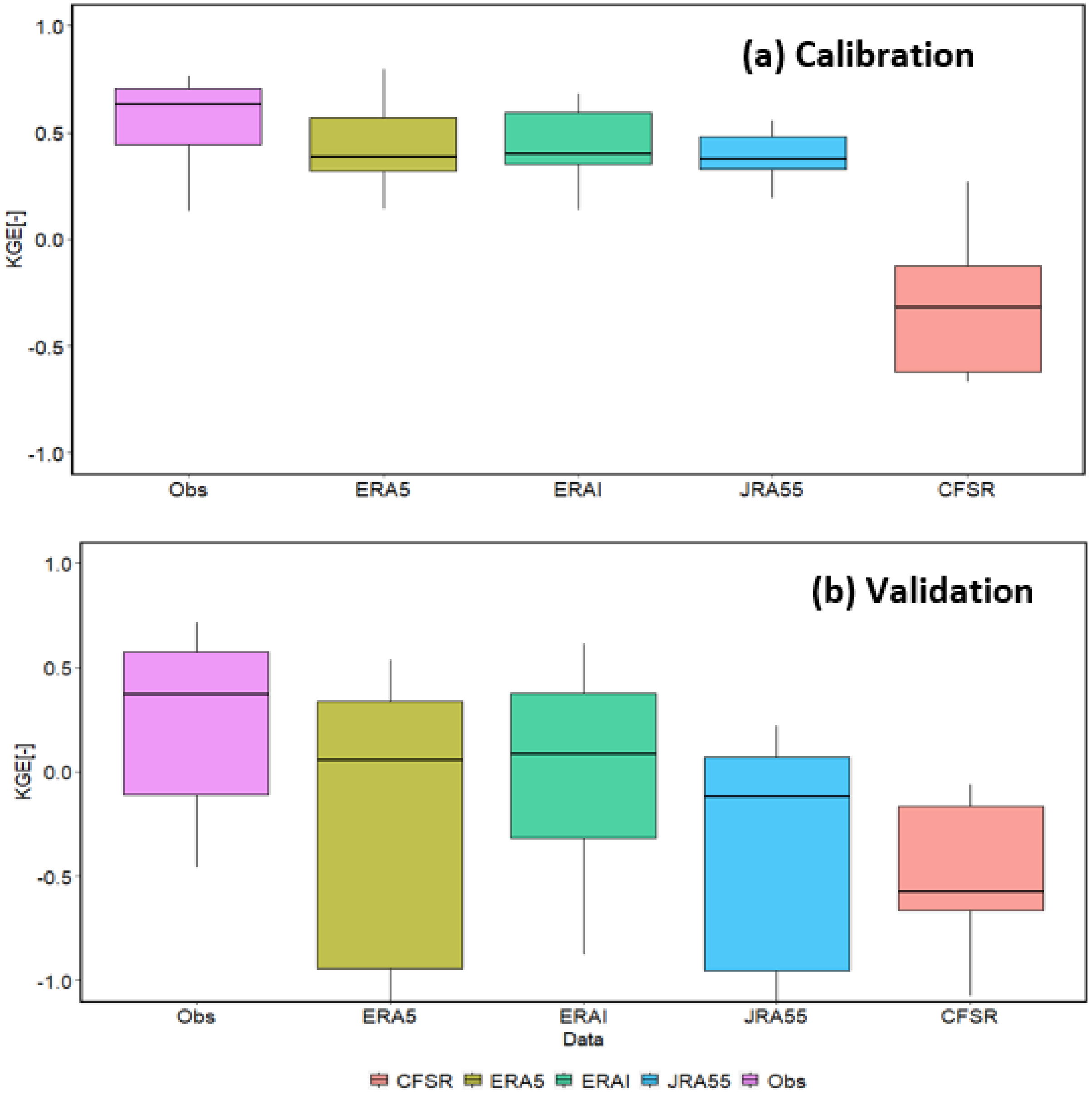
Model Calibration Results

Kling Gupta Efficiency (KGE)

The KGE in calibration (top panel) and validation (bottom panel) scores obtained using different datasets

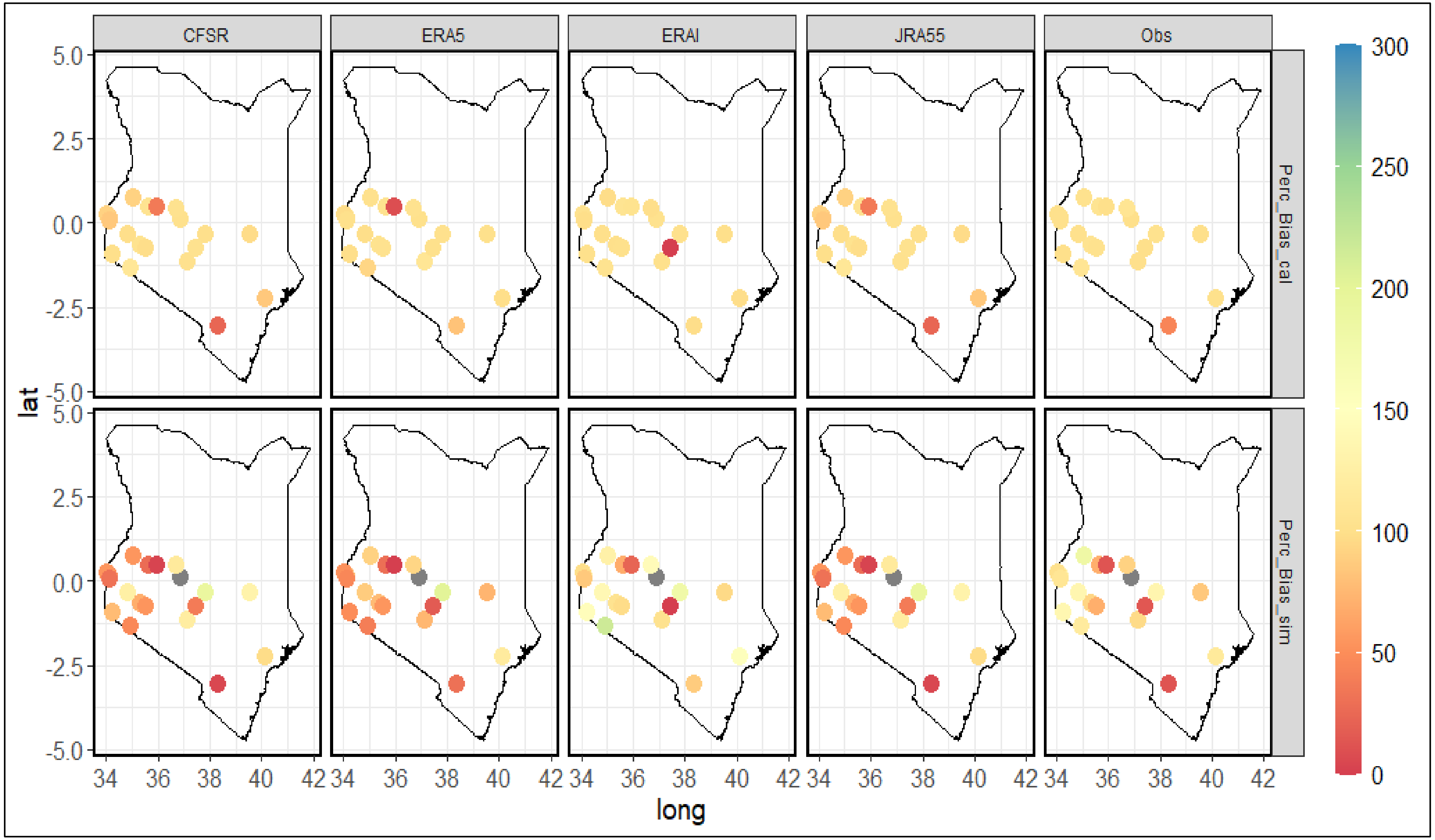
- Wetland catchments in the western and highlands of Kenya obtained relatively better calibration scores than those in the semi-arid regions.
- For each of the catchments, ERA5 showed better calibrated KGE scores compared to observations, while CFSR and JRA55 obtained poorer KGE scores.
- Caution- Strong influence by human activities and uncertainty in the input data.

Model Calibration and Validation



Kling Gupta Efficiency (KGE)

- ERA5, ERAI, & JRA55 obtained better KGE scores whereas CFSR had lower scores in both calibration and validation
- The 3 best performing datasets give similar scores to observations in calibration, but more variable and less robust results in validation (especially ERA5 and JRA55)



Source:- Wanzala et al., 2022

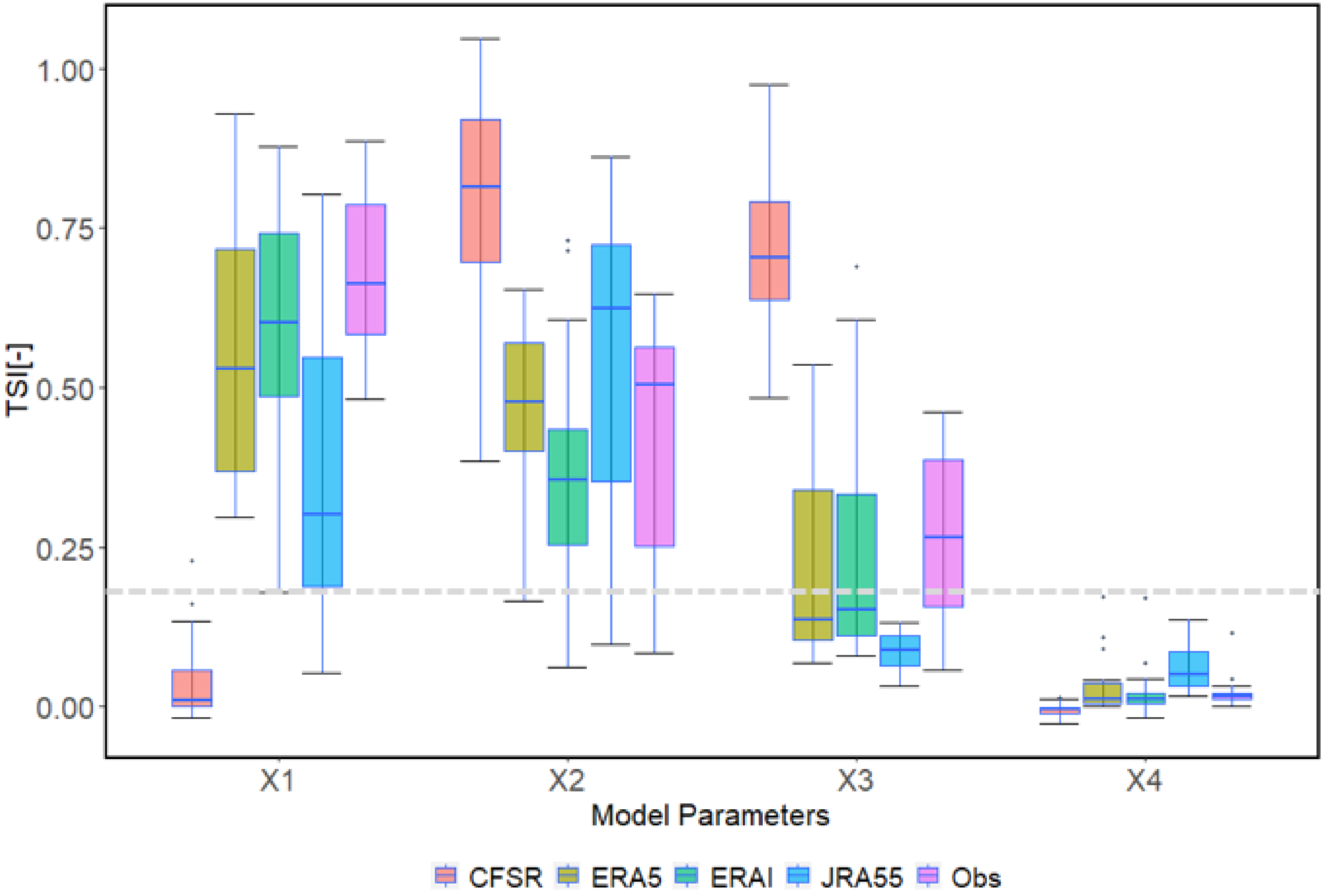
Percentage Bias

- The bias in all the four reanalysis is higher in calibration, whereas in validation most catchments exhibit lower biases, except for Perkerra.

The percentage KGE - Bias in calibration (top panel) and validation (bottom panel) scores obtained using different datasets

Sensitivity Analysis

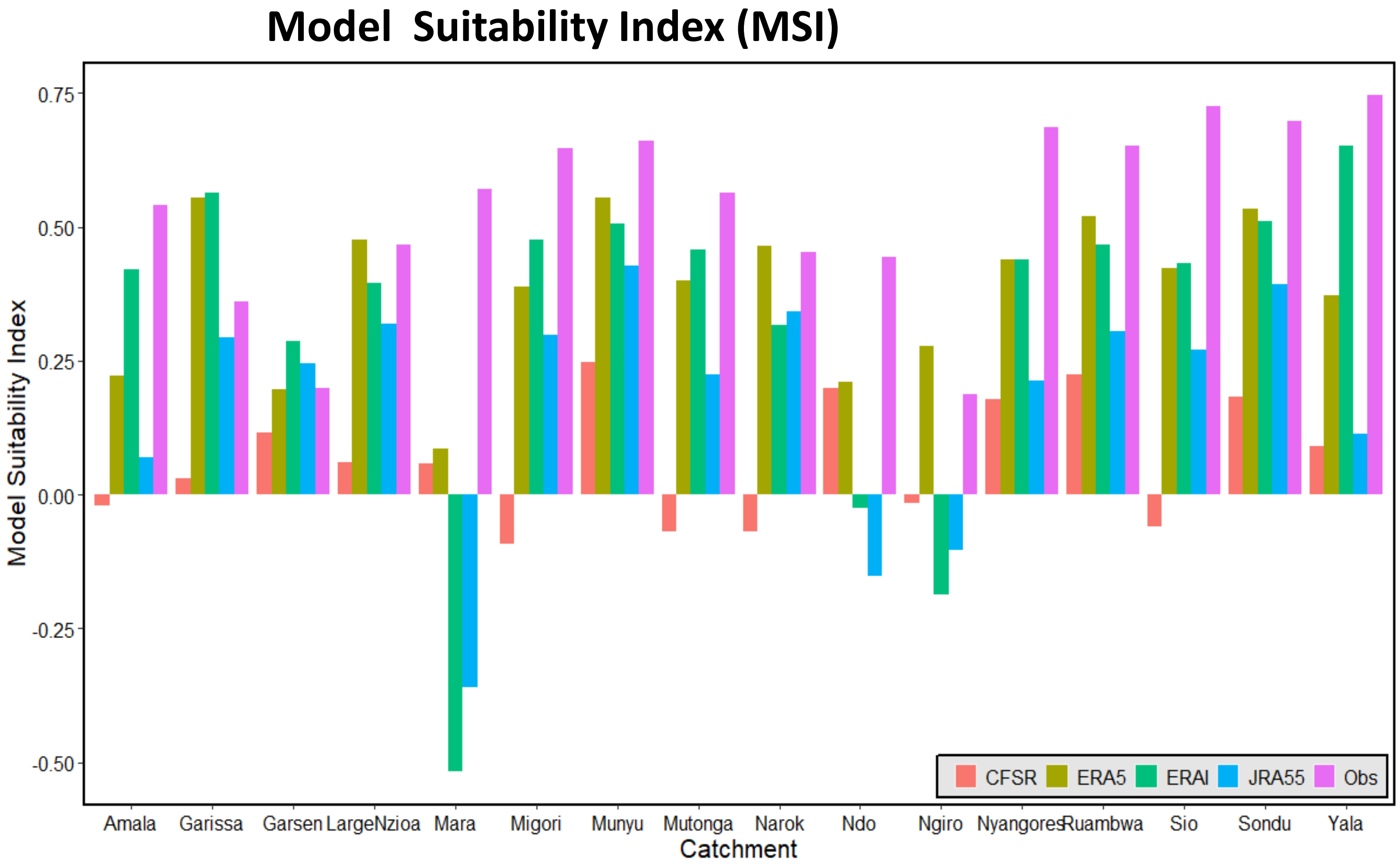
Total Sensitivity Index (TSI)



- In all datasets, the production store capacity (X1) has the highest total effects (Total Sensitivity Index) whereas the time base of the unit hydrograph (X4) is the least influential parameter

- ERA5 show similar sensitivity of each of the model parameters compared to observations, whereas CFSR has highest **uncertainty**

Model Suitability Index



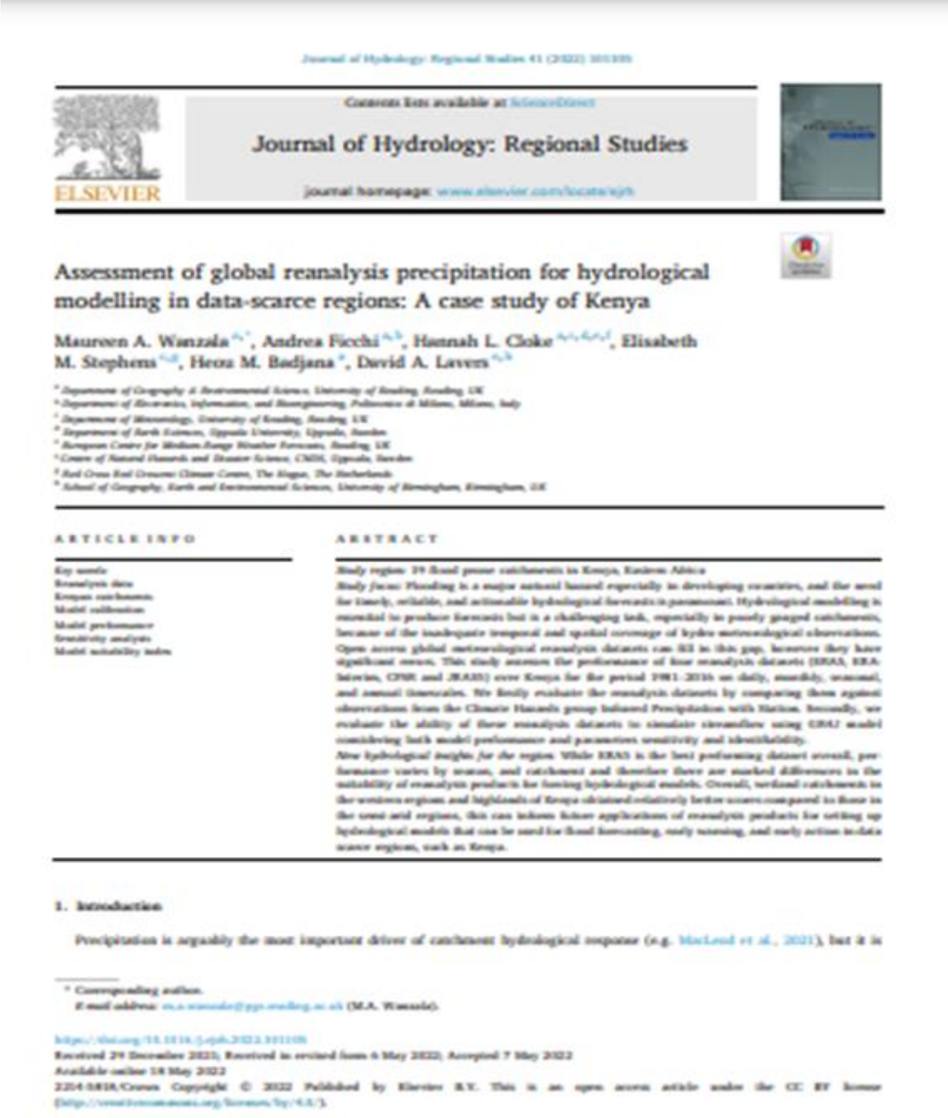
Bar chart comparing model suitability in terms of performance and parameter sensitivity across different reanalysis in the 19 catchments.

- MSI considers both sensitivity indices and performance statistics, on average, ERA5, ERAI & JRA have better scores across most of the catchments
- **MSI** has the strength of ease and clearness to judge the **superiority and inferiority** of the reanalysis when compared to observations at catchment scale

- The ERA5 has the highest MSI compared to observations across the nineteen catchments, followed by the ERAI reanalysis.
- Overall, the four reanalysis datasets obtained relatively lower MSI values particularly in catchments that are mainly in arid and semi-arid areas of Kenya.

Key Take Aways

- **Hydrological model performance**: ERA5, ERAI, & JRA55 obtained better KGE scores whereas CFSR had lower scores in both calibration and validation
- The 3 best performing datasets give similar scores to observations in calibration, but more variable and less robust results in validation (especially ERA5 and JRA55)
- **Sensitivity analysis**: ERA5 show similar Sobol's **sensitivity indices** for all model parameters compared to observations, whereas CFSR has highest **uncertainty**
- The MSI aggregates both **sensitivity indices & performance statistics**, providing a clear index to judge the **superiority** (or inferiority) of a reanalysis with respect to observations
- On average ERA5, ERAI (& JRA55) have better MSI scores across most of the Kenyan catchments: ERAI & ERA5 perform better than JRA55 & CFSR, and lead to more robust model parameters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ABSTRACT

1. Introduction

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THANK YOU FOR YOUR ATTENTION

Happy to take Your Questions & Comments

Email: maureen.wanzala@welthungerhilfe.de

or

manyango03@gmail.com

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