Nile and GERD Conference

Advances in Water Resources Assessment and Optimal Management of Multipurpose Cascade Reservoirs in the Nile River Basin

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Contents

1. The Nile River Basin

- ✓ The Nile River Basin includes portions of 11 countries:

  Ethiopia, Eritrea, Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania, Uganda, South Sudan, Sudan, and Egypt.

- ✓ Area coverage: 3.18×10^6 km^2

- ✓ The average monthly flow of the White Nile ranging from 580 to 1,270 m^3/s at Malakal in South Sudan. 15% of the annual Nile discharge. Fairly stable flow throughout the year

- ✓ The average monthly flow of the Blue Nile ranging from 150 to 5,600 m^3/s at the Soba gauging station in Khartoum. 85% of the annual Nile discharge. Highly seasonal.

Water resources development in the Nile River Basin

- ✓ The Low Aswan Dam (1902) in Egypt across the main Nile
- ✓ The Sennar Dam (1925) and Jebel Aulia Dam (1937) in Sudan across the Blue Nile and White Nile, respectively.

- ✓ A 1959 agreement between Egypt and Sudan initiated the construction of the Roseries Dam (1966) and Khashm El Girba Dam (1964) in Sudan.
- ✓ The High Aswan Dam (1970) in Egypt.

- ✓ Sudan’s modern expansion: The Merowe Dam (2009), the Upper Atbara and Setit Dam complex (2016), and the heightening of the Roseries Dam (2013).

- ✓ Ethiopia’s major project: The Finchaa (1973, expanded in 2012), Tekeze Dam (2009), and the Tana-Beles hydropower project (2010).

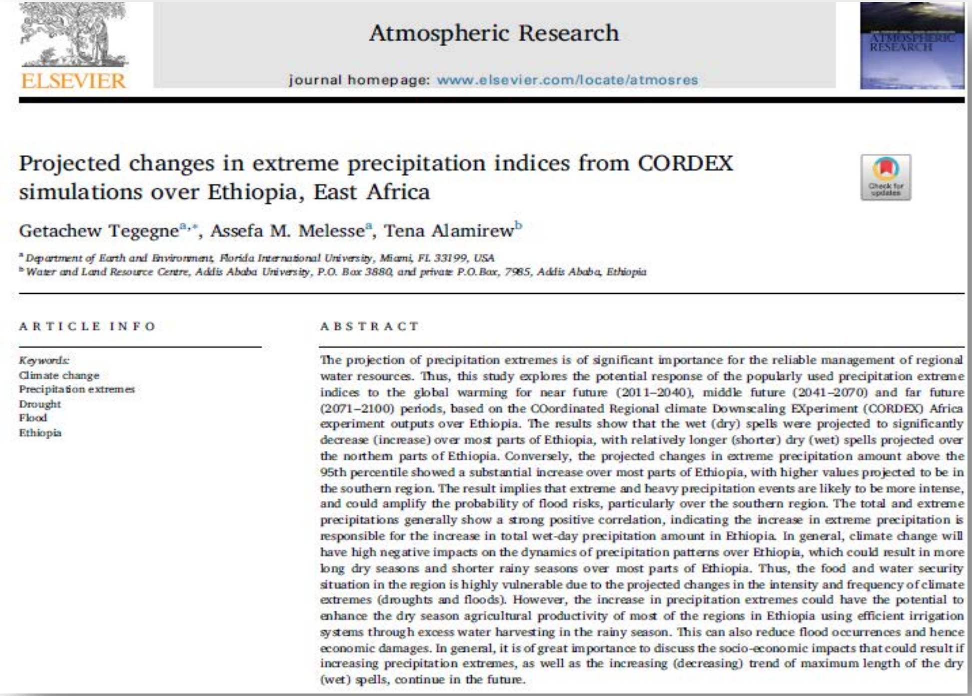
Motivation: why is the water demand growing in the Nile basin?

✓ This is due to climate change and population growth

Temperature → evaporation → water scarcity

- The climate projection over Ethiopia showed that the wet (dry) spells are projected to significantly decrease (increase).

- However, the climate projection also showed the increase in extreme precipitation amount above the 95th percentile, which may cause floods in Sudan and Egypt.



ELSEVIER

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Projected changes in extreme precipitation indices from CORDEX simulations over Ethiopia, East Africa

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ARTICLE INFO

Keywords:
Climate change
Precipitation extremes
Drought
Flood
Ethiopia

ABSTRACT

The projection of precipitation extremes is of significant importance for the reliable management of regional water resources. Thus, this study explores the potential response of the popularly used precipitation extreme indices to the global warming for near future (2011–2040), middle future (2041–2070) and far future (2071–2100) periods, based on the COordinated Regional climate Downscaling EXperiment (CORDEX) Africa experiment outputs over Ethiopia. The results show that the wet (dry) spells were projected to significantly decrease (increase) over most parts of Ethiopia, with relatively longer (shorter) dry (wet) spells projected over the northern parts of Ethiopia. Conversely, the projected changes in extreme precipitation amount above the 95th percentile showed a substantial increase over most parts of Ethiopia, with higher values projected to be in the southern region. The result implies that extreme and heavy precipitation events are likely to be more intense, and could amplify the probability of flood risks, particularly over the southern region. The total and extreme precipitations generally show a strong positive correlation, indicating the increase in extreme precipitation is responsible for the increase in total wet-day precipitation amount in Ethiopia. In general, climate change will have high negative impacts on the dynamics of precipitation patterns over Ethiopia, which could result in more long dry seasons and shorter rainy seasons over most parts of Ethiopia. Thus, the food and water security situation in the region is highly vulnerable due to the projected changes in the intensity and frequency of climate extremes (droughts and floods). However, the increase in precipitation extremes could have the potential to enhance the dry season agricultural productivity of most of the regions in Ethiopia using efficient irrigation systems through excess water harvesting in the rainy season. This can also reduce flood occurrences and hence economic damages. In general, it is of great importance to discuss the socio-economic impacts that could result if increasing precipitation extremes, as well as the increasing (decreasing) trend of maximum length of the dry (wet) spells, continue in the future.

Nile Basin needs more water infrastructures!!!

2. Statement of the problem

- Lack of sufficient water storage
- Poor water use efficiencies in agriculture
- Insufficient knowledge on the hydrology of the Nile system
- Lack of cooperation for mutually beneficial mechanisms

Climate change - I

Temperature increases *evaporation increases water scarcity*

Climate change - II

15% increase in flow amount – ***50% increase in flow variability***

Impact

Increasing the risk of flooding and droughts

Problem

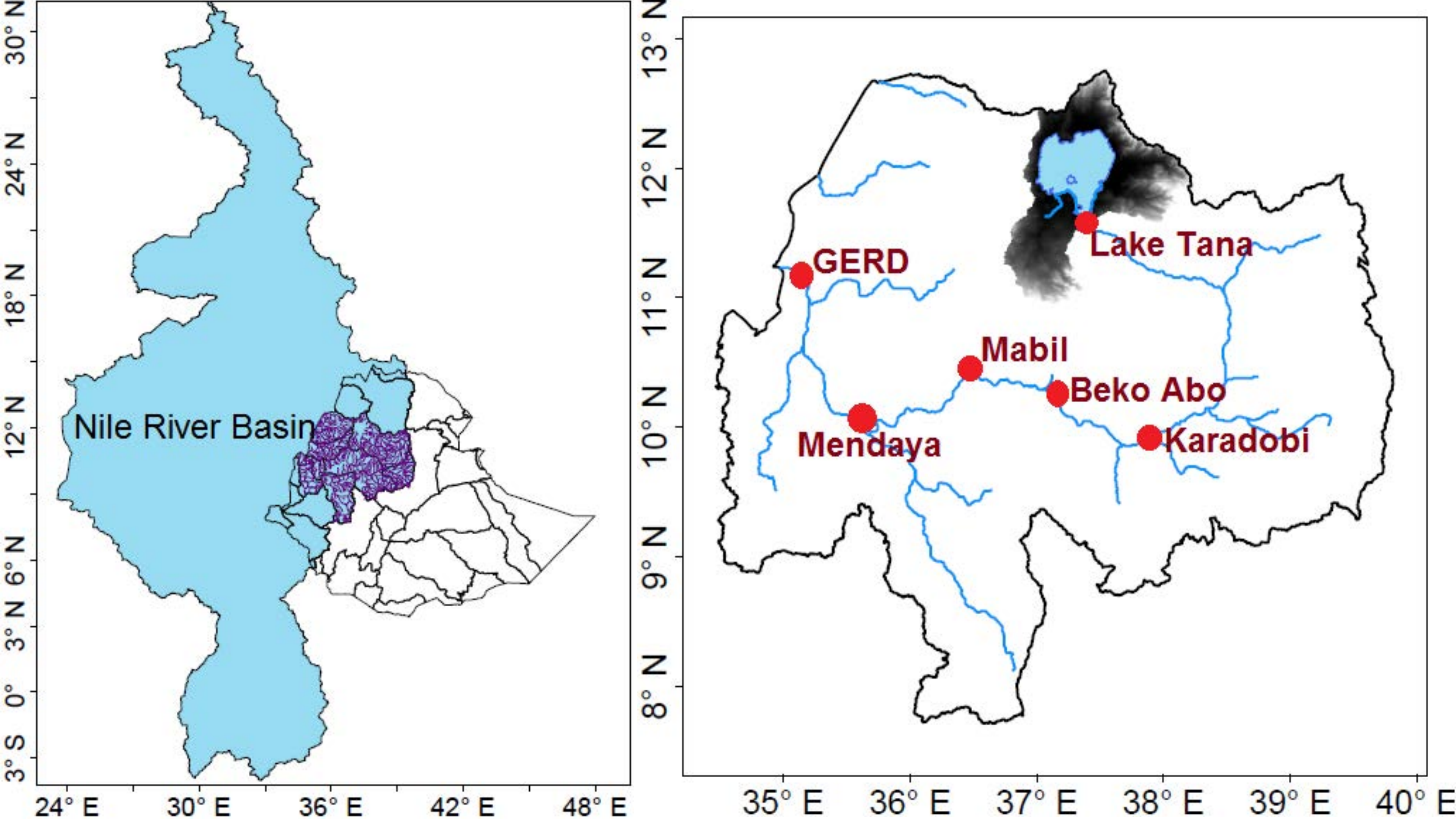
The inter-annual flow variability reduces reliability of maintaining flows

Solution

Implement additional storage reservoir

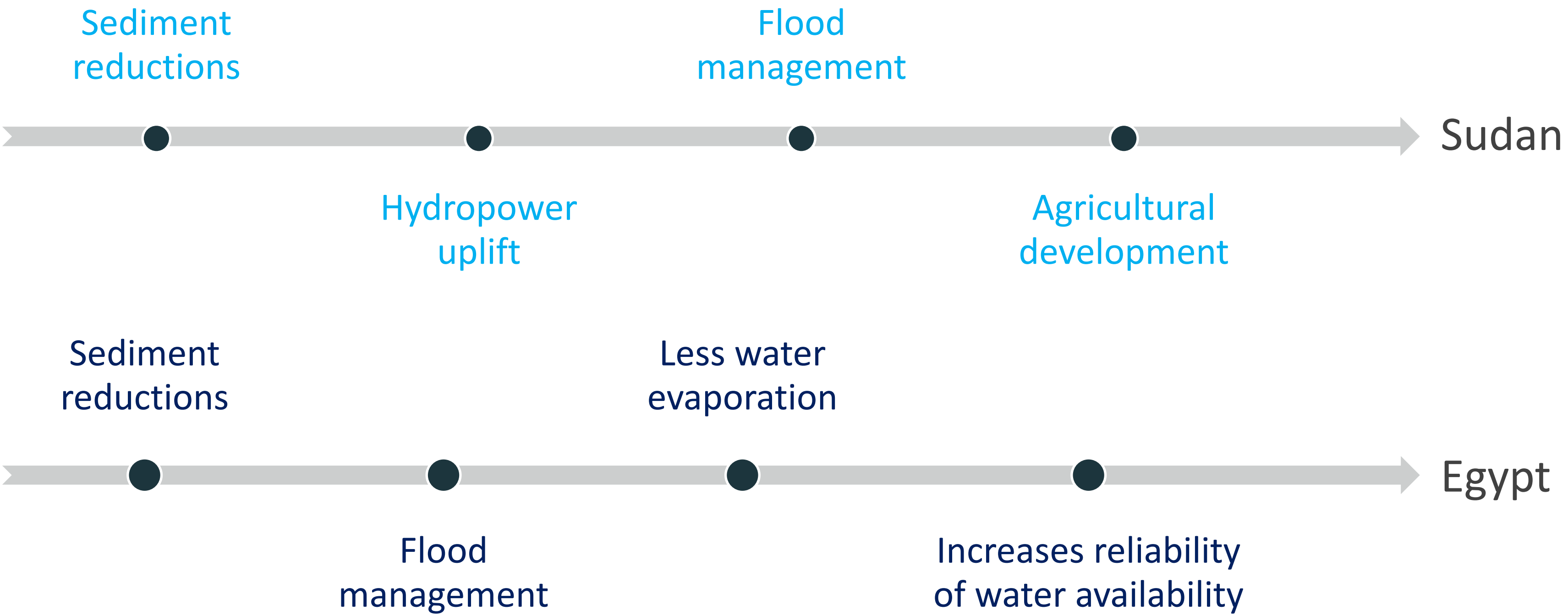
How much?

55% additional storage capacity to achieve existing levels of reliability



Nile River Basin
GERD
Lake Tana
Mabil
Beko Abo
Mendaya
Karadobi
30° N
24° N
18° N
12° N
6° N
3° N
0°
3° S
24° E
30° E
36° E
42° E
48° E
13° N
12° N
11° N
10° N
9° N
8° N
35° E
36° E
37° E
38° E
39° E
40° E

- The water resources development in Ethiopia would likely to provide a wide-range of benefits for Sudan and Egypt. For example, the ***Grand Ethiopian Renaissance Dam (GERD)*** is likely to provide:



Sustainable water resources management of the Nile river

Establish Nile Basin wide cooperative framework agreement

↓

The water resources assessment and management approach need to be reviewed and updated on a regular basis

↓

Assess the outcomes for various users in the region under a range of different development, allocation, and hydrological scenarios

↓

The multi-objective evolutionary and/or direct policy search algorithms need to be considered to search solutions along the Pareto frontier with an aim to satisfy various actors in the region

3. Water resources assessment from both the gauged and ungauged basins

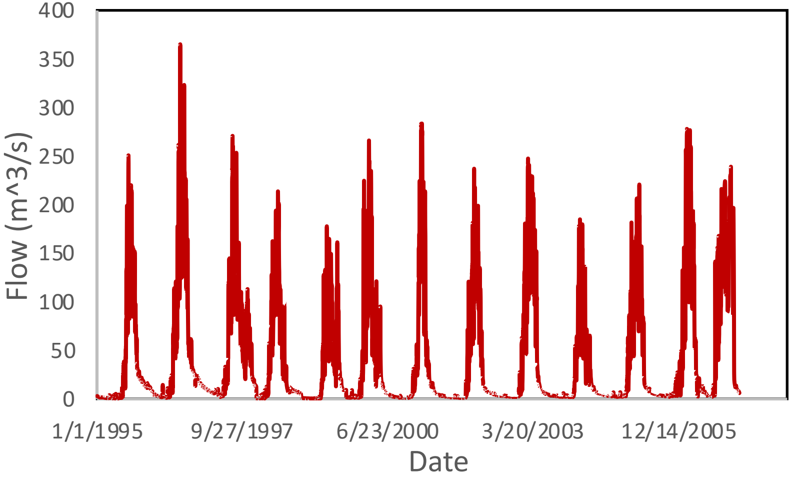
3.1 Hydrologic model parameterization in the gauged basins

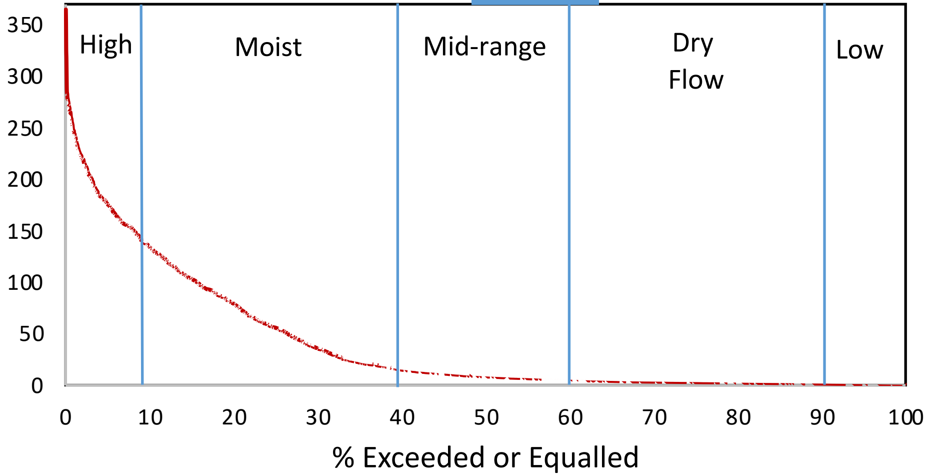
k-fold cross-validation: k = 4 folds,
9 yrs = calibration and 3 yrs = validation

Fold-I	Fold-II	Fold-III	Fold-IV
2001	2001	2001	2001
2002	2002	2002	2002
2003	2003	2003	2003
2004	2004	2004	2004
2005	2005	2005	2005
2006	2006	2006	2006
2007	2007	2007	2007
2008	2008	2008	2008
2009	2009	2009	2009
2010	2010	2010	2010
2011	2011	2011	2011
2012	2012	2012	2012

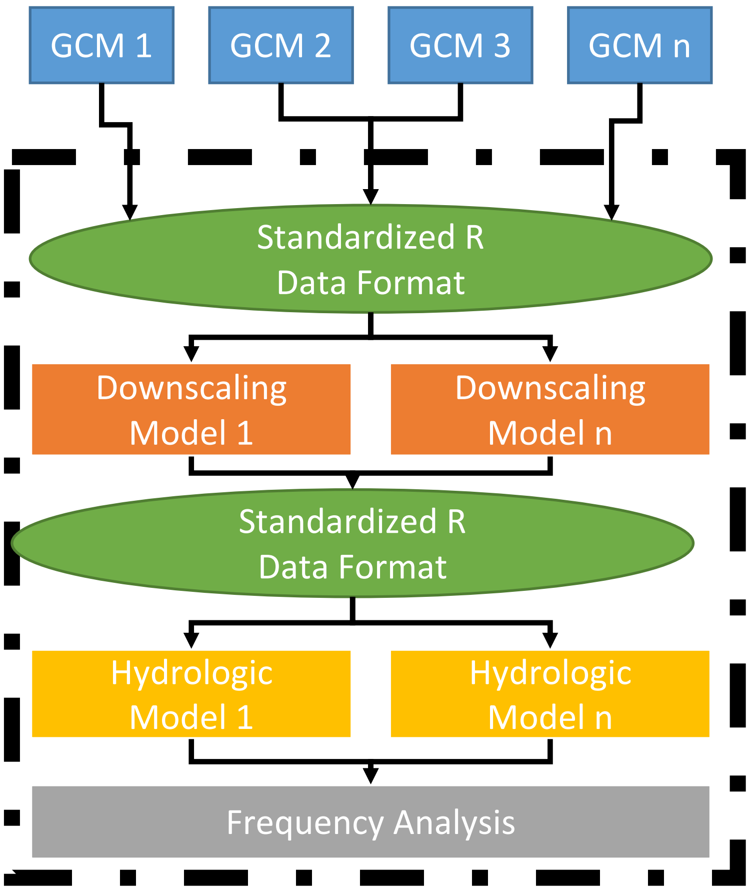
Legend
Calibration
Validation

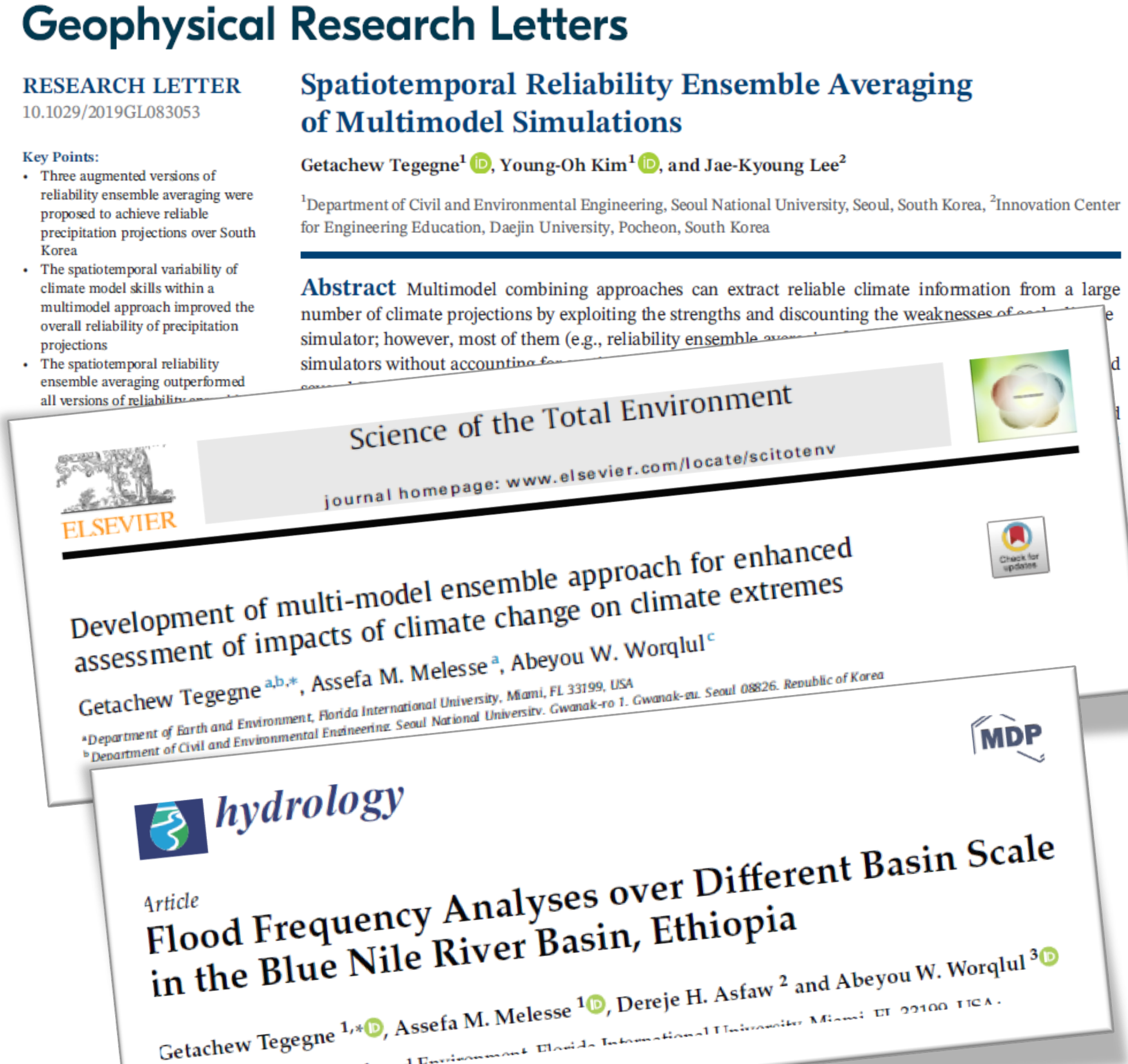
Assessment	Time-domain	Quantile-domain
Hydrology	Real-time operation	Climate Change
Simulation	Process wise	Water Balance
Water System	Management	Planning





Automation of Integrated hydro-climatological models





Geophysical Research Letters

RESEARCH LETTER

10.1029/2019GL083053

Spatiotemporal Reliability Ensemble Averaging of Multimodel Simulations

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Key Points:

- Three augmented versions of reliability ensemble averaging were proposed to achieve reliable precipitation projections over South Korea
- The spatiotemporal variability of climate model skills within a multimodel approach improved the overall reliability of precipitation projections
- The spatiotemporal reliability ensemble averaging outperformed all versions of reliability ...

Abstract Multimodel combining approaches can extract reliable climate information from a large number of climate projections by exploiting the strengths and discounting the weaknesses of each ... simulator; however, most of them (e.g., reliability ensemble ... simulators without accounting for ...

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Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Development of multi-model ensemble approach for enhanced assessment of impacts of climate change on climate extremes

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hydrology

MDPI

Article

Flood Frequency Analyses over Different Basin Scale in the Blue Nile River Basin, Ethiopia

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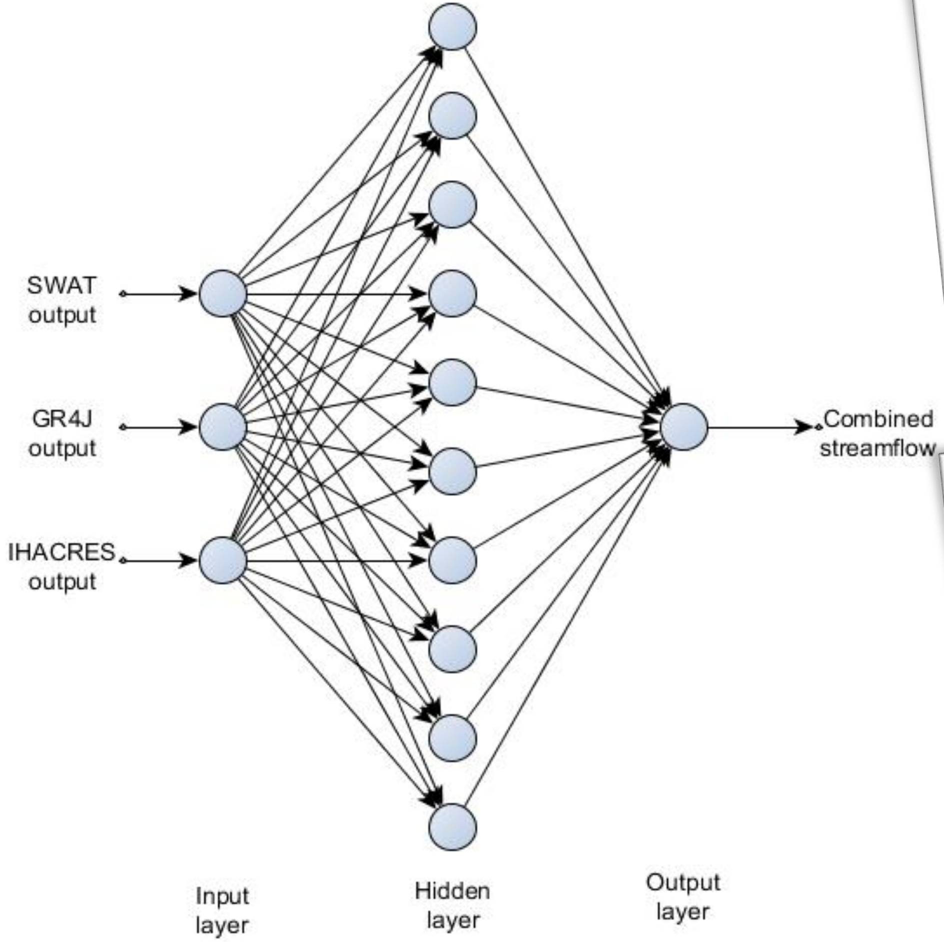
Artificial neural network



ELSEVIER
Journal of Hydrology: Regional Studies
journal homepage: www.elsevier.com/locate/ejrh

Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin

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ARTICLE INFO
Keywords:
Simple conceptual model
Semi-distributed model
Model comparison
Lake Tana Basin

ABSTRACT
Study region: The Lake Tana Basin (15,114 km²) in Ethiopia, which is a source of the Blue N
River Basin.
Study focus: We assessed daily streamflow predictions by applying two simple conceptual mod
and one complex model for four major gauged watersheds of the study area and compared th
model's capabilities in reproducing observed streamflow in the time and quantile domains.

Taylor & Franc
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HYDROLOGICAL SCIENCES JOURNAL
https://doi.org/10.1080/02626667.2019.1587562

Hydrological modelling uncertainty analysis for different flow quantiles: a cas study in two hydro-geographically different watersheds

Getachew Tegegne[a], Young-Oh Kim[a], Seung Beom Seo[b] and Youngil Kim[c]
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ARTICLE HISTORY
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EDITOR

ABSTRACT
This study focuses on analysis of hydrological model parameter uncertainty at varying sub-basin spatial scales. It was found that ... sub-basin spatial scale had little influence on the entire flow simulations ... had a significant impact on the reproduc... spatial scale provided a better cover... However, the finer sub-basin spatial ... closer to the observations. In genera... entire watershed size) in the two test ... and 2–4% for good simulation of hig... while to put more effort into repro... appropriate sub-basin spatial scale

Journal of Hydrology (NZ) 56 (1): xx-xx 2017

Selecting hydrologic modelling approaches for water resource assessment in the Yongdam watershed

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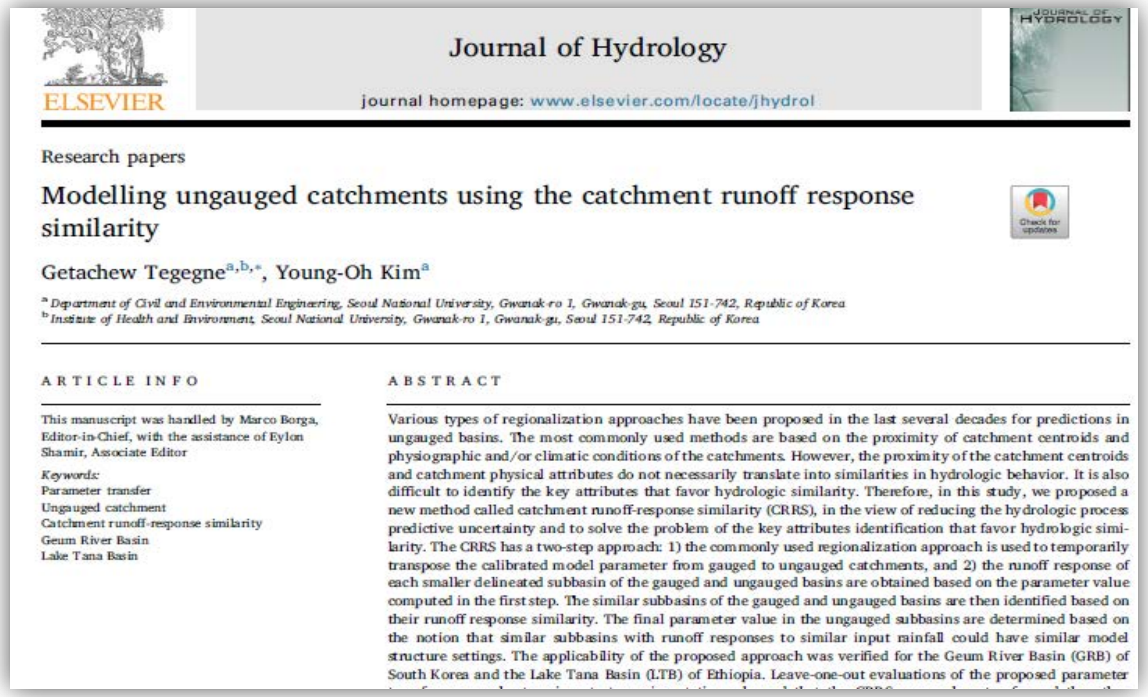
3.2 Water resources assessment in the ungauged basins

- **Ungauged hydrology**
  - Arithmetic mean
  - Physical similarity
  - Spatial proximity
  - **Catchment runoff response similarity**



Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Modelling ungauged catchments using the catchment runoff response similarity

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ARTICLE INFO

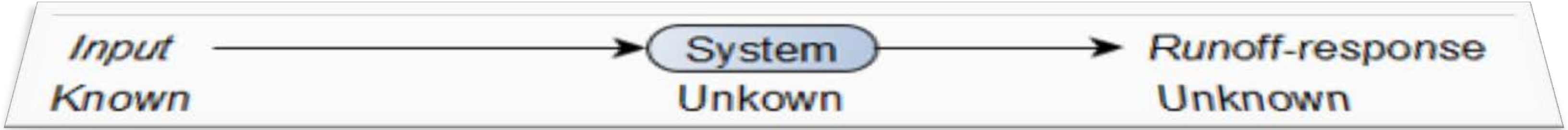
This manuscript was handled by Marco Borga, Editor-in-Chief, with the assistance of Eylon Shamir, Associate Editor

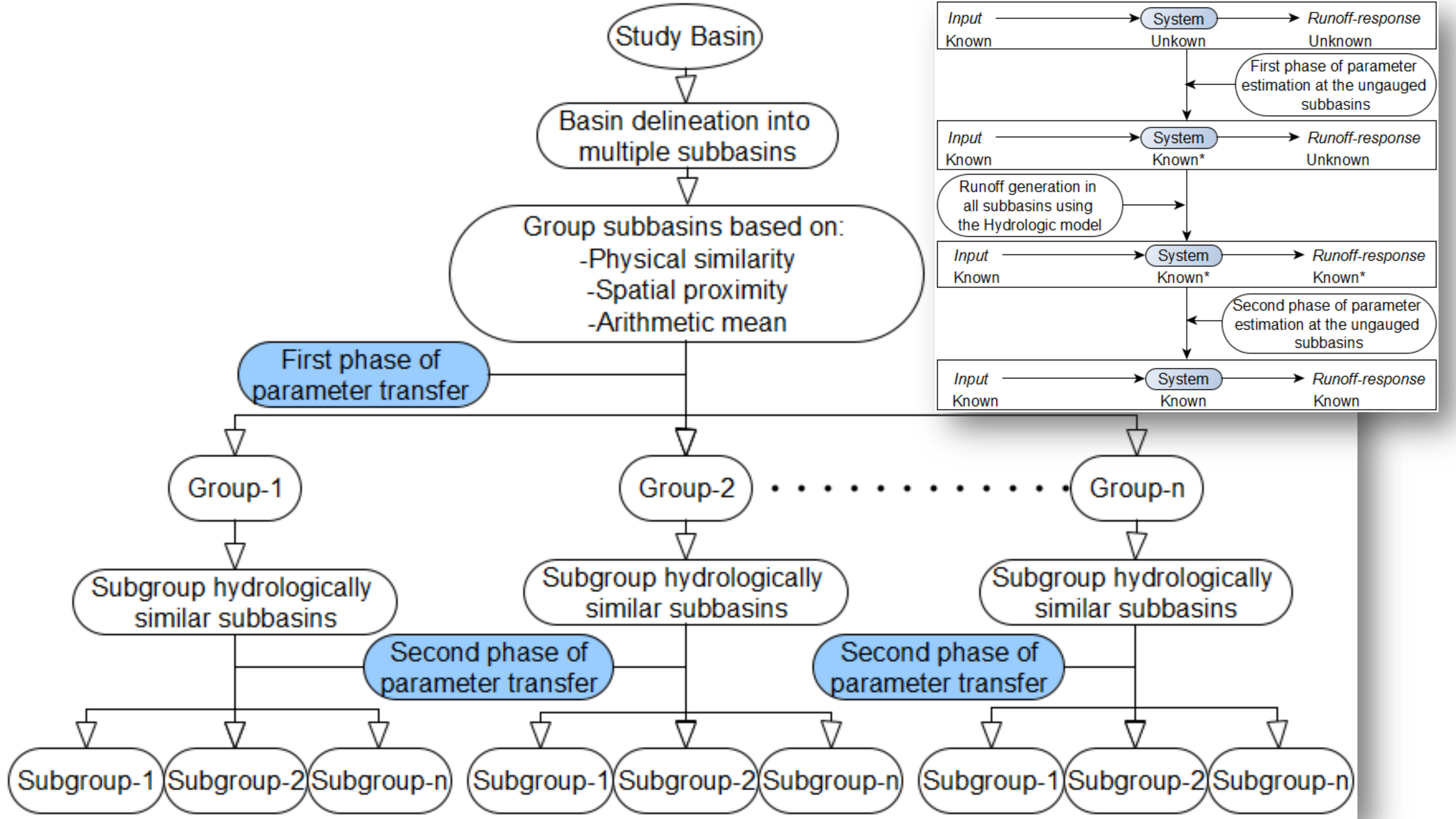
Keywords:
Parameter transfer
Ungauged catchment
Catchment runoff-response similarity
Geum River Basin
Lake Tana Basin

ABSTRACT

Various types of regionalization approaches have been proposed in the last several decades for predictions in ungauged basins. The most commonly used methods are based on the proximity of catchment centroids and physiographic and/or climatic conditions of the catchments. However, the proximity of the catchment centroids and catchment physical attributes do not necessarily translate into similarities in hydrologic behavior. It is also difficult to identify the key attributes that favor hydrologic similarity. Therefore, in this study, we proposed a new method called catchment runoff-response similarity (CRRS), in the view of reducing the hydrologic process predictive uncertainty and to solve the problem of the key attributes identification that favor hydrologic similarity. The CRRS has a two-step approach: 1) the commonly used regionalization approach is used to temporarily transpose the calibrated model parameter from gauged to ungauged catchments, and 2) the runoff response of each smaller delineated subbasin of the gauged and ungauged basins are obtained based on the parameter value computed in the first step. The similar subbasins of the gauged and ungauged basins are then identified based on their runoff response similarity. The final parameter value in the ungauged subbasins are determined based on the notion that similar subbasins with runoff responses to similar input rainfall could have similar model structure settings. The applicability of the proposed approach was verified for the Geum River Basin (GRB) of South Korea and the Lake Tana Basin (LTB) of Ethiopia. Leave-one-out evaluations of the proposed parameter

- **Catchment runoff response similarity (CRRS)**





Study Basin
Basin delineation into multiple subbasins
Group subbasins based on:
-Physical similarity
-Spatial proximity
-Arithmetic mean
First phase of parameter transfer
Group-1
Group-2
Group-n
Subgroup hydrologically similar subbasins
Second phase of parameter transfer
Subgroup-1
Subgroup-2
Subgroup-n
Input
Known
System
Unkown
Runoff-response
Unknown
First phase of parameter estimation at the ungauged subbasins
Known*
Runoff generation in all subbasins using the Hydrologic model
Second phase of parameter estimation at the ungauged subbasins

4. Water resources management: multi-objective reservoir operation

➢ Mathematical formulation of a multi-objective reservoir operation

a. Objective functions

- **Minimize the total squared deviations (TSD) for irrigation annually**

$$TSD = \sum_{n=1}^{n} \left[\sum_{t=1}^{12} (D_{nt} - IR_{nt})^2 \right]$$

- **Maximize annual hydropower production (HP)**

$$HP = \sum_{n=1}^{n} \left[\sum_{t=1}^{12} p(R_{nt} H_{nt}) \right]$$

b. Constraints

- **Storage continuity**

$$S_{n(t+1)} = S_{nt} + I_{nt} - (IR_{nt} + R_{nt} + E_{nt} + O_{nt})$$
$$\forall t = 1, 2, \ldots, 12 \text{ , and } \forall n = 1, 2, \ldots$$

- **Storage limits**

$$S_{nmin} \le S_{nt} \le S_{nmax}$$
$$S_{nmin} \le S_{n(t+1)} \le S_{nmax}$$
$$\forall t = 1, 2, \ldots, 12 \text{ , and } \forall n = 1, 2, \ldots$$

- **Maximum power production limit**

$$p(R_{nt} H_{nt}) \le HP_{nmax}$$

- **Irrigation demands**

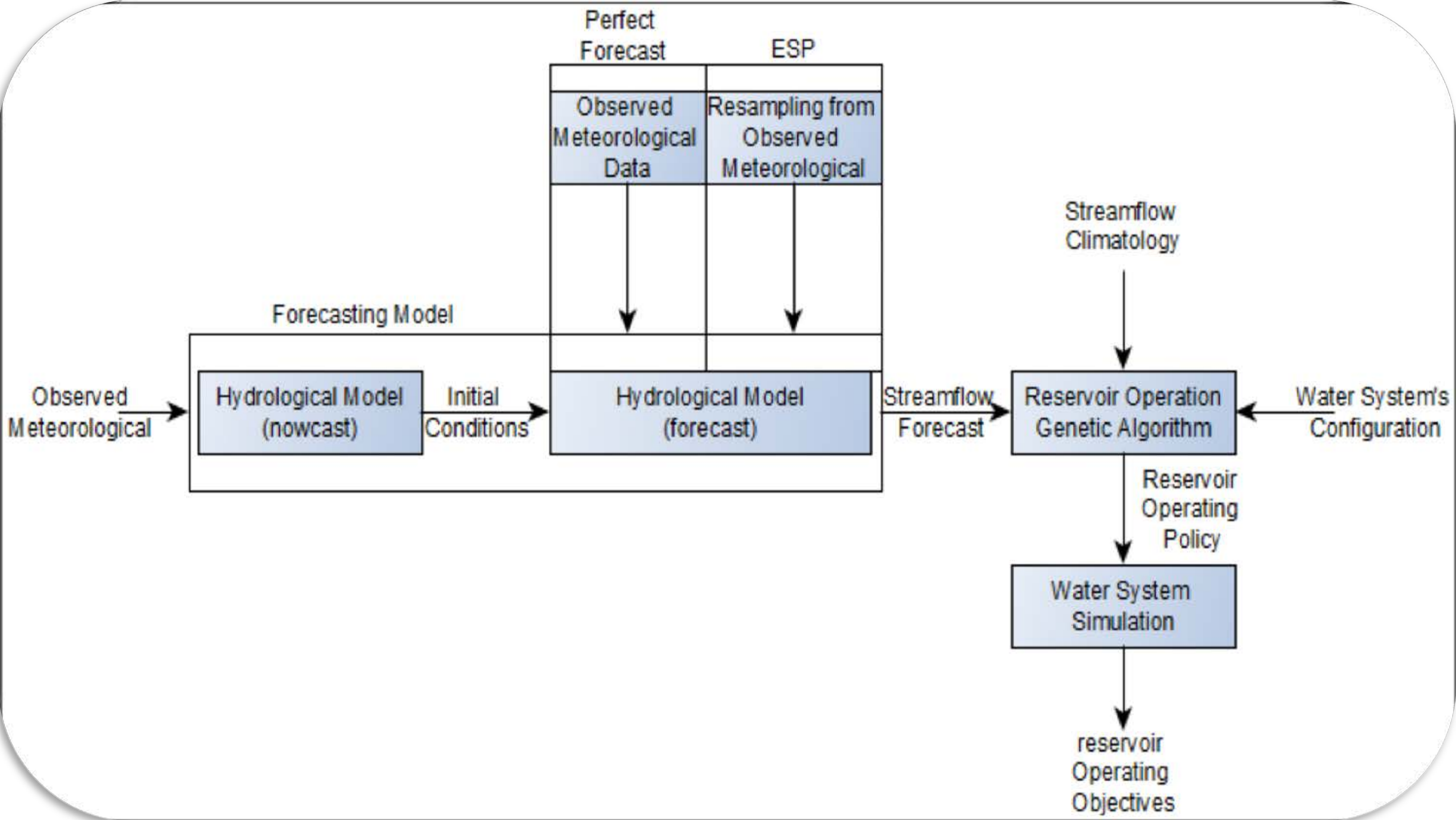
$$0 \le IR_{nt} \le D_{nt}$$

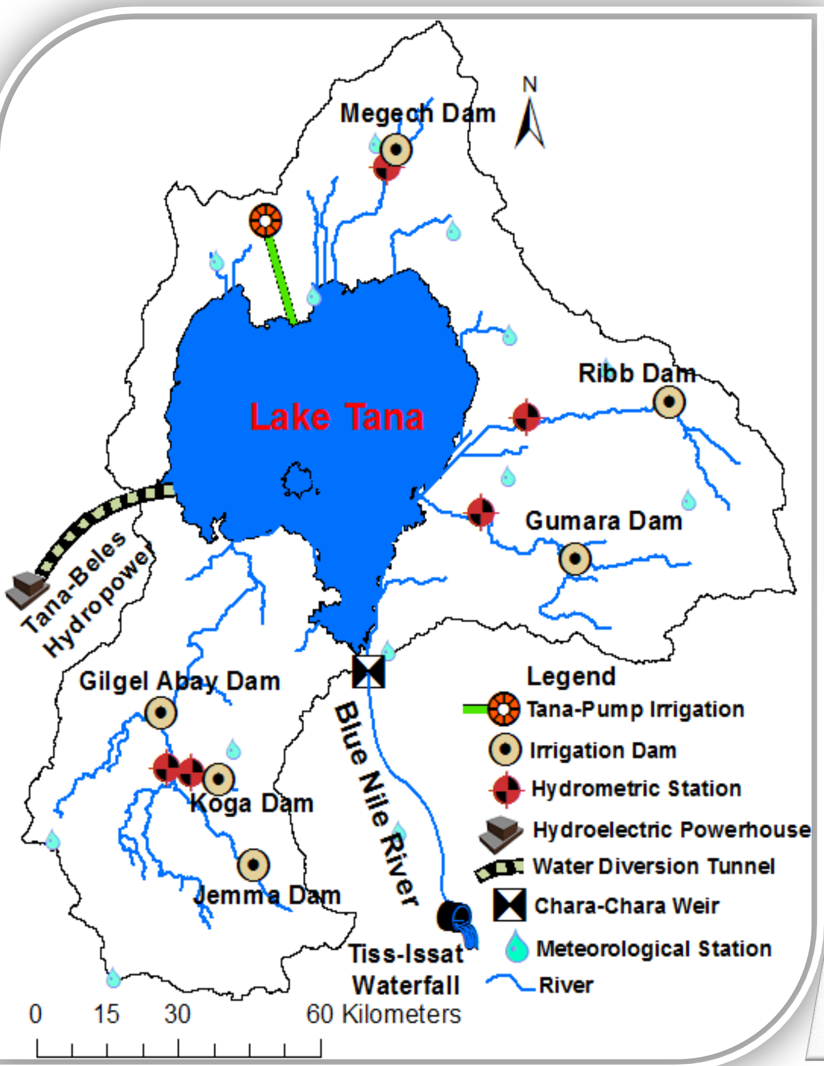
- **Downstream requirement**

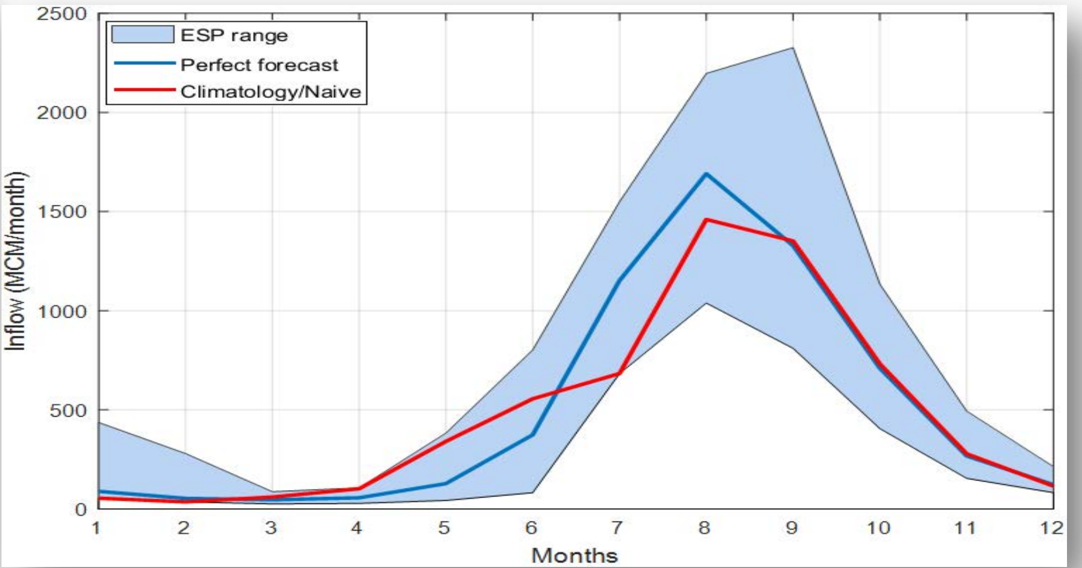
$$DR_{nt} \ge MDR_{nt}$$

- **Spill**

$$0 \le O_{nt}$$


Perfect Forecast
ESP
Observed Meteorological Data
Resampling from Observed Meteorological
Streamflow Climatology
Forecasting Model
Observed Meteorological
Hydrological Model (nowcast)
Initial Conditions
Hydrological Model (forecast)
Streamflow Forecast
Reservoir Operation Genetic Algorithm
Water System's Configuration
Reservoir Operating Policy
Water System Simulation
reservoir Operating Objectives





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Journal of Hydrology
journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Representing inflow uncertainty for the development of monthly reservoir operations using genetic algorithms

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ARTICLE INFO

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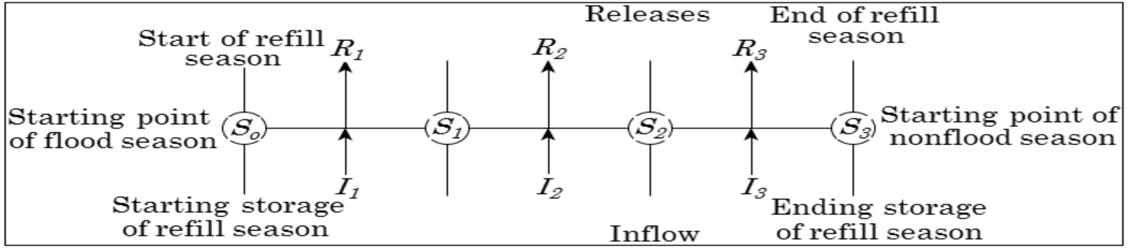
Keywords:
Genetic algorithm
Multi-reservoir operation
Inflow uncertainty
Cluster
Optimal release

ABSTRACT

Genetic Algorithms (GAs) have been commonly applied in the last two decades as a substitute for the traditiona mathematical programming algorithms in searching for optimal operating rules of reservoir systems. Howeve only a few GA studies related to reservoir operations addressed the inflow uncertainty. In this study, the re servoir operation rules were developed and evaluated by reflecting the uncertainty of reservoir inflows using th non-dominated sorting GA II algorithm (NSGA-II) through the following procedure: (1) the historical inflow dat were classified into four clusters using the self-organizing map (SOM) clustering technique; (2) NSGA-II searche for an optimal release rule in each cluster with all the inflow data of the corresponding cluster; (3) a relea response function was then derived for each cluster by regressing the calculated optimal release data against t storage at the beginning of the month and the inflow during the month; and (4) finally, the derived release ru for each cluster were tested with three performance indices, namely, reliability, resilience, and vulnerability. T

Example: Reservoir operation with simple approach

Three stage reservoir refilling approach



a. Objective function: Minimization problem

$$f(R,S)=\omega\left[\left(\frac{R_1-D_1}{D_1}\right)^2+\left(\frac{R_2-D_2}{D_2}\right)^2+\cdots+\left(\frac{R_{12}-D_{12}}{D_{12}}\right)^2\right]+(1-\omega)\left[\left(\frac{S_9-S_9^T}{S_9^T}\right)^2\right]$$

b. The Lagrangian function of the formulated reservoir operation problem

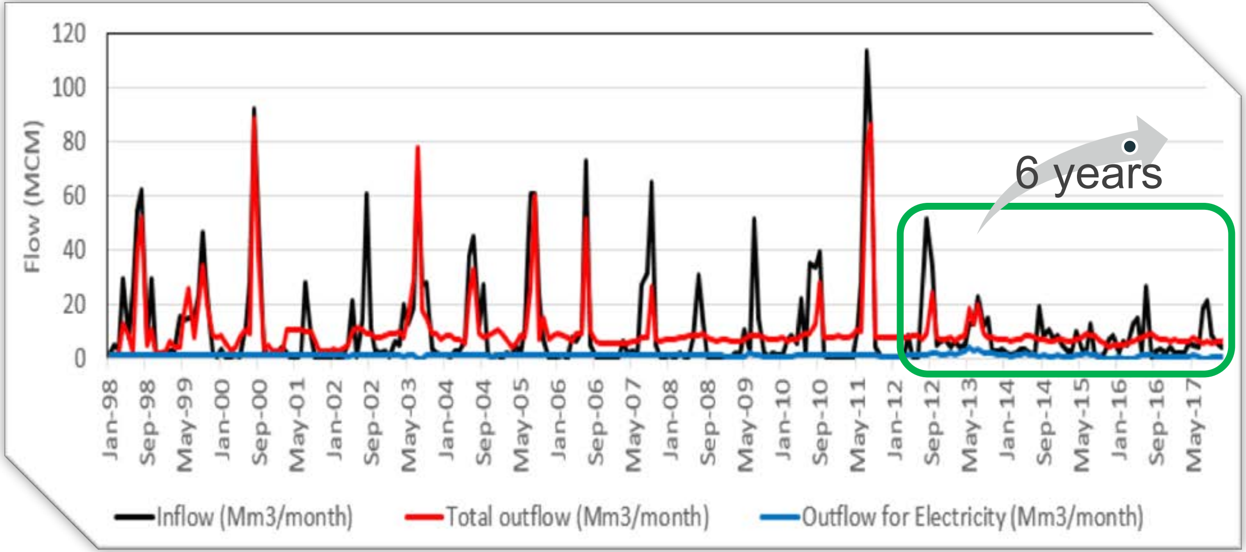
$$L=\omega\left[\left(\frac{R_1-D_1}{D_1}\right)^2+\left(\frac{R_2-D_2}{D_2}\right)^2+\cdots+\left(\frac{R_{12}-D_{12}}{D_{12}}\right)^2\right]+(1-\omega)\left[\left(\frac{S_9-S_9^T}{S_9^T}\right)^2\right]+$$

$$\lambda_1\left(A_{12}-R_1-R_2-R_3-R_4-R_5-R_6-R_7-R_8-R_9-R_{10}-R_{11}-R_{12}\right)$$

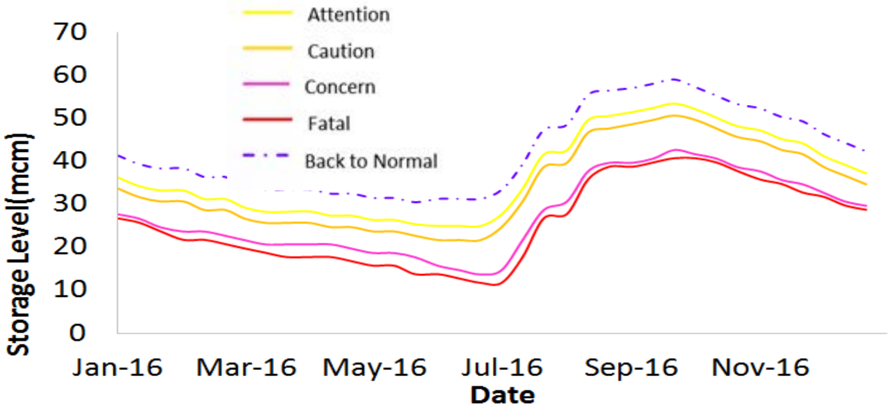
c. The Karush-Khun-Tucker (KKT) conditions

$$\frac{\partial L}{\partial R_1}=0=\frac{2\omega R_1}{D_1^2}-\frac{2\omega}{D_1}-\lambda_1 \qquad \frac{\partial L}{\partial R_2}=0=\frac{2\omega R_2}{D_2^2}-\frac{2\omega}{D_2}-\lambda_1 \quad \cdots \quad \frac{\partial L}{\partial R_{12}}=0=\frac{2\omega R_{12}}{D_{12}^2}-\frac{2\omega}{D_{12}}-\lambda_1 \qquad \frac{\partial L}{\partial S_9}=0=(1-\omega)\left(\frac{2S_9}{{S_9^T}^2}-\frac{2}{S_9^T}\right)-\lambda_1$$

Reservoir operation rules during extended drought period



Actual Dam Level	Water Supply for
> Attention	Municipal + Agriculture + Instream
> Caution	M&I + Agriculture
> Concern	M&I
> Fatal	Partial M&I



Demand = Agricultural supply + Municipal supply + Environmental supply

5. Water resources planning and development in the Nile region

- ✓ Planning of new water infrastructures in the Nile basin should be carefully evaluated with ***ROBUST*** and **ADAPTIVE** decision making perspectives.
- ✓ ***Robust***: an alternative performs satisfactorily over a wide range of scenarios
- ✓ ***Adaptive***: reduction of risk over time (flexibility)

Real Option Analysis (ROA)

Discounted cash flow?

- ✓ ROA spread risks over time using options
  - which is consistent with the adaptive perspective.
- ✓ ROA can also consider uncertainty in a modelling framework
  - which is consistent with the robust perspective.

Planning Period: 30 years

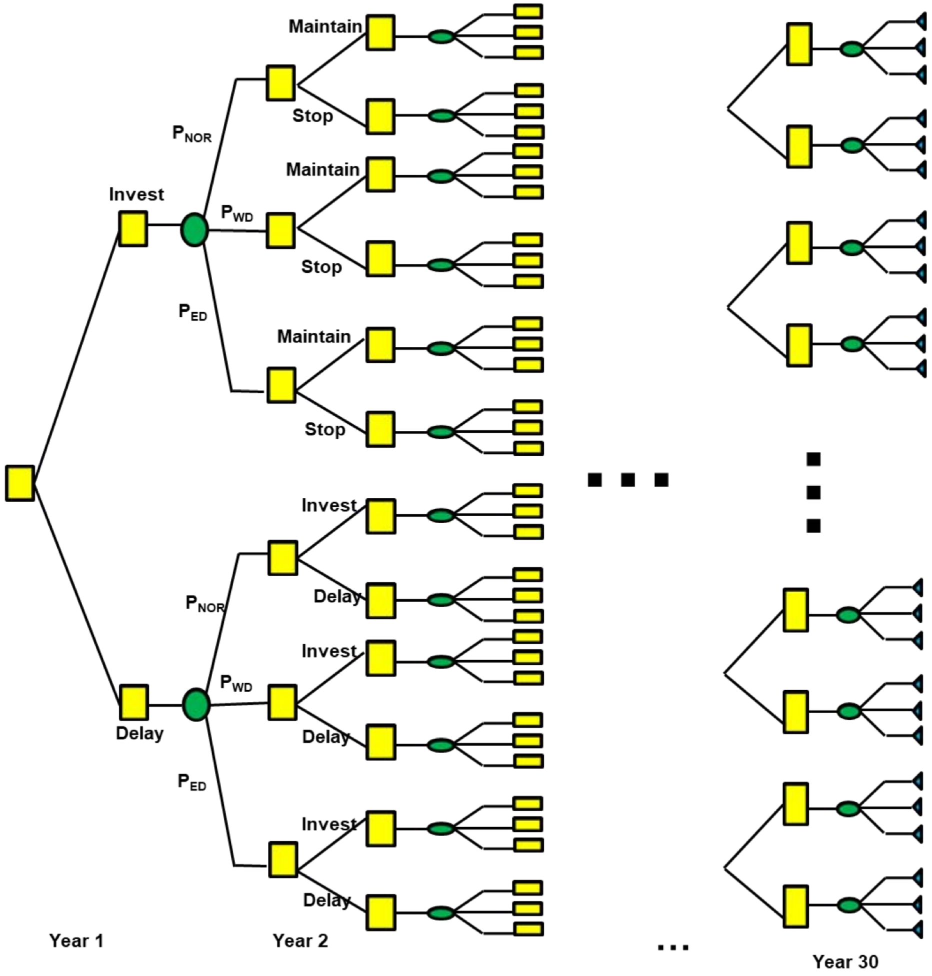
No of Nodes: $(4*3)^{12}$

- ✓ Decision node: 4 options

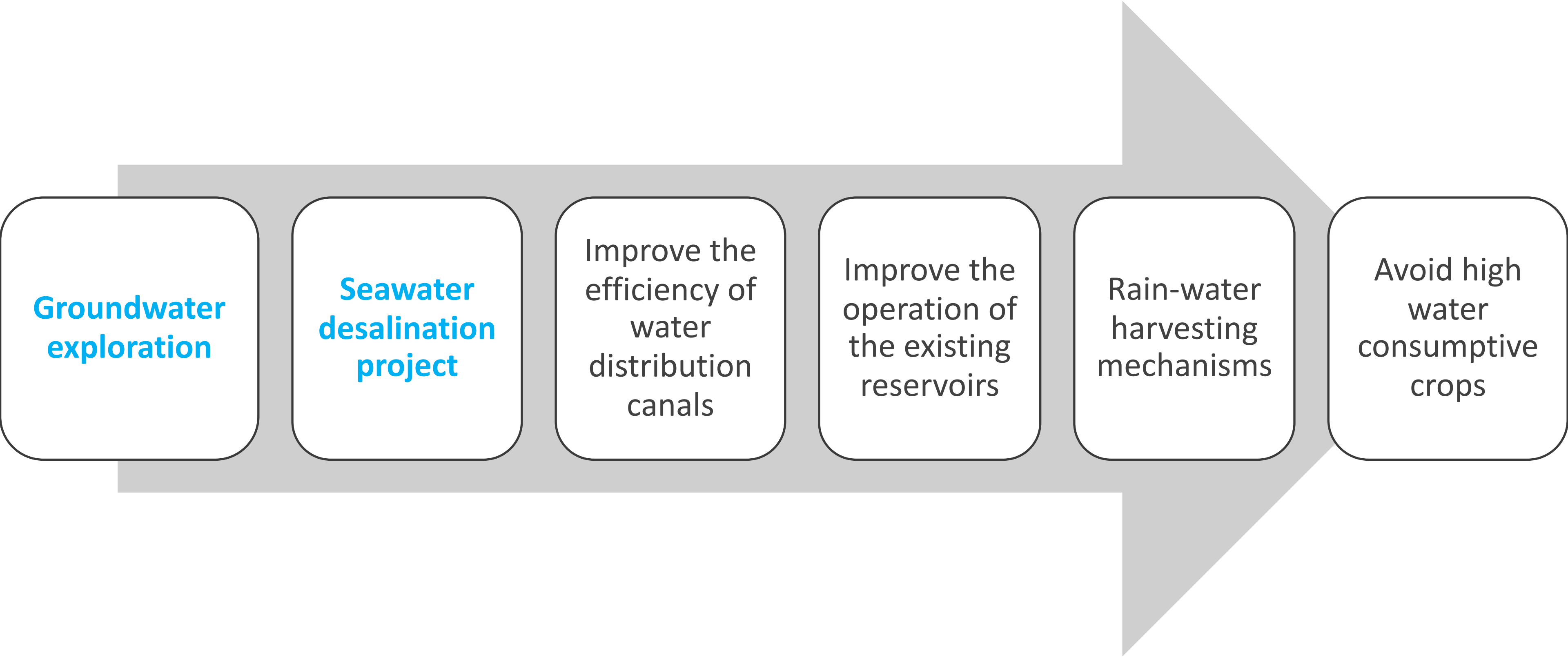
  Invest, delay, stop, and maintain

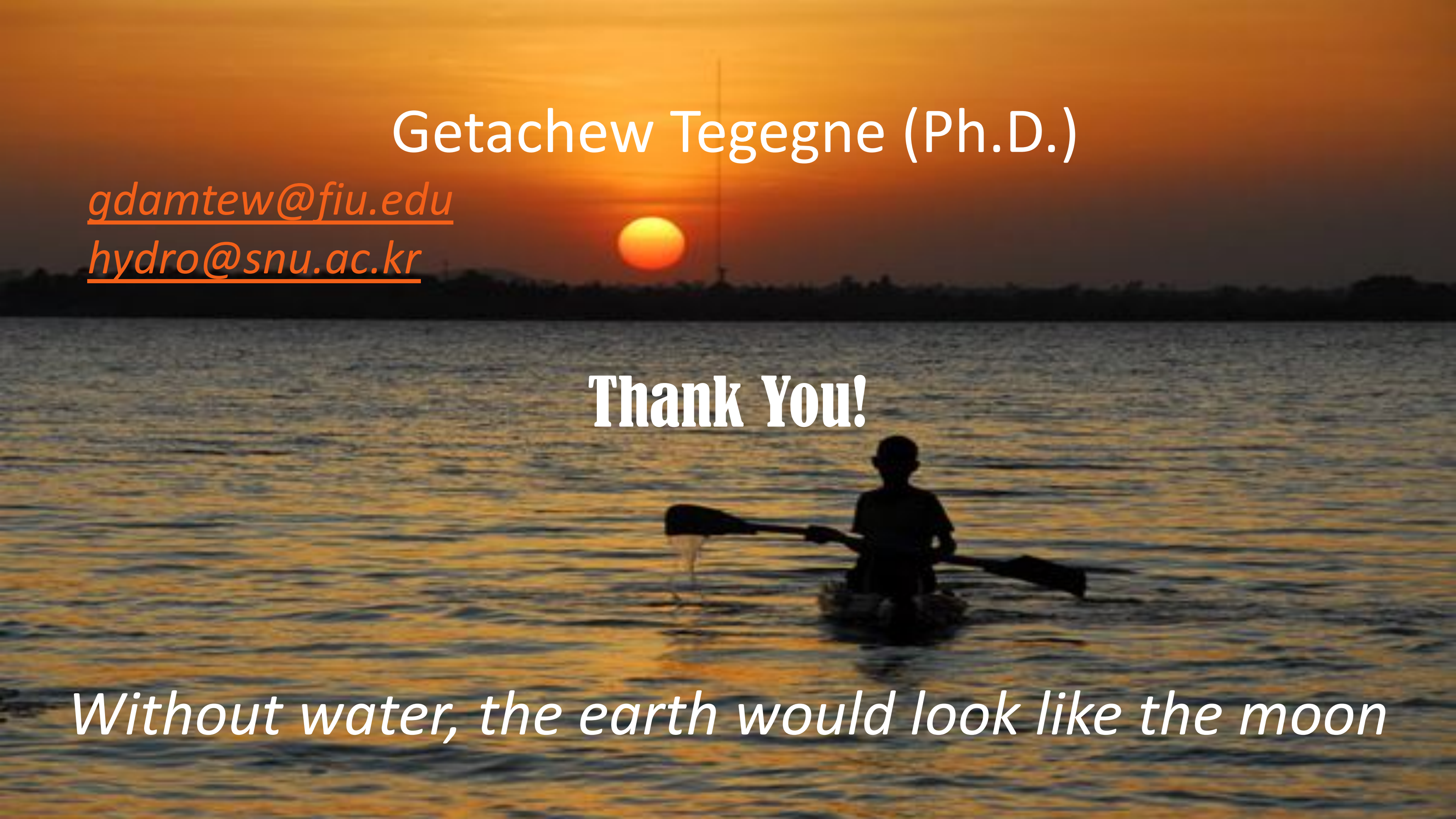
- ✓ Chance node: 3 Scenarios

  Normal, moderate drought, and severe drought



Proposed adaptation plans for Egypt due to further upstream development





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Thank You!

Without water, the earth would look like the moon