Modelling the Impact of Projected Future Climate Change on Water Resources: Case Study the Nile River

By

Doaa M. Amin, PhD
Water Resources Research Institute (WRRI), National Water Research Center (NWRC), Ministry of Water Resources & Irrigation (MWRI), Egypt

Outline

- Introduction
- Hydrological Models (NFS)
- Previous Studies
- Assessment the Drought in Future Climate Change Scenarios
  - Study Area (Blue Nile and Atbara River)
  - Methodology
  - Result
  - Conclusion
  - Next Step
Analyzing the Results and understanding the Impacts

Hydrological Models

- Rainfall – Runoff Model (rainfall → the source of water)
- Distributed model (to simulate the runoff variability)
- Accurate sub-basins delineation.
- Well Calibrated (to access the hydrological errors itself)

Why Nile Forecasting System?
Nile Forecasting System

- Hydro-meteorological System
- Developed in 1992, for monitoring, Forecasting and simulating the flow till HAD
- Precipitation & PET is the primary inputs variable for the NFS hydrological models
- NFS was evaluated in 2011, through the period (1989-2010)
- The Sub-basins are re-delineated in 2012
- The latest Calibration was in 2012

Beirut, 8-10 June 2015
Previous Studies

Previous Studies (1)
Lake Nasser Flood & Drought Control Project (2008)
- 6 Transient scenarios (3 GCMs x 2 Emission Scenarios)
- Statistically downscaled using a spatio-temporal weather generator
- Changes at Dongola from 2010-2100

Previous Studies (2)
Climate Change Risk Management in Egypt
- 6 ensembles of scenarios (HadCM3 x A1B Emission Scenario)
- RCM downscaled
- DCFs to Modify the NFS daily rainfall
- Changes at key locations on Nile River from 2021-2050
  - -19% to +29% for the Blue Nile (Diem)
  - -8% to +10% for the White Nile (Malakal)
  - -13% to +36% for the Whole Nile (Dongola)
Previous Studies

Previous Studies (3)
The Impact of Climate Change on the Arab Region using RCM

- Ensembles of scenarios (HadCM3 x A1B Emission Scenario)
- RCM downscaled
- DCFs of Temp., Precip., PET, and Evap.
Assessment the Drought in Future Climate

- Meteorological droughts are periods of less than normal rainfall over a specified region.
- For assessing meteorological drought, the approach is to apply the Standardized Precipitation Index (SPI) to different rainfall datasets to assess its applicability in the study area.
- In terms of hydrological drought, a set of indices will be applied to the projected Future Flow (SDI, and MWRI flood year classification).

Study Area (Blue Nile & Atbara River)

- Low specific discharge
- Variable topography
- High runoff variability
- High Sensitivity to Climate
Methodology

Pre-processing

Bias Correction

The method to bias correct precipitation is based on monthly means, by applying a multiplicative correction factor

\[
\text{Corr. } F = \frac{\text{Mean Monthly Precipitation (NFS)}}{\text{Mean Monthly Precipitation (base: 1961-1990)}}
\]

This is a simple bias correction that only guarantees that the mean climate scenario is similar to the base dataset.
Meteorological Drought Assessment

SPI was calculated for 1, 3, 6, 9, and 12 months lead times to assess the drought using the catchment rainfall from several sources:

1. For historical rainfall, three datasets (CRU, ERA40, & NFS) are used and results are compared in terms of drought frequency for a period starting in 1961 and ending in 1990 or beyond (except for the NFS dataset which starts in 1992).

2. The baseline rainfall series from the ensemble members (1961-1990) are first compared to observed rainfall.

3. Future rainfall is taken from an ensemble of 6 RCM simulations for the period 2021-2050.

Meteorological Drought Assessment

SPI Values and Corresponding Drought Intensity - McKee et al. (1993)

<table>
<thead>
<tr>
<th>SPI Value</th>
<th>Drought Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 or more</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1.5 to 1.99</td>
<td>Very wet</td>
</tr>
<tr>
<td>1.0 to 1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>-.99 to .99</td>
<td>Near normal</td>
</tr>
<tr>
<td>-1.0 to -1.49</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>-1.5 to -1.99</td>
<td>Severely dry</td>
</tr>
<tr>
<td>-2 and less</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>
Results

1- Observed Rainfall Comparisons

a) Annual “Observed” Rainfall Series

![Graph showing annual observed rainfall comparisons for Blue Nile at Khartoum and Atbara at Atbara town.](image)

Results

1- Observed Rainfall Comparisons

b) Mean Monthly Distribution of “Observed” Rainfall Series

![Graph showing mean monthly rainfall distribution for Blue Nile at Khartoum and Atbara at Atbara town.](image)
Results

2- Climate Change Impacts

a) Impact of Climate Change from 6 RCM Simulations on Rainfall Frequency Distribution of the Blue Nile and Atbara

(The yellow band indicate the range across the 6 PRECIS simulations)
Beirut, Beirut, 8-10 June 2015

Results

2- Climate Change Impacts

Blue Nile - Present (1961-1990)

6-Monthly SPI 9-Monthly SPI 12-Monthly SPI

Blue Nile - Future (2021-2050)

6-Monthly SPI 9-Monthly SPI 12-Monthly SPI

Hydrological Year

Atbara - Present (1961-1990)

6-Monthly SPI 9-Monthly SPI 12-Monthly SPI

Atbara - Future (2021-2050)

6-Monthly SPI 9-Monthly SPI 12-Monthly SPI
Results

2- Climate Change Impacts

Atbara - Present (1961-1990)

Atbara - Future (2021-2050)

Conclusion

- CRU has higher flood probabilities than NFS, but similar drought probabilities.
- SPI reduce the bias from RCM model because it involves normalization of rainfall distributions.
- The current set of climate simulations indicate a general increase in rainfall, but this does not exclude the increase of drought probability for some lead times.
- The uncertainty bandwidth increases near the ends of the SPI probability distributions but not for all lead times.
- The SPI proved to be a useful way to characterize meteorological drought across different catchments and at different time scales.
**Next Step**

**Assessment the Hydrological Drought:**

1. Identify the suitable hydrological drought Indices
2. Applying these indices on historical data (Observed & NFS_sim)
3. Applying these indices on the baseline projected flow series (1961-1990)
4. Applying these indices on the future projected flow that is taken from an ensemble of 6 RCM simulations for the period 2021-2050

**Suggested Drought Indices**

**1- Standardized Discharge Index (SDI)**

This Index SDI requires stream flow volume values

The formula of the SDI is:

\[ SDI = \frac{(V-V_{mean})}{Std} \]

<table>
<thead>
<tr>
<th>Category</th>
<th>SDI Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non drought</td>
<td>≥ 0.0</td>
</tr>
<tr>
<td>Mild drought</td>
<td>-1.0 to 0.0</td>
</tr>
<tr>
<td>Moderate drought</td>
<td>-1.5 to -1.0</td>
</tr>
<tr>
<td>Severe drought</td>
<td>-2.0 to -1.5</td>
</tr>
<tr>
<td>Extremely Dry</td>
<td>&lt; -2.0</td>
</tr>
</tbody>
</table>
Suggested Drought Indices

2- MWRI Drought Classification

The total annual flow of the Nile over the hydrologic year (1st August – 31st July), categorized based on the annual naturalized flow of the Nile at Aswan.

The average annual natural flow of the Nile is 84 BCM, therefore the categories are centred around this figure.

<table>
<thead>
<tr>
<th>Category</th>
<th>Natural Flow at Aswan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely dry</td>
<td>&lt; 56</td>
</tr>
<tr>
<td>Very dry</td>
<td>56 - 70</td>
</tr>
<tr>
<td>Dry</td>
<td>70 - 77</td>
</tr>
<tr>
<td>Lightly dry</td>
<td>77 - 81</td>
</tr>
<tr>
<td>Near normal</td>
<td>81 - 87</td>
</tr>
<tr>
<td>Lightly wet</td>
<td>87 - 91</td>
</tr>
<tr>
<td>Wet</td>
<td>91 - 98</td>
</tr>
<tr>
<td>Very wet</td>
<td>98 – 112</td>
</tr>
<tr>
<td>Extremely Wet</td>
<td>&gt; 112</td>
</tr>
</tbody>
</table>

MWRI-Based Flow Classification and Corresponding Naturalized Flow Ranges (BCM) at Key Locations along the Blue Nile, and the Atbara

<table>
<thead>
<tr>
<th>Category</th>
<th>Khartoum</th>
<th>Diem</th>
<th>Atbara</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely dry</td>
<td>&lt; 24.5</td>
<td>&lt; 27.5</td>
<td>&lt; 6.5</td>
</tr>
<tr>
<td>Very dry</td>
<td>24.5 – 32.7</td>
<td>27.5 – 36.8</td>
<td>6.5 – 8.7</td>
</tr>
<tr>
<td>Dry</td>
<td>32.7 - 36.9</td>
<td>36.8 – 41.5</td>
<td>8.7 – 9.8</td>
</tr>
<tr>
<td>Lightly dry</td>
<td>36.9 – 39.2</td>
<td>41.5 – 44.1</td>
<td>9.8 – 10.4</td>
</tr>
<tr>
<td>Near normal</td>
<td>39.2 – 42.8</td>
<td>44.1 – 48.1</td>
<td>10.4 – 11.4</td>
</tr>
<tr>
<td>Lightly wet</td>
<td>42.8 – 45.1</td>
<td>48.1 – 50.7</td>
<td>11.4 – 12.0</td>
</tr>
<tr>
<td>Wet</td>
<td>45.1 – 49.3</td>
<td>50.7 – 55.4</td>
<td>12.0 – 13.1</td>
</tr>
<tr>
<td>Very wet</td>
<td>49.3 – 57.5</td>
<td>55.4 – 64.7</td>
<td>13.1 – 15.3</td>
</tr>
<tr>
<td>Extremely Wet</td>
<td>&gt; 57.5</td>
<td>&gt; 64.7</td>
<td>&gt; 15.3</td>
</tr>
</tbody>
</table>
Thank You