Applications of Downscaling to Assess the Impacts of Climate Change on the Nile Basin Water Resources

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Egypt’s Vulnerability to Climate Change

- Coastal Zone
- Water Resources (Nile & Flash flooding)
- Agriculture
- Tourism
- Health
- Energy

Sea Level Rise

Hotter & Drier Weather

Nile Inflow Changes
The Nile Basin

- Large area (2.9 \times 10^6 \text{ km}^2)
- Low specific discharge
- Spans several climate regions
- Variable topography
- High runoff variability
- High sensitivity to climate
- Climate sensitivity varies

Example: 1961-1962 Rainfall over Equatorial Lakes
Sensitivity to Climate

![Graph showing flow change percentage against precipitation change percentage for different rivers: Atbara, Kagera, and Gilgel Abbay.](image)
Historical Rainfall Simulation

Source: LNDFC 2005
CC Impacts on Rainfall

Change in rainfall (mm/year)

ECHAM4 2040-’69

HADCM2 2040-’69

CSIRO 2040-’69

CGCM1 2040-’69

GFDL 2010-’49

NCAR 2010-’49

CCSR 2040-’69
Methodology for Climate Change Impact Studies

- Emissions
- Concentrations
- Radiative Forcing
- Global Circulation Models
- Regional Details (Downscaling)
- Impact Models (e.g. Hydrology)
- Observations

Scope
The Problem of Scale

Too Dynamic Atmosphere

High Computing Needs

Coarse Spatial Resolution

Parameterization Needed (Upscaling)

Impact Studies Require Local Info

Downscaling

Uncertainty
Downscaling Methods

Dynamic
- RCM Nesting
- Global Time Slice
- Stretching

Statistical
- Factors
- Regression
- Resampling
- Weather Typing
- Weather Generators

Hybrid
- RCM for a Single Weather Type
- Atmospheric Model with Disaggregated Rainfall

Based on Kilsby, 2000
Previous Studies (1)

• Strzepek et al. (1995, 1996)
  – 3 2xCO₂ Equilibrium GCM Scenarios
  – Changes range: -77% to +30% for Nile Yield
• Yates et al. (1996)
  – 3 Equilibrium + 1 Transient GCM scenarios
  – Changes range: -11% to +61% for Egypt’s Quota
• Conway and Hulme (1998)
  – 3 GCM scenarios (dry, wet, composite)
  – Changes range: -9% to +12% for Nile Yield
Previous Studies (2)

• Yates and Strzepek (1998)
  – 6 Equilibrium Scenarios (expected 2060)
  – 5 showed increased, the 6th showed 15% Reduction in Nile Yield

• Arnell (1999)
  – 6 Transient Scenarios from HadCM2 and HadCM3 till 2050
  – Increases in Rainfall are counterbalanced by increases in PET – little effect on the river discharge

• Elshamy (2000)
  – 16 Transient scenarios from 7 GCMs till 2050
  – Changes in Temperature: 2-4.3°C
  – Changes in Rainfall: -18% to +22%
Previous Studies (3)

- **Strzepek et al. (2001)**
  - 9 statistically (transient) derived scenarios from different climate models termed “non-implausible”
  - 8 predicted reductions to various degrees with only one showing a modest increase

- **Sayed (2004)**
  - 4 statistically derived scenarios using MAGICC-SCHENGEN based on the results of several GCMs
  - Changes range: -14% to 32% in Nile Yield by 2030

- **LNFDC (2008)**
  - 6 Transient scenarios from 3 GCMs and 2 Emission Scenarios
  - Statistically downscaled used a spatio-temporal weather generator
Application #1

STATISTICAL DOWNSCALING BASED ON WEATHER GENERATION
SDM - Dongola Flows

- Coarse Monthly GCM Rainfall
- SDM: Spatio-Temporal WG
- Fine-Scale Daily Rainfall
- NFS Hydrological Model

Flow at Dongola
10 Traces x 3 GCMs x 2 Scenarios

Compatible PET Scenarios
SDM-WG Concept

- **Spatial Resolution**: 5km x 5km grid resolution
  - 1st July
  - 2nd July
  - 3rd July

- **Temporal Resolution**: GCM Resolution
Methodology

- Global Climate Models’ Output:
  - Monthly Rainfall Data
  - Large Gridboxes (e.g. $2.5^\circ \times 3.75^\circ$)
- SDM Model developed to get:
  - Daily Data
  - Fine Resolution ($5 \times 5$ km) NFS Scale
- SDM is Stochastic – Ensembles are used to sample the variability
Future Simulations – Decadal

HadCM3 – A2

HadCM3 – B2

CGCM2 – A2

CGCM2 – B2

ECHAM4 – A2

ECHAM4 – B2
Future Simulations – Annual & Summary

Uncertainty Analysis (1)

GLUE Analysis:
- Weights: NSE of monthly flows
- Looked at 95, 90, 75, 50, 25, 10, and 5 percentiles
- Analyzed A2 & B2 scenarios for each GCM separately (sample size: 10) then combined for 3 GCMs (sample size: 30)
Uncertainty Analysis (2)
Uncertainty Analysis (4)
Application #2

STATISTICAL DOWNSCALING USING BIAS CORRECTION
Metholodogy and Basin

- Coarse Daily GCM Rainfall
- Bias Correction Downscaling
- Fine-Scale Daily Rainfall
- NFS Hydrological Model
- Flow at Diem
  - 17 GCMs x 1 Scenario

Compatible PET Scenarios
Bias Correction Downscaling (1)

- Bias correction for downscaling rainfall (based on fitting the gamma distribution to daily rainfall)
- Simple bias correction for PET (ratio)
- NFS for hydrological modeling
- An ensemble approach (17 GCMs – A1B)
- Baseline 1961-90, Future 2081-98, Daily rainfall data & Monthly PET data
Bias Correction Downscaling (2)

Probability (CDF) vs Rainfall

GCM

Observed
Rainfall Distributions (Baseline)
Future Distributions

Uncertainty Analysis

GLUE Analysis:
- Weights: NSE of monthly flow/rainfall
- Looked at 95, 90, 75, 50, 25, 10, and 5 percentiles
- Sample size: 17
Flow vs Rainfall Changes

ΔQ = 3.0108 ΔR - 0.1474
R² = 0.9378

ΔQ = 3.2475 ΔR - 0.1002
R² = 0.9702
ΔPET = 0.0375 ΔT - 0.037

\[ R^2 = 0.69 \]

ΔPET = 0.056 ΔT - 0.06

\[ R^2 = 0.74 \]

Mean Annual Temperature Change (ΔT °C)

Mean Annual PET Change (ΔPET)

Mean JJAS Temperature Change (ΔT °C)

Mean JJAS PET Change (ΔPET)
Conclusions

- The Uncertainty is still high – several reasons
- Changes in precipitation range between -14% and +15%
- Changes in Temperature range between 2-5°
- Changes in PET range between +2-14%
- Changes in Flow range between -60% to +45%
- Simple linear relationships can be used as a fast-track method to assess the impacts
- Relative Contributions of Emission Scenarios, GCMs, and downscaling methods to the uncertainty bandwidth can be quantified – GCMs are responsible for the largest component
Way Forward

- Collaboration within the Nile Basin to exchange data and experience
- Translating Climate impacts into hydrological → agricultural → socio-economic, hydropower, ... impacts
- Expansion to other Emission Scenarios, RCMs, etc to better characterize the uncertainty
- Further research on uncertainty propagation to decision making – adaptation planning
Thank You
Nile Forecast System

Rain gauge Data → Satellite Images → Rainfall Estimation Models → Rainfall Estimates → Hydrological Models → Simulation and Extended Stream Flow Prediction (ESP) → Historical Climate

GIS