Estimating Current and Future Groundwater Resources of the Republic of Maldives

Ryan Bailey
Department of Civil & Environmental Engineering

Abedalrazq Khalil
Vansa Chatikavanij

The World Bank
Background & Motivation

Water Resources
- Rainwater harvesting
- **Groundwater**
- Desalinization

Atoll

Area: 1.4 km²
Population: 95,000
Project Objectives

- Assess current and future Groundwater Resources for the most populous islands of the Maldives

I. General Assessment of Groundwater Resources (most populous islands)
   1. Freshwater lens thickness
   2. Freshwater lens volume
   3. Safe yield

   - Current conditions
   - Year 2030 (SLR, population)


III. Assess Impact of Future Climate (2012-2050) (Numerical Modeling)
Atoll Island Hydrology

Island Freshwater Lens

- Large island
- High rainfall

Thick lens

Atoll Island Freshwater Lens

Majuro Atoll

30-60 ft

Fine Sediments

Truncation
Methods

Estimate Freshwater Lens Thickness

1. Algebraic Model

\[ Z_{MAX} = Z_{Lim} \left(1 - e^{-bR}\right)S \]

- Developed from numerical modeling simulations *(Ground Water, 2009)*
- Applied successfully to 100 islands in the Federated States of Micronesia *(Hydrogeology Journal, 2013)*

2. Apply to Maldives (52 islands)

- Island Width (average)
- Annual recharge (historical data)
- Depth to contact (~ 15 m)

Compare against observed data
Methods

Estimate Volume of Fresh Groundwater

1. Algebraic Model

\[ Z_{MAX} = Z_{Lim} \left( 1 - e^{-bR} \right) S \]

- 5-10 cross sections for each island \((n)\)
- Record distance between the cross sections
- 2D volume for each cross section
- Estimate volume between the cross sections

\[ V_{total} = \sum_{i=1}^{n-1} \left( \frac{Area_i + Area_{i+1}}{2} \right) x_i S_y \]

2. Apply to Maldives (52 islands)

First, Test the Method:

\[ V_{total} \]

Compare against observed data (6 islands)
Methods
Estimate Volume of Safe Yield

1. Volume of Safe Yield
   1. Estimate areal extent of freshwater lens
   2. Calculate annual volume of recharge
      - Recharge = 0.40 * Annual Rainfall
      - Annual depth * lens area
   3. Safe Yield = 30% of annual recharge volume
      (Falkland 2000; Falkland 2001)

2. Safe Yield Per Capita (per day)
   - Use population data for each island
     (national census 2012)
Methods
Estimating resources in 2030

1. Sea Level Rise \(\rightarrow\) Shoreline Recession

- Decrease in island width
- Affects Lens Thickness
- Affects Lens Volume
- Safe Yield

2012 - 2030:
- 1.0 mm/yr (min)
- 6.5 mm/yr (max)
- Beach slope (2%, 1%, 0.5%)

2. Population Increase \(\rightarrow\) Affects Per Capita Safe Yield

- Government estimates for 2030
Results

Freshwater Lens Thickness (Current)

1. Comparison with Observed Values
Results
Freshwater Lens Thickness (Current)

1. Comparison with Observed Values

2. 52 Islands
1. Comparison with Observed Values
Results
Freshwater Lens Volume (Current)

1. Comparison with Observed Values

2. 52 Islands
Results

Per Capita Safe Yield (Current)

52 Islands

2012 Census

World Health Organization 50 L/day
Results

Year 2030

Decrease in Island Width, Freshwater Lens Thickness

SLR = 6.5 mm/yr
SLR = 1.0 mm/yr
Results
Year 2030

Decrease in Surface Area, Safe Yield

SLR = 6.5 mm/yr
SLR = 1.0 mm/yr

Due to population increase
Summary & Conclusions

- **52 islands (Current):**
  - Average lens thickness: **4.5 m**
  - Average lens volume: **1300 ML**
  - Average Per capita safe yield: **500 L/day** (> WHO recommended 50 L/day)

- **52 islands (2030, using max rate of SLR):**
  - Lens thickness decrease by **6.5%**
  - Lens volume decrease by **11.5%**
  - Per capita safe yield decrease by **35%**

- Groundwater resources are a **vulnerable** resource for the Maldives

- **HOWEVER**: groundwater is a viable source of water (especially for islands with large surface area and low population)
Next Phases

- Analyze lens dynamics under variable climate scenarios
- Assess Water Quality (and remediation strategies)