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ORIGINAL RESEARCH ARTICLE

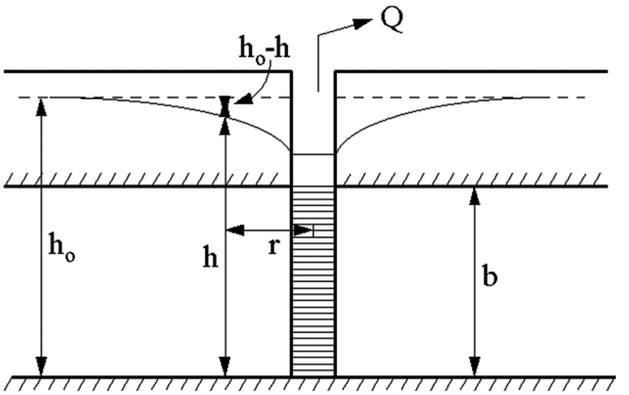
# Sustainable groundwater management in northwestern and west-central Bangladesh: Variability, human impacts, and food security implications

## Supplementary Files

**S1. Theis equation calculation for aquifer testing and well drawdown[1]**

An aquifer test (or pumping test) evaluates an aquifer by "stimulating" it through constant pumping and observing the aquifer's response (drawdown) in observation wells. Aquifer testing is a common tool used by hydrogeologists to characterize aquifers, aquitards, and flow system boundaries.

Aquifer tests are typically interpreted using an analytical model of aquifer flow, with the Theis solution being the most fundamental. Model parameters are matched to field observations, and the results are then assumed to represent the real-world aquifer.




Theis Equation

$$h_0 - h = \frac{Q}{4\pi T}\int_u^{\sim} \frac{e^{-a}}{a}\partial a, \quad where \quad u = \frac{r^2 s}{4Tt}$$

Q = Constant pumping rate
h = The hydraulichead (PWL)/pumping water level
$h_0$ = The initial hydraulic head (SWL)/static sater level
$s = h_0$-h= the drawdown (difference between PWL and SWL)
t = Time since pumping has began]
r = Radial distance from pumping well
S = Aquifer storativity coefficient
The finite series has been called the well function is generally called as W(u)

$$h_0 - h = \frac{Q}{4\pi T} W(u)$$

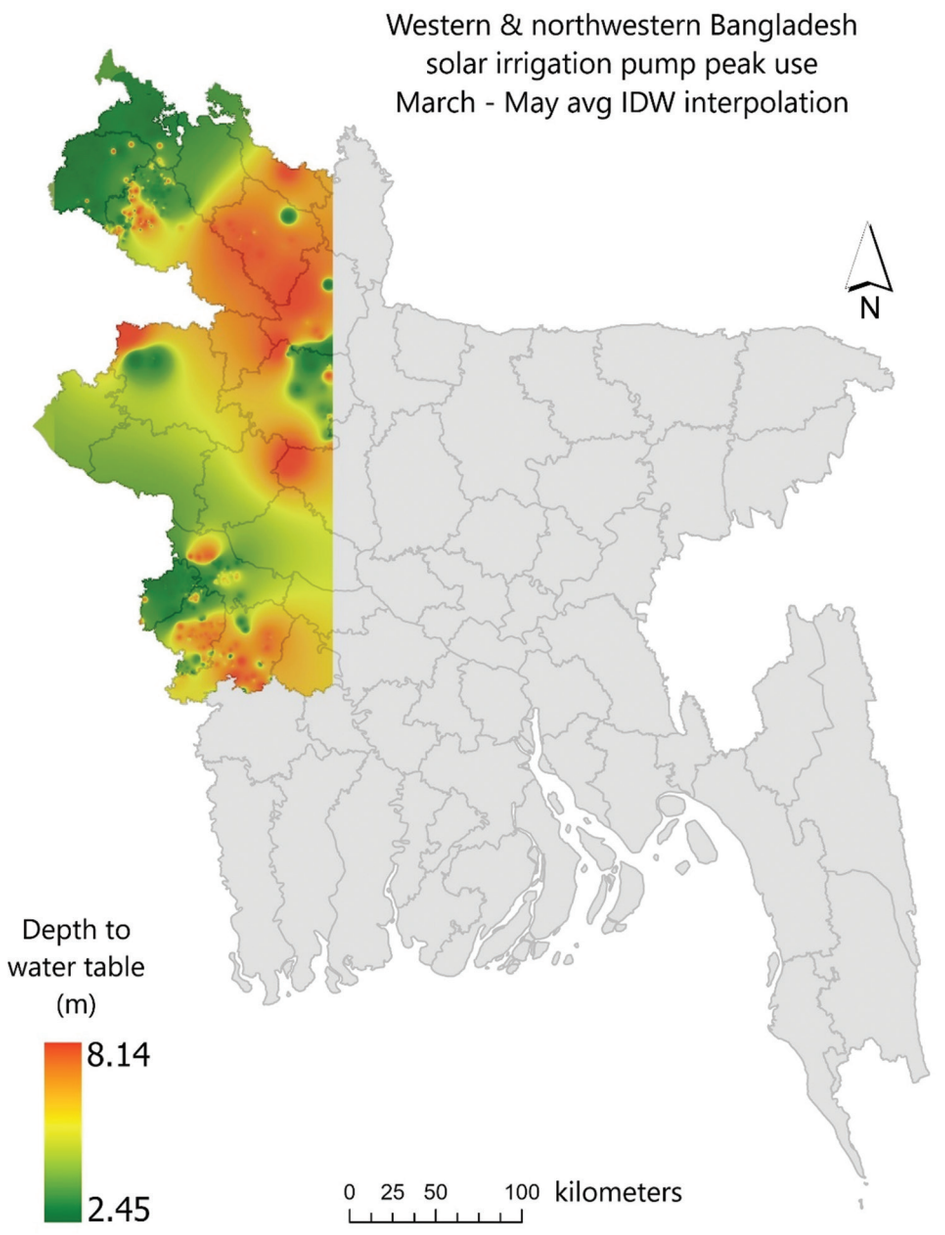



**Figure S1. Inverse distance weighted interpolated map showing spatial variation in groundwater depth during peak irrigation (drawdown) across the study area, based on the solar irrigation pump database (2021–2023)**

For example, using a pumping rate of 2,500 $m^3$/day (representing the upper range of solar irrigation pumps), a transmissivity of 1,800 $m^2$/day, and a storage coefficient of 0.1, the drawdown of 10 m from the pumping well was calculated after 1 day of continuous pumping (although in practice, solar irrigation typically operates for ~7 h/day). After converting units to those compatible with open-source software),[2] the calculated drawdown was 0.68 m, which is well below the 5 m threshold of concern. This open-source software can be used to calculate drawdown under different scenarios using the aquifer properties shown in the table below.

The table below presents the transmissivity, storage coefficient, and hydraulic conductivity/permeability of aquifers in Bangladesh, based on aquifer test (pumping test) analysis.[1]

| Regions | T minimum ($m^2$/day) | T maximum ($m^2$/day) | S minimum | S maximum | K minimum (m/day) | K maximum (m/day) |
|---|---|---|---|---|---|---|
| Northeast | 200 | 3000 | 0.002 | 0.10 | 3 | 90 |
| Northwest | 300 | 4000 | 0.003 | 0.23 | 12 | 114 |
| Southwest | 900 | 3200 | 0.01 | 0.15 | 11 | 65 |
| Southeast | 140 | 1900 | 0.0007 | 0.07 | 5 | 23 |

Source: Bangladesh Water Development Board.[1]
Abbreviations: K: Hydraulic conductivity; S: Storage coefficient; T: Transmissivity.

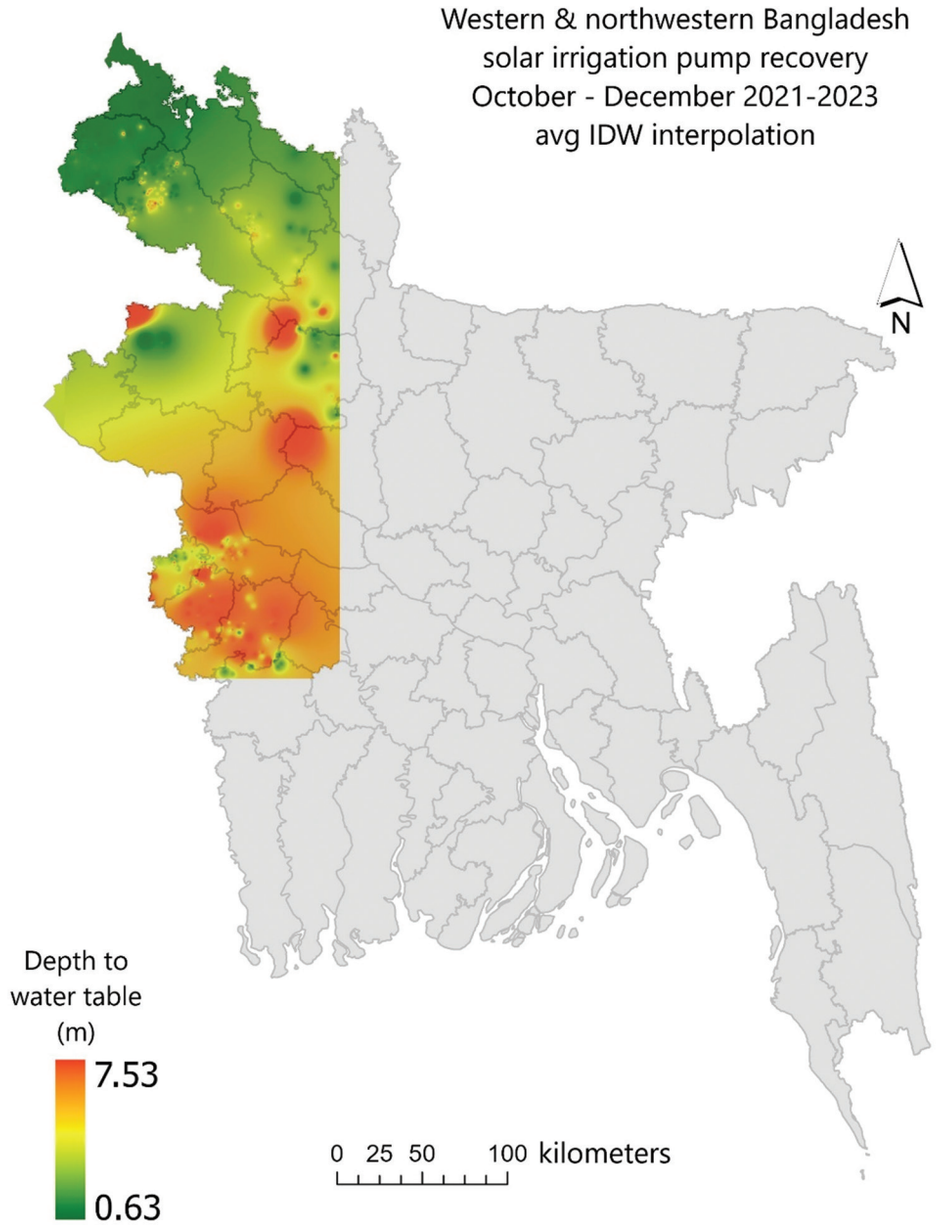



**Figure S2. Inverse distance weighted interpolated map illustrating groundwater recovery conditions across the study area derived from the solar irrigation pump database (2021–2023)**

## References

1. *Bangladesh Water Development Board, Report on the Compilation of Aquifer Test Analysis Results, Ground Water Circle- II, BWDB Water Supply Paper-502*; 1988.
2. *An Open-Source Theis Calculator Provided by the Utah Division of Water Rights was Used for Computation*. Available from: https://waterrights.utah.gov/wellinfo/theis/theis_input.asp [Last accessed on 2025 Oct 01].