An assessment of the mean annual precipitation needed to sustain Mid-Holocene lakes in Rajasthan, India

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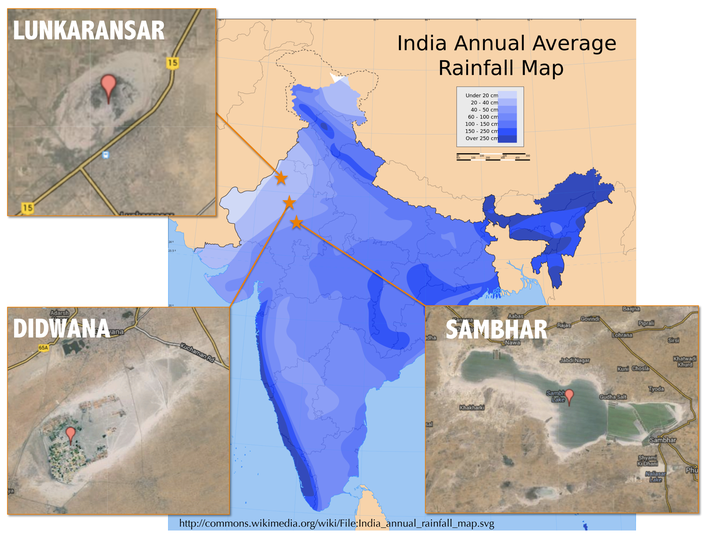
ABSTRACT

Climate models predict increasing monsoon rainfall over India, but no increase has been seen during the past decade. Mid-Holocene India was wetter and warmer than today, and some consider it an analog for a future warmer climate there. Geologic studies suggest mid-Holocene lakes in Rajasthan, India, where current climate is arid. Some have inferred almost double the present-day precipitation at that time.

An application of a simple water balance model to likely climatic conditions of Lake Sambhar provides tighter bounds on the range of increased precipitation seen during the early- to mid-Holocene. This study found that: (a) early- to mid-Holocene rainfall was likely in a range of 40-65% greater than present levels, and (b) despite 50% greater precipitation than present day, Lake Sambhar maintained high inter-annual variability, which may account for the lack of clear shorelines.

STUDY AREA



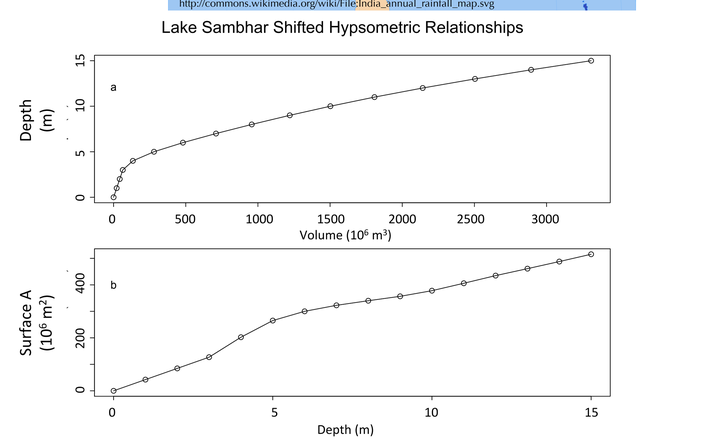


Figure 1. *Rajasthan, a desert region of India that experienced wetter and warmer conditions during the early- to mid-Holocene. Shown also are the hypsometric relationships for Lake Sambhar, derived using DEMs, Google Earth and ESRI ArcMap. Hypsometric relationships consider sedimentation rates that have occurred since 6 ka (~ 2 m for Lake Sambhar).*

LAKE MODEL FRAMEWORK

Input:
- 1°x1° gridded precip 1969-2005 [*Rajeevan et al., 2005*]
- 1°x1° gridded temp 1969-2005 [*Srivastava et al., 2008*]
- Monthly latitudinal insolation (past 10ka) [*Berger, 1992*]

Evaporation via Penman-Monteith:

$$E = \omega \, (R_n/\lambda_v) \, (\Delta/\Delta+\gamma)$$

[*Priestley and Taylor, 1972; Shuttleworth, 2012*]

E = evaporation
ω = Priestley-Taylor constant
R_n = net radiation
λ_v = latent heat of vaporization
Δ = slope of e_{sat} – temp curve
Γ = psychrometric constant

Runoff via Curve Number:

$$S = [100/CN] - 10$$

$$R = (P-I_a)^2 / (P + I_a + S)$$

[*USDA, 1972; Mays, 2011*]

CN = curve number
S = potential max retention
I_a = intial abstraction
R = runoff
P = precipitation

Lake Balance:

$$V_{lake} = P + R - E$$

V_{lake} = lake volume

ANALYSIS 1: Lake Model and Present-Day

Current precipitation and temperature, along with current insolation are used to simulate lake depth over the observed period of 1969-2005. The lake responds to precipitation as expected. During present-day conditions, Lake Sambhar fluctuates between 0.1 and 3 meters, regardless of starting condition.

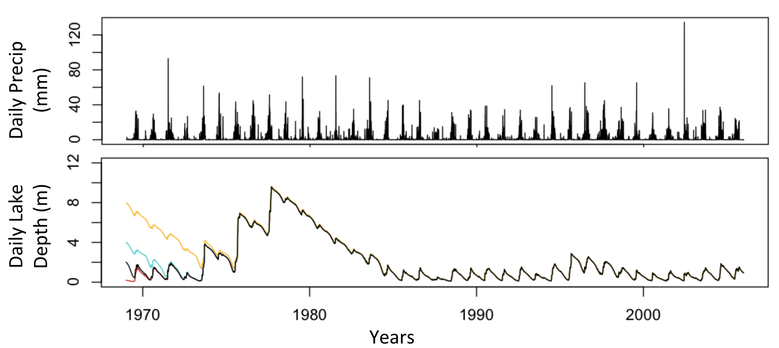


Figure 2. *Daily observed precipitation (mm) from 1969-2005 (top) and modeled Lake Sambhar depth (m) under current precipitation, temperature and insolation records (bottom). The various colors correspond to different initial depths of the lake (red = 0 m or empty, black = 2 m, blue = 4 m, and yellow = 8 m).*

ANALYSIS 2: Lake Depth and Precipitation

We investigate the feasibility of various increases in precipitation (up to double present-day values) suggested by paleoclimate data, and the consequent increases in lake depth. A 40% increase in precipitation resulting in a 21-m lake, as proposed by *Swain et al.* [1983], disagrees with our model. According to our model, it would take a doubling of precipitation to fill Lake Sambhar to a maximum depth of 21 m. *Singh et al.* [1974] estimated an increase in precipitation, from pollen calibration, of 250 mm/yr (40% increase) and mention evidence of a beach 6 m above present Sambhar depth. According to our model, a 6-8 m lake, accounting for 2 m of sedimetation, would require 40-65% greater precipitation.

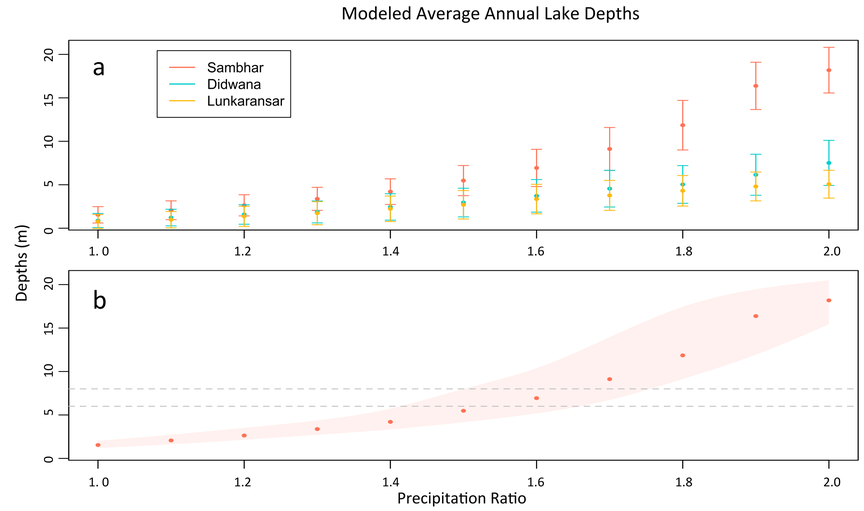


Figure 3. *Calculated average annual lake depths for ratios of different annual amounts of precipitation to that of present (1.0) up to a doubling (2.0) of current precipitation showing both error from (a) variability in precipitation, and (b) curve number shift through time.*

ANALYSIS 3: Lake Dynamics for Sambhar

We implemented a Hidden Markov Model (HMM) to investigate the underlying states in lake depth. With a 50% increase in precipitation, there is a shift in PDFs towards higher depths, but variability remains. With a doubling of precipitation, levels are greater than 12-m and persistently deep. With no evidence of shorelines, this lake depth regime is unlikely.

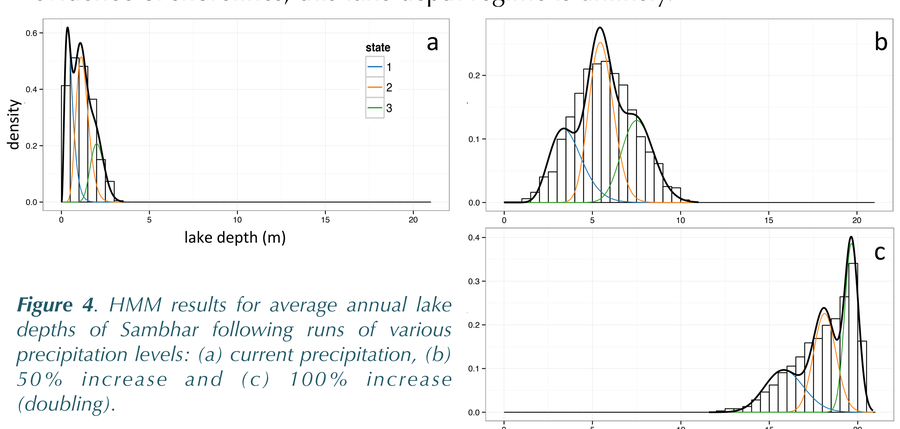


Figure 4. *HMM results for average annual lake depths of Sambhar following runs of various precipitation levels: (a) current precipitation, (b) 50% increase and (c) 100% increase (doubling).*

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