A sixth-century groundwater manual tested against India's well network

Plant indicators and depth claims in Varāhamihira's *Bṛhatsaṃhitā*

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Abstract. The *Dakārgala* chapter of Varāhamihira's *Bṛhatsaṃhitā* (sixth century CE) is one of the oldest detailed manuals for finding groundwater. It names trees, often together with anthills, as signs of water and gives the depth at which water will be found. It is often cited as early hydrological knowledge, but its claims have not been tested systematically. We coded the chapter's plant indicators and 48 stated depths and compared them with India's groundwater monitoring network: 11,530 dug wells from a quality-controlled release of Central Ground Water Board data, aggregated to 2,385 grid cells of 0.25°. We combined these with GBIF plant-occurrence records and WorldClim climate data, following an analysis plan written before the plant and climate data were obtained. Four results stand out. (1) The text's lists of trees indicating near water and far water separate in the predicted direction: near-water species make up a larger share of plant records where the water table is shallow, after controlling for climate (difference in mean coefficient -0.40, permutation $p = 0.020$, spatial block bootstrap 95% CI -0.61 to -0.11). The effect kept its sign in all six analysis variants but was significant in only three, and it is not unusual compared with randomly chosen pairs of species lists in most variants. (2) The broader set of trees used as signs is no more associated with shallow water than common Indian plants ($p = 0.43$). (3) The text's rule that the same signs mean water at 3, 5 and 7 man-lengths in wet, dry and desert country is right in direction. The modern desert-to-wet ratio of 1.99 (95% CI 1.68–2.41) brackets the text's 2.33, but the dry-to-wet ratio of 1.12 is far below the text's 1.67. (4) Depths stated for wet and dry country (about 3–17 m) match modern dug-well depths. By contrast, a third of the depths in the desert sequence exceed the deepest plant root ever recorded, and the sequence is ordered almost perfectly by verse ($\rho = 0.996$), more like a constructed catalogue than field observations. The chapter reads as a practical, partly empirical tradition: plausible at the scale of ordinary wells, schematic at its extremes, and untested at the micro-site scale on which most of its claims are made. We describe a field design that could test those claims.

Keywords. groundwater; phreatophytes; indigenous hydrological knowledge; history of science; Sanskrit; depth to water; GBIF

1 Introduction

Before drilling rigs and geophysical surveys, people looking for groundwater in semi-arid South Asia relied on surface signs: particular trees, termite mounds, soil colour, and the behaviour of animals. One of the most detailed written records of this practice is the *Dakārgala* ("water-bar") chapter of the *Bṛhatsaṃhitā*, a sixth-century CE Sanskrit compendium by the astronomer Varāhamihira. The chapter runs to more than 120 verses. It pairs named plants, often with an adjacent anthill

or snake hole, with a direction, a horizontal distance in cubits (*hasta*), and a depth in "man-lengths" (*puruṣa*) at which water will be found.

The chapter is well known in Indian hydrology. Prasad (1980) argued that its plant indicators are phreatophytes, plants whose roots habitually reach the water table (Meinzer, 1927), and illustrated the argument with photographs from field work in Andhra Pradesh. A companion paper made the case for its bioindicators (Prasad, 1986), and it is summarised in reviews of ancient Indian water management (Singh et al., 2020). Modern tests have focused on one indicator, the termite mound, with mixed or case-study evidence (Ahmed et al., 2020). To our knowledge, no study has coded the chapter's claims systematically and compared them with independent, large-sample groundwater data. Existing treatments are descriptive or anecdotal: they show that a well was found near a predicted tree, not how often indicator plants occur where water is shallow compared with where it is not.

Two developments make such a test possible. The Central Ground Water Board (CGWB) of India monitors water levels in tens of thousands of wells, and a quality-controlled release of these data is now openly available (Kuruva et al., 2025). Herbarium and observation records from the Global Biodiversity Information Facility (GBIF) give the distribution of the named plant species across the same territory.

This paper uses those data to test four claims, each stated in advance (Section 3). Two are about plants. The text contains two contrasting lists, plants that indicate water close by (v. 101–102) and plants that indicate water far away (v. 105). Are the first more associated with shallow water tables than the second? Is the broader set of indicator trees in vv. 6–96 more associated with shallow water tables than the typical recorded plant? Two are about depth. The text says that the same signs mean water at 3, 5 and 7 *puruṣa* in wet (*anūpa*), dry (*jāṅgala*) and desert (*maru*) country (v. 89). Does modern depth to water scale this way across climate? And are the stated depths physically plausible as depths that a root, or a well-digger, could reach?

The aim is not to show that the text "anticipated" modern hydrogeology, a framing that has attracted justified criticism in other contexts. The text is treated as a set of falsifiable empirical claims made by practitioners. We ask which of those claims are consistent with modern data at the scale the data allow, which are not, and which cannot be tested this way.

2 The text

2.1 Edition and structure

We use the GRETIL e-text of the *Bṛhatsaṃhitā* (GRETIL), which follows Kern's numbering (Kern, 1865). In that numbering the chapter is 53 (it is 54 or 55 in some later editions and secondary sources, e.g. Prasad, 1980; Singh et al., 2020). The chapter states its own composite origin. Verse 99 says that the preceding verses (in *āryā* metre) follow the *dakārgala* composed by the sage Sārasvata, and that what follows (in other metres) is the *mānava*, Manu's, version. The two parts differ in form. The Sārasvata section (vv. 6–98) gives individual signs, each with direction, distance and depth. The Mānava section (vv. 100–122) gives lists: plants indicating water near (vv. 100–102), plants indicating water far (v. 105), soils and rocks, then rock-splitting recipes, tank construction and water purification.

2.2 Units and regions

Depths are given in *puruṣa*. Following the commentator Bhaṭṭotpala, Prasad (1980) took 1 *puruṣa* = 5 *hasta* = 2.29 m (7 ft 6 in), the height of a man with arms raised. We report results under this convention and under a shorter 1.8 m (standing height) for sensitivity. The text distinguishes three kinds of country. *Anūpa* is wet or marshy land, *jāṅgala* is dry open land, and *maru* is desert. Verse 89 says the same signs indicate water at 3, 5 and 7 *puruṣa* in these three settings, and v. 86 says desert depths are double. Verses 62–85 form a separate desert sequence whose depths run from 5 to 75 *puruṣa* (11–171 m at 2.29 m).

2.3 Coding

We coded every plant named as an indicator, with its verse, its role (near, far, desert) and a modern botanical identification graded high, medium or low confidence (supplementary file `indicator_coding.csv`). Identifications follow the equivalences tabulated by Prasad (1980, Table III) where available, and common botanical-Sanskrit usage otherwise. Where usage conflicts, we graded the identification low and excluded it from primary analyses. One choice departs from Prasad: we read *kharjūra* as the wild date *Phoenix sylvestris* rather than the cultivated *P. dactylifera*, which is rare in peninsular India outside plantations. We cross-checked each identification in the two primary lists against the plant-name entries compiled by the Wisdom Library (Wisdom Library, 2026), which collect dictionary, Ayurvedic and botanical sources. Every identification we used is attested there, but several names have other attested identities: *śrīparṇī* (also *Premna* and *Clerodendrum* species), *sarja* (also *Vateria indica*), *śiṃśapā* (also *Dalbergia latifolia*), *madayantikā* (also glossed as a jasmine) and *śāka* (also *Terminalia chebula* in some dictionaries). A specialist study of the plants of the *Bṛhatsaṃhitā* (Sharma, 1976) was not accessible to us, and a check against it is the most useful next step for the coding. We also coded every stated depth for vv. 6–85 (48 statements; `text_depths.csv`). Two features of the coding matter later. First, *arjuna* (*Terminalia arjuna*) is listed both among near-water plants (v. 101) and among far-water plants (v. 105), and *bilva* (*Aegle marmelos*) appears in near-water pairings (vv. 18, 50, 76) and in the far-water list (v. 105). Second, many of the Sārasvata indicators are compound: the tree by itself is not the sign, but the tree together with an anthill or snake hole on a stated side.

Table 1. Plant lists used in the primary contrast (H1). Identification confidence in brackets. *Arjuna* appears in both lists and is excluded; low-confidence identifications (*vetasa*, *ariṣṭā*) and unidentified names (*chatra*, *ibha*, *aśvakarṇa*) are excluded from the primary test.

Near water, vv. 101–102 (W+)		Far water, v. 105 (W−)	
kharjūra	*Phoenix sylvestris* [m]	*śāka*	*Tectona grandis* [h]
jambū	*Syzygium cumini* [h]	*bilva*	*Aegle marmelos* [h]
nāga	*Mesua ferrea* [m]	*sarja*	*Shorea robusta* [m]
nīpa	*Neolamarckia cadamba* [h]	*śrīparṇī*	*Gmelina arborea* [h]
naktamāla	*Pongamia pinnata* [h]	*dhava*	*Anogeissus latifolia* [h]
sinduvāra	*Vitex negundo* [h]	*śiṃśapā*	*Dalbergia sissoo* [h]
vibhītaka	*Terminalia bellirica* [h]		
madayantikā	*Lawsonia inermis* [m]		

3 Hypotheses

The hypotheses, tests, data filters and sensitivity analyses were written into a timestamped analysis plan before any plant-occurrence or climate data were downloaded (supplementary `ANALYSIS_PLAN.md`). The groundwater file had been downloaded and its headers inspected, but nothing had been computed from it. The plan was not registered with a third party. Departures from it are listed in Section 8.

H1 (primary). Species in the near-water list (W+) are more enriched, relative to all recorded plants, in places with a shallow water table than species in the far-water list (W−), after controlling for climate.

H2. The tree indicators named in vv. 6–96 are, on average, more enriched at shallow water tables than the 300 most-recorded vascular plant species in India.

H3. Modern depth to water increases from wet to dry to desert climates, in the ratio 3:5:7 stated in v. 89.

H4 (descriptive). The stated depths fall within the range of modern depths to water in the corresponding climates, and within documented plant rooting depths.

4 Data and methods

4.1 Groundwater

We used the quality-controlled CGWB seasonal water-level release of Kuruva et al. (2025) (figshare, `https://doi.org/10.6084/m9.figshare.29293877`; CC BY 4.0). We used its 3-sigma-filtered table of 31,169 wells with readings in January, May, August and November, 2000–2024. For each well we took the median May (pre-monsoon) depth to water below ground level, requiring at least five May readings, which gave 15,505 wells. The primary analyses use the 11,530 dug wells among them, because dug wells tap the shallow unconfined aquifer that both phreatophytes and hand-dug wells depend on. Bore, tube and piezometer wells are included in sensitivity analyses. Wells were aggregated to 0.25° grid cells (about 27 km). A cell's depth to water (DTW) is the median of its wells' medians, for cells with at least two wells. This gave 2,385 cells for the primary analysis (Fig. 1a).

4.2 Climate

Annual mean temperature (BIO1), annual precipitation (BIO12) and precipitation seasonality (BIO15) were taken from WorldClim 2.1 at 10 arc-minutes (Fick and Hijmans, 2017), sampled at each cell centre. For H3, cells were classed as wet (BIO12 $\geq$ 1500 mm), dry (500–1500 mm) or desert (<500 mm) (Fig. 1b). These thresholds were fixed in the analysis plan as a coarse proxy for *anūpa*, *jāṅgala* and *maru*.

4.3 Plant occurrences

For every 0.25° cell intersecting the analysis grids (4,208 cells) we queried the GBIF occurrence API for records in India of vascular plants (Tracheophyta) with coordinates, no flagged geospatial issues, and a year between 1900 and 2025. For each cell we recorded the total number of vascular-plant records (sampling effort) and the exact number of records of each focal species and each of

the 300 most-recorded species in India. Queries were repeated for preserved (herbarium) specimens only, which are less likely than observations to record planted trees. Names were matched to GBIF accepted species keys (two coded names, *Anogeissus latifolia* and *Haldina cordifolia*, resolve to accepted synonyms).

4.4 Model

For each species s we fitted a binomial generalised linear model across cells,

$$y_{sc} \sim \text{Binomial}(n_c, p_{sc}), \quad \text{logit}\, p_{sc} = a_s + b_s\, z(\log \text{DTW}_c) + \mathbf{c}_s^{\top}\mathbf{x}_c,$$

where y_{sc} is the number of records of s in cell c, n_c is the total number of vascular-plant records in the cell, and $\mathbf{x}_c$ holds standardised log precipitation, its square, temperature and precipitation seasonality. Modelling the share of all plant records, rather than raw presence, controls for the very uneven sampling of GBIF data in India. This is the cell-level form of a target-group background (Phillips et al., 2009). Dispersion was estimated from the Pearson statistic (quasi-binomial). A negative b_s means the species makes up a larger share of records where the water table is shallow, at a given climate. Species with fewer than 20 records in the analysis cells were not fitted.

H1 compares the mean b of W+ with that of W−. Significance is by exact permutation of set labels among the pooled species, one-sided in the predicted direction (W+ < W−). Because individual-species standard errors ignore spatial autocorrelation, we also report a spatial block bootstrap (2° blocks, 300 replicates) of the difference. Two further checks on H1 were added after the results were seen (Section 8). **H2** compares the mean b of the broad indicator set with 10,000 random draws of equal size from the reference species (excluding any focal species). **H3** compares ratios of median DTW between climate classes, with 95% bootstrap intervals (cells resampled within class). **H4** compares the 48 stated depths with the distribution of per-well May DTW, all well types, in the corresponding climate classes, and with the maximum rooting depths compiled by Canadell et al. (1996).

Analyses used Python (statsmodels, rasterio). Code and derived data are described under Data availability.

5 Results

5.1 H1: near-water versus far-water plants

In the primary analysis (2,315 cells with both dug-well and plant data; 370,384 vascular-plant records), all 14 species in the two lists had enough records to fit. The near-water list (W+) had a mean coefficient of -0.165 and the far-water list (W−) $+0.232$, a difference of -0.397 in the predicted direction (exact one-sided permutation $p = 0.020$, 3,003 permutations; Table 2, Fig. 2a). Five of the eight W+ species were relatively more common where the water table is shallow, and five of the six W− species where it is deep. The spatial block bootstrap gave a 95% interval of -0.61 to -0.11 for the difference, so the result is not an artefact of treating neighbouring cells as independent. No single species drives it: dropping each of the 14 in turn left the difference between -0.48 and -0.32 (post hoc).

The result is, however, sensitive to analytic choices (Table 2). The difference kept the predicted sign in all six pre-specified variants, but it was significant at the 5% level in only three: the primary

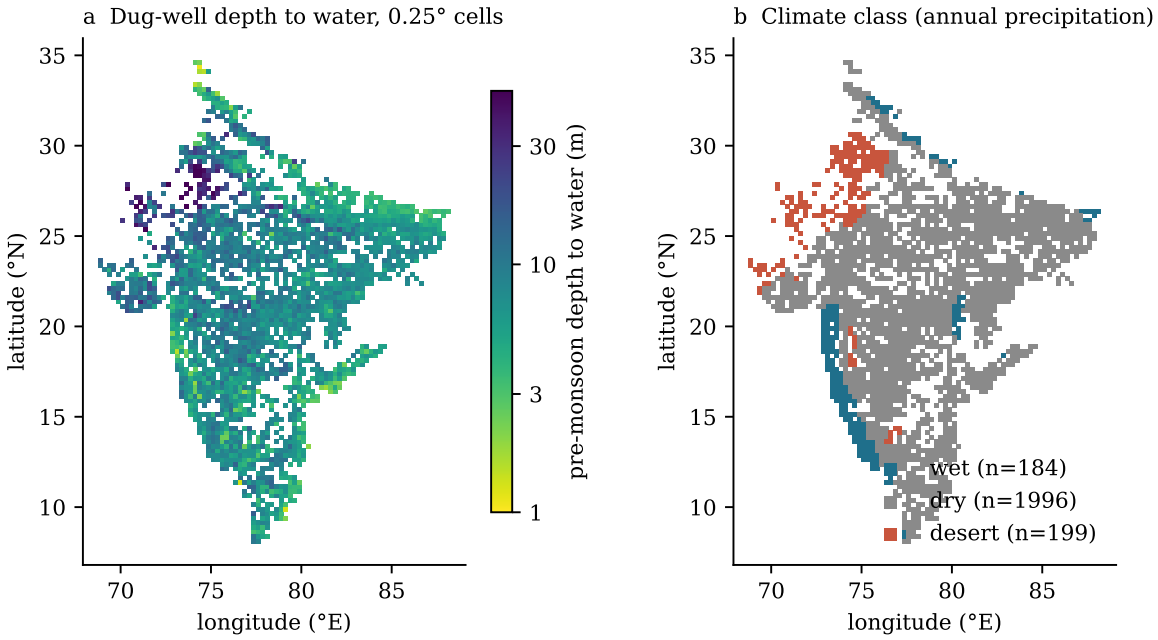


Figure 1. (a) Median pre-monsoon (May) depth to water in dug wells, 2000–2024, aggregated to 0.25° cells with at least two wells (2,385 cells). (b) Climate classes used as proxies for the text's wet (*anūpa*), dry (*jāṅgala*) and desert (*maru*) country. The north-eastern states and most of Jammu & Kashmir are poorly represented in the source data.

analysis, the analysis including the low-confidence name *ariṣṭā* ($p = 0.012$), and the herbarium-only analysis ($p = 0.048$, but with only six W+ and three W− species fitted). It was smaller and not significant when all well types were used (-0.18, $p = 0.12$), at 0.5° resolution (-0.25, $p = 0.12$), and in November (-0.03, $p = 0.45$). The November variant is not a like-for-like check: it adds 454 cells that have no qualifying May record, and 58 of them, on the south-western coast (south of 13°N and west of 77.5°E, mostly Kerala), hold 65% of its plant records.

The permutation test only asks whether the two lists differ from each other. As a stricter post-hoc check, we compared the observed difference with 20,000 pairs of lists of the same sizes drawn at random from the reference species. In the primary analysis, 3.8% of random pairs gave a difference as large in the predicted direction. In the all-wells, November and 0.5° variants the figures were 15%, 44% and 18%. Species' coefficients vary widely (standard deviation 0.40 among reference species in the primary analysis), so two short lists can differ by chance by about as much as W+ and W− do.

5.2 H2: the broad indicator set

H2 was not supported. The 33 identifiable trees named in vv. 6–96 had a mean coefficient of -0.032, against -0.015 for the 256 reference species fitted ($p = 0.43$ against random draws). Fifty-two per cent of the indicator trees had negative coefficients, compared with 60% of reference species. The result was the same in every variant (p from 0.19 to 0.77; Table 2, Fig. 2b). As a group, the trees used as signs in the Sārasvata section are no more concentrated where water is shallow than India's commonly recorded plants. Per-species estimates are given in Table 4.

Table 2. H1 and H2 across the pre-specified analysis variants. b is the change in log-odds of a record belonging to the species per standard deviation of log depth to water, controlling for climate; negative values mean enrichment where water is shallow. H1: mean b of the near-water list (W+) and far-water list (W−), their difference, and the one-sided exact permutation p for W+ < W−. H2: mean b of the vv. 6–96 indicator trees and of the reference species, with the one-sided p from 10,000 random equal-sized draws of reference species.

			H1					H2		
Variant	cells	records	n_+/n_-	$\bar{b}_{W+}$	$\bar{b}_{W-}$	diff.	p	$\bar{b}_{\text{broad}}$	$\bar{b}_{\text{ref}}$	p
Dug wells, May, 0.25° (primary)	2,315	370,384	8/6	-0.165	+0.232	-0.397	0.020	-0.032	-0.015	0.429
All wells, May	2,679	413,306	8/6	-0.120	+0.061	-0.181	0.122	-0.048	+0.005	0.189
Dug wells, November	2,735	1,152,861	8/6	+0.012	+0.038	-0.026	0.453	-0.129	-0.177	0.766
Herbarium specimens only	862	42,656	6/3	+0.031	+0.422	-0.391	0.048	—	—	—
Incl. low-confidence names	2,315	370,384	9/6	-0.192	+0.232	-0.424	0.012	—	—	—
Dug wells, May, 0.5°	855	642,005	8/6	-0.147	+0.098	-0.245	0.122	-0.128	-0.125	0.499

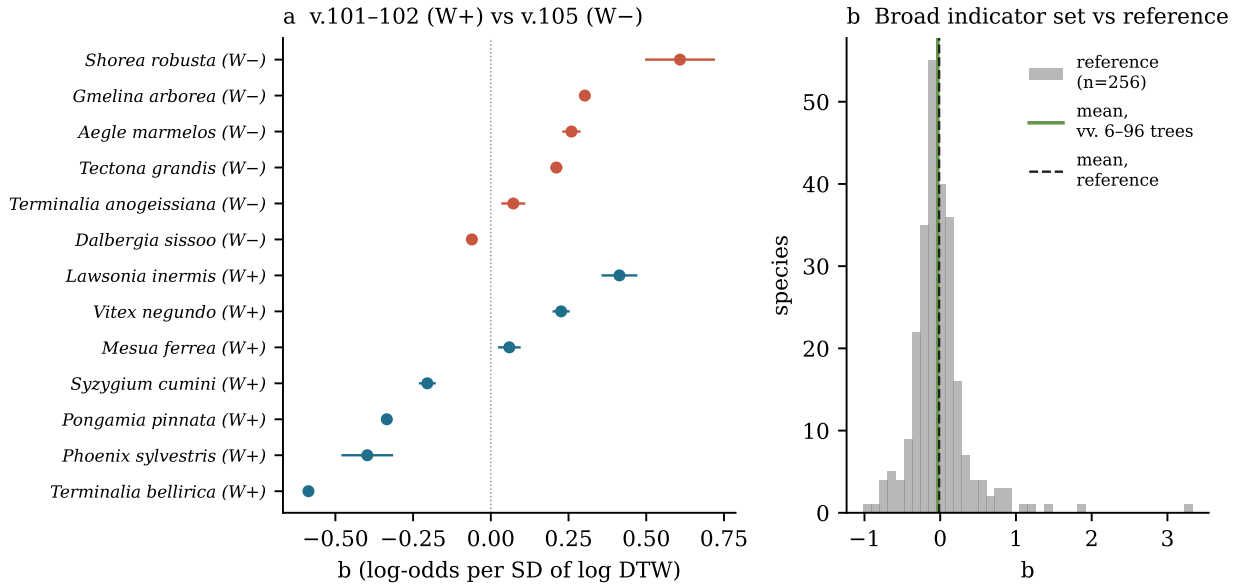


Figure 2. (a) Coefficient b for each species in the near-water (W+, vv. 101–102) and far-water (W−, v. 105) lists, primary analysis; negative values mean the species makes up a larger share of plant records where the water table is shallow, at a given climate. Bars are ±1 quasi-binomial standard error, which ignores spatial autocorrelation and is therefore too narrow. *Terminalia anogeissiana* is the accepted GBIF name for *Anogeissus latifolia*. (b) Distribution of b among the reference species, with the means of the reference species and of the indicator trees of vv. 6–96.

5.3 H3: depth scaling across climate

Modern depth to water increases monotonically from wet to dry to desert cells, as the text says (Fig. 3; Table 3). In the primary analysis (dug wells, May), median DTW was 6.7 m in wet cells (n = 184), 7.4 m in dry cells (n = 1,996) and 13.3 m in desert cells (n = 199). Across all cells, DTW falls with precipitation, with an elasticity of -0.41 (95% CI -0.47 to -0.36; log–log regression).

The proportions match the text only in part. The desert-to-wet ratio was 1.99 (95% CI 1.68–2.41), which brackets the text's 7:3 = 2.33. In every sensitivity analysis the interval either contains 2.33 or lies above it (Table 3). The dry-to-wet ratio, however, was 1.12 (1.03–1.25), well below the

Table 3. Ratios of median cell depth to water between climate classes (95% bootstrap CI), compared with the 3:5:7 rule of v. 89. Rows marked † were added after the analysis plan.

Variant	cells (wet / dry / desert)	dry / wet	desert / wet
Text, v. 89	—	1.67	2.33
Dug wells, May, 0.25° (primary)	184 / 1,996 / 199	1.12 (1.03–1.25)	1.99 (1.68–2.41)
All wells, May	188 / 2,267 / 302	1.17 (1.05–1.27)	2.55 (2.14–3.03)
Dug wells, November	412 / 2,198 / 200	1.29 (1.21–1.38)	3.72 (3.08–4.28)
Dug wells, May, 0.5°	67 / 692 / 102	1.18 (1.02–1.29)	2.42 (1.88–3.14)
Excluding NW states†	183 / 1,947 / 160	1.11 (1.03–1.25)	2.50 (2.03–3.09)
May 2000–2005 only†	140 / 1,355 / 113	1.10 (1.01–1.27)	1.65 (1.41–2.06)
Both of the above†	139 / 1,308 / 70	1.10 (1.02–1.28)	2.31 (1.76–3.22)

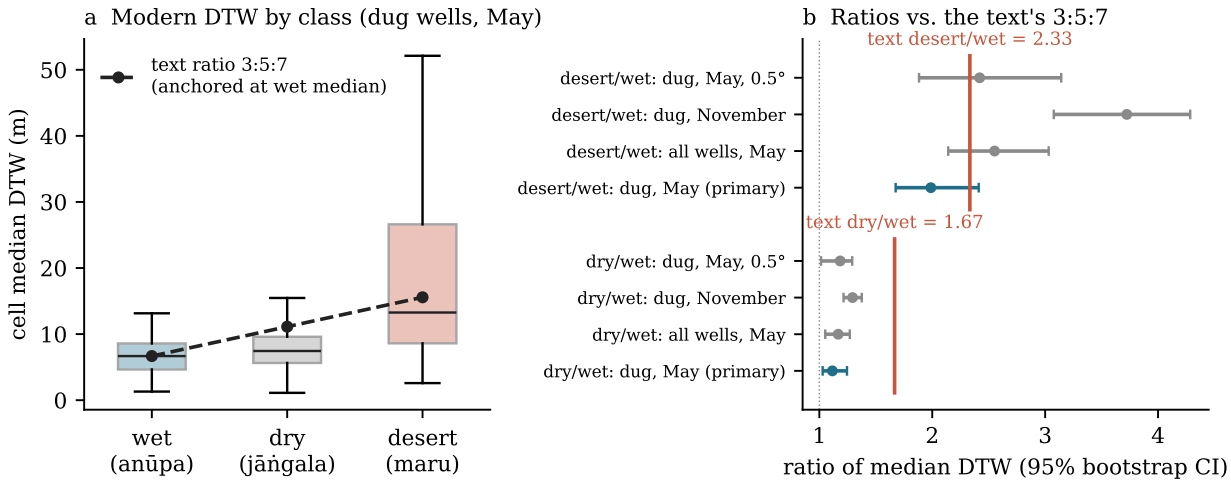


Figure 3. (a) Cell median DTW by climate class (boxes: interquartile range; whiskers: 1.5×IQR), with the 3:5:7 rule of v. 89 anchored at the wet-class median. (b) Ratios of class medians with 95% bootstrap intervals for the pre-specified variants, against the text's ratios (vertical lines).

text's 5:3 = 1.67, and no variant came close (largest upper bound 1.38). The text's step from wet to dry country is therefore too large relative to the modern data, while its overall contrast between wet country and desert is of the right size.

Pumping is an obvious confound: the deepest modern water tables in the "desert" class include the irrigated plains of Punjab and Haryana (Fig. 1). Two post-hoc checks, not in the analysis plan, address this. Dropping Punjab, Haryana, Delhi and Chandigarh raised the desert-to-wet ratio slightly (2.50, 2.03–3.09). Restricting to the earliest years (May 2000–2005) lowered it (1.65, 1.41–2.06). Neither moved the dry-to-wet ratio (1.11 and 1.10).

5.4 H4: plausibility of the stated depths

The 30 depths given for wet and dry country (vv. 6–59) range from 1.5 to 7.5 *puruṣa*, with a median of 3.4. That is 3.4–17.1 m (median 7.7 m) at 2.29 m per *puruṣa*, or 2.7–13.5 m at 1.8 m. They sit in the middle of the modern distribution. The median May DTW of all wells in wet and dry cells is 7.9 m (n = 13,985; dug wells only 7.2 m), and no stated depth exceeds the modern 95th percentile (24.8 m) (Fig. 4).

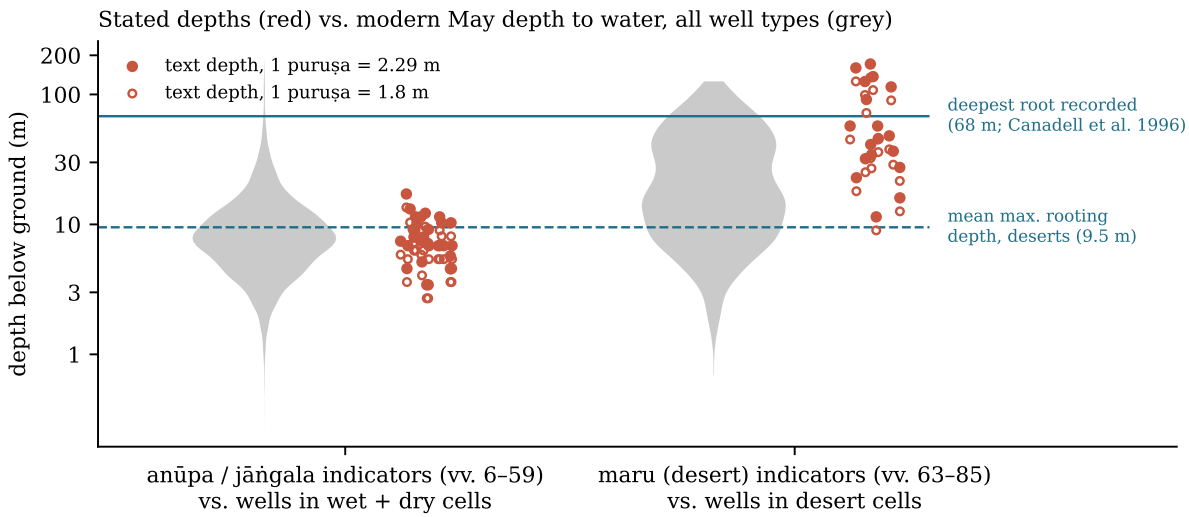


Figure 4. Depths stated in the text (red; filled at 2.29 m per *puruṣa*, open at 1.8 m) against the distribution of modern per-well May DTW (grey; all well types, 2000–2024) in the corresponding climate classes. Horizontal lines: deepest recorded plant root (68 m) and mean maximum rooting depth of desert vegetation (9.5 m), from Canadell et al. (1996).

The 18 desert depths (vv. 63–85) behave differently. They run from 5 to 75 *puruṣa*: 11–171 m, median 47 m, at 2.29 m. Modern May DTW in desert cells has a median of 17.5 m and a 95th percentile of 78 m (n = 1,520 wells; maximum 126 m). Six of the 18 stated depths (33%) exceed both the modern 95th percentile and the deepest root ever recorded, 68 m for *Boscia albitrunca* in the Kalahari (Canadell et al., 1996). The same six exceed 68 m even at 1.8 m per *puruṣa*. The mean maximum rooting depth of desert vegetation is about 9.5 m (Canadell et al., 1996). The desert sequence is also almost perfectly ordered: depth rises with verse number from 5 to 75 *puruṣa* with a single inversion (Spearman $\rho = 0.996$ between verse number and depth, $n = 18$).

6 Discussion

6.1 What the data support

The plant tests give a mixed answer. The Mānava section's two short lists point in the right direction: the near-water trees are, on average, relatively more common where the modern water table is shallow, and the far-water trees where it is deep. That ordering holds in every variant of the analysis. But it reaches conventional significance in the primary specification and only two of the five sensitivity analyses, and it is not large compared with the difference between two lists of species picked at random. We read it as weak, specification-dependent support, not a demonstration.

The ecology of the two lists suggests why they might separate. Several near-water trees are typical of stream banks and moist ground: *jambū* (*Syzygium cumini*), *nīpa* (*Neolamarckia cadamba*), *naktamāla* (*Pongamia pinnata*). The far-water list is largely made up of trees of dry deciduous upland forest: teak, *sāl*, *Gmelina*, *bilva* and *dhava*. A practitioner who had learned which trees grow along watercourses and which on dry ridges would produce lists like these. The same contrast is also a possible confound. Records of forest trees may come disproportionately from forest surveys, while *jambū* and *naktamāla* are widely planted along roads and in towns, so the two lists may differ

in how and where they are recorded as well as where they grow. The herbarium-only analysis, which keeps the direction of the effect, partly addresses this, but with very few species.

The broad set of trees used as signs in vv. 6–96 is, as a group, no more associated with shallow water than India's commonly recorded plants. This is consistent with how those verses work. In most of them the tree is not the sign by itself: what matters is a tree with an anthill or snake hole on a particular side, or a particular combination of trees. The broad set includes some of the commonest trees in India (*pippala*, *udumbara*, *madhūka*), and a sign that depended on the tree alone would have been useless. H2 therefore says little about the compound signs. It shows only that, as a group, the trees chosen as anchors are no more associated with shallow water than common plants, although some are individually (*udumbara*, *Ficus racemosa*, has one of the most negative coefficients of all coded taxa; Table 4).

The depth claims split cleanly by region. For wet and dry country the stated depths, about 3–17 m, are ordinary values for the shallow unconfined aquifer as it is measured today. That is what one would expect if they record the working knowledge of well-diggers. The text's rule that the same signs mean deeper water in drier country (v. 89) is also right in direction, and its overall contrast between wet country and desert (7:3) is within the range of modern ratios. Its intermediate step (5:3 for dry versus wet country) is too large: in the modern data, most of the increase in depth to water happens between dry country and desert, not between wet and dry. A rule with round numbers that gets the direction and the end points about right, but not the shape, is what one would expect from a practical heuristic rather than a measured relation.

6.2 What the data contradict

The desert sequence (vv. 63–85) cannot be a record of roots reaching water, which is the mechanism Prasad (1980) proposed for the chapter as a whole. A third of its depths are deeper than any plant root documented anywhere (Canadell et al., 1996), under either value of the *puruṣa*. The sequence is also arranged in nearly strict order of increasing depth, verse by verse, from 5 to 75 *puruṣa*. Such regularity is unlikely in a set of independent field observations, and more consistent with a schematic catalogue built to cover a range. Some of the deep values are not absurd as well depths: in the modern data, monitored water levels in desert cells reach 126 m. But they cannot be explained by the indicator plant sensing that water.

The text is also internally inconsistent in a way that matters for any claim of a coherent empirical system. *Arjuna* is listed as a near-water plant in v. 101 and as a far-water plant in v. 105, both in the Mānava section. *Bilva* is a near-water sign in combination (vv. 18, 50, 76) and a far-water sign alone (v. 105). The chapter says itself that it compiles at least two traditions (v. 99), so contradictions are not surprising. But they caution against reading the chapter as a single tested method.

6.3 What this study cannot test

The chapter's characteristic claims are about the micro-site: a particular tree with an anthill on its east side means water at two *puruṣa*, three cubits to the south. A 27-km grid cell cannot resolve that, because depth to water varies over short distances with topography (Fan et al., 2013), and this study does not test it. Our plant tests ask a weaker, regional question: do the named species occur disproportionately where the water table is shallow? A positive answer would be consistent with the indicators being useful, and a negative answer would not refute the local claims. The

appropriate test of the micro-site claims is a field design. One would select indicator trees, with and without the stated anthill configuration, and matched control trees in the same landscape, without knowledge of the groundwater. One would then measure depth to water at the predicted spot, using existing wells, electrical resistivity or test bores. The coding and depth tables provided here are intended to make such a test straightforward to pre-register.

6.4 Limitations

Four limitations bound every result above. (i) *Modern water tables are not ancient ones.* Twenty-five years of monitoring in a period of intensive pumping (Rodell et al., 2009; Asoka et al., 2017) is not a measure of sixth-century conditions. The post-hoc checks (excluding the most heavily pumped states; using the earliest years) leave the main conclusions unchanged, but they cannot remove the confound. (ii) *GBIF records are biased* toward cities, roads, protected areas and planted trees, and Indian GBIF data are dominated by a few tree-census datasets: mango and jackfruit are the two most-recorded species. Modelling each species' share of all plant records controls for overall effort but not for differences in what is recorded where. The specimen-only sensitivity analysis addresses this only partly. (iii) *Taxon identification* of Sanskrit plant names is uncertain. We graded it and excluded the least certain names, but a name could be wrong, particularly where other identities are attested (*nāga*, *sarja*, *śrīparṇī*; Section 2). (iv) *Precipitation classes* are a crude proxy for the text's *anūpa*, *jāṅgala* and *maru*, which are as much about soils and landscape as about rainfall.

7 Conclusion

Read as a set of empirical claims and tested against modern data at the regional scale, the *Dakārgala* is neither a lost science nor folklore. Its depths for ordinary country are the depths at which wells in India still find water. Its rule that water lies deeper in drier country is right in direction and, between the extremes, roughly right in size, though not in shape. Its two lists of near-water and far-water trees separate in the right direction, but the evidence is weak and depends on analytic choices. Its broad set of sign trees is unremarkable on its own, as one would expect if the signs were compound. Its desert sequence, with depths beyond the reach of any root and arranged in near-perfect order, is better read as a schematic catalogue than as a record of observation. Its own text says it combines at least two traditions, and it contradicts itself in places.

These are modest conclusions, and they depend on modern water tables altered by pumping, on biased occurrence data, and on identifications of Sanskrit plant names that a specialist should check. The chapter's most specific claims, about particular trees and anthills at particular spots, remain untested. The coding tables and analysis code released with this paper are meant to make a pre-registered field test of those claims straightforward.

8 Departures from the analysis plan

(1) Before any model was fitted, the `verse` field of the coding table was completed for seven taxa whose earlier verses had been omitted. This changed only the membership of the H2 set. (2) The spatial block bootstrap for H1 was added. (3) The H3 sensitivity analyses that exclude north-western states and use 2000–2005 data were added after the climate-class map showed deep, pumped water tables in Punjab and Haryana within the desert class. (4) After the H1 results were seen, a leave-one-species-out check and a comparison of the H1 difference with random pairs of

lists drawn from the reference species were added, because H1 was significant in the primary analysis but not in three of the five sensitivity analyses. All four are marked in the text and tables.

Data and code availability

Groundwater data: Kuruva et al. (2025); dataset Kumar et al. (2026), CC BY 4.0. Plant occurrences: GBIF.org (2026), queried through the public occurrence API on 1 November 2026 (per-cell counts are included with the code; a GBIF derived-dataset DOI will be registered before journal submission). Climate: WorldClim (2020). Sanskrit text: GRETIL. Code, the coding tables, the analysis plan and all derived data: available from the author on request, and to be deposited in a public archive with a DOI before journal submission.

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A Per-species coefficients

Table 4. Per-species coefficients, primary analysis. n: records in analysis cells; cells: cells with $\geq$1 record. Standard errors are quasi-binomial and ignore spatial autocorrelation, so they are too small; they are shown for ordering only.

Taxon	Sanskrit	set	n	cells	b	s.e.
Terminalia bellirica	*vibhītaka*	W+	563	130	-0.587	0.008
Ficus racemosa	*udumbara*	broad	2,393	250	-0.554	0.004
Neolamarckia cadamba	*nīpa, kadamba*	W+	1,153	205	-0.493	0.008
Phoenix sylvestris	*kharjūra*	W+	493	130	-0.397	0.042
Ficus hispida	*kākodumbarikā*	broad	281	140	-0.372	0.025
Pongamia pinnata	*naktamāla*	W+	5,611	243	-0.335	0.003
Hardwickia binata	*añjana*	broad	33	23	-0.309	0.047
Albizia lebbeck	*śirīṣa*	broad	1,068	166	-0.301	0.007
Salvadora persica	*pīlu*	broad	218	61	-0.263	0.017
Crateva adansonii	*varuṇaka*	broad	56	30	-0.254	0.023
Syzygium cumini	*jambū*	W+	5,475	283	-0.204	0.014
Ziziphus mauritiana	*badarī*	broad	1,559	168	-0.188	0.010
Madhuca longifolia	*madhūka*	broad	3,476	165	-0.132	0.327
Ficus religiosa	*pippala*	broad	5,542	351	-0.125	0.004
Limonia acidissima	*kapittha*	broad	62	37	-0.120	0.022
Haldina cordifolia	*haridru*	broad	90	49	-0.082	0.017
Dalbergia sissoo	*śiṃśapā*	W−	967	152	-0.061	0.007
Terminalia arjuna	*arjuna*	both lists	1,158	158	-0.030	0.009
Grewia asiatica	*parūṣaka*	broad	91	39	+0.010	0.020
Oroxylum indicum	*śoṇāka*	broad	68	46	+0.018	0.023
Mesua ferrea	*nāga*	W+	202	41	+0.060	0.019
Anogeissus latifolia	*dhava*	W−	243	85	+0.072	0.020
Ficus benghalensis	*nyagrodha*	broad	4,490	361	+0.086	0.004
Bauhinia variegata	*kovidāra*	broad	77	53	+0.088	0.056
Semecarpus anacardium	*bhallātaka*	broad	197	65	+0.101	0.064
Mallotus philippensis	*kampillaka*	broad	478	129	+0.118	0.021
Prosopis cineraria	*śamī*	broad	81	44	+0.158	0.017
Spondias pinnata	*āmrātaka*	broad	41	25	+0.174	0.086
Capparis decidua	*karīra*	broad	215	91	+0.174	0.024
Tectona grandis	*śāka*	W−	2,785	361	+0.211	0.010
Alstonia scholaris	*saptaparṇa*	broad	3,244	204	+0.217	0.006
Vitex negundo	*sinduvāra*	W+	279	125	+0.226	0.014
Aegle marmelos	*bilva*	W−	1,825	217	+0.259	0.015
Gmelina arborea	*śrīparṇī*	W−	1,142	109	+0.303	0.006
Butea monosperma	*palāśa*	broad	3,849	387	+0.327	0.009
Lawsonia inermis	*madayantikā*	W+	334	116	+0.414	0.029
Alangium salviifolium	*aṅkola*	broad	168	61	+0.442	0.023
Borassus flabellifer	*tāla*	broad	1,339	181	+0.508	0.011
Shorea robusta	*sarja*	W−	102	31	+0.609	0.057
Tecomella undulata	*rohītaka*	broad	45	24	+0.788	0.164