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External features of vegetation as hydrologic indicators in Varahamihira's *Brihat Samhita*

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Abstract

Varahamihira (A.D. 505–587), in his magnum opus *Brihat Samhita*, described various morphologic and physiologic features of vegetation as hydrologic indicators to locate sources of ground water at depths ranging from 3·43 m (11′–3″) to as much as 171·40 m (562′–6″). All these indicators are the responses resulting from high relative humidity and reduced transpiration in a microhabitat underlain by a ground water reservoir in arid and semiarid regions.

Key words: Hydrologic indicator plants, Geobotany.

1. Introduction

Varahamihira (A.D. 505–587) was a renowned astronomer, astrologer, and mathematician. His magnum opus *Brihat Samhita* is a massive compendium on diverse subjects of human and social interest. This great ancient Sanskrit work was published in *Bibliotheca Indica* by the German Indologist, Dr. H. Kern, who has also published an English translation in the *Journal of Royal Asiatic Society* of Great Britain and Ireland (1870–74) as a series of articles. Chidambara Iyer (1884) and Sastry and Bhat (1947) have also provided English translation of this work.

In this ancient Sanskirt work, the fiftyfourth chapter, entitled *dakargalam*, with 125 *slokas* (verses), deals with ground water exploration with a multidisciplinary approach[1–4] involving earth sciences and life sciences. Nowhere in this work did Varahamihira advocate water divining and all the methods, employed to locate sources of ground water, had empirical bases.

Varahamihira suggested various biological, pedological, geological, and geophysical characteristics as hydrologic indicators; and a critical study of these indicators reveals that they are all primarily the results of the interactions between biotic and abiotic environment due to high relative humidity consequential to the occurrence of ground water in arid and semiarid regions (Fig. 1). The hydrologic details, described in this ancient Sanskrit work, include :

1. The distance and direction, with respect to the hydrologic indicator, of occurrence of the aquifers and their depth varying from 3·43 m (11′–3″) to as much as 171·40 m (562′–6″);

2. Direction of flow of water in the aquifers;

3. Quality and quantity of water in the aquifers;

4. Geologic logs; and

5. Occurrence of certain cold-blooded animals—fish, lizard, rat, scorpion, tortoise, snake, and mongoose in the subsoil at depths in the range of 0·46 m (1′–6″) to 2·29 m (7′–6″); it refers to aestivation of the animals[3].

The details, described in the original Sanskrit *slokas*, have been given in Tables I and II. They are based on the following :

a. Bhattotpala, the commentator of *Brihat Samhita*[5], states that *purusha* is the distance or depth covered by an average man standing with his hands stretched overhead; it is equal to 5 *Hasthas*. *Hastha*, or cubit, which is the distance from the elbow to the tip of the fingers, is equal to 18 inches or 45·7 cm. Thus the units of measure, given in the *slokas*, are converted based on:

1 *Hastha* = 18 inches or 45·7 cm; and

1 *Purusha* = 5 *Hasthas* (cubits) or 2·28 cm (7′–6″).

b. In the existing literature, the Sanskrit name of a plant has been found to denote different botanical terms (Table III). It needs standardisation.

2. Ground water plants

The plant indicators suggested in this ancient work are the phreatophytes[7] whose roots habitually reach the water table (Fig. 2) and are largely independent of rain periodicity. With reference to each plant indicator, Varahamihira described the direction and distance of occurrence of the aquifer and its depth from the ground surface. Obviously these coordinates refer to those of the tip of the primary root descending to the water table (Fig. 3). From the data, given in various *slokas*[1], the following observations are made :

1. The primary root most commonly deviates, at some depth below ground, from the axis of the trunk and occurs at a distance, varying from 0·46 m (1′–6″) to 3·23 m (10′–6″).

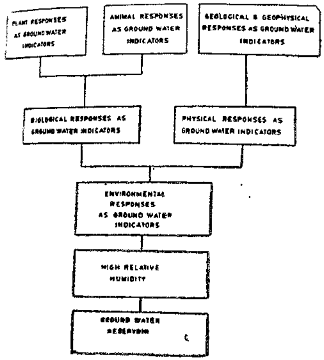


FIG. 1. Hydrologic indicators in Varahamihira's *Brihat Samhita.*

FIG. 2. The roots of a phreatophyte (*Ficus religiosa*) reaching the ground water penetrating the wall of a well which is at a distance of 10 feet from the tree; water table : 20 feet.

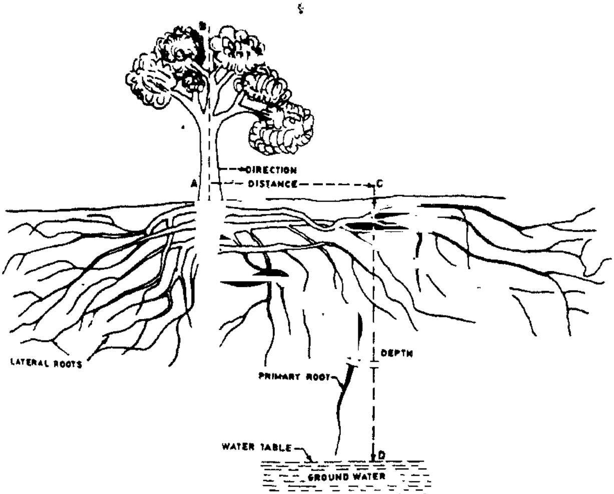


FIG. 3. Diagrammatic representation of the distance, direction, and depth of occurrence of the tip of the primary root of a phreatophyte; these coordinates refer to those of the ground water described in various *slokas* in *Brihat Samhita.*

FIG. 4. *Ficus benghalensis* united with *Azadirachta indica*; water table : 35 feet.

FIG. 5. *Borassus flabellifer* united with a *Ficus* sp.; water table : 15 feet.

FIG. 6. *Sapindus trifoliata* united with *Ficus* sp.; water table : 18 feet.

FIG. 7. *Ficus* sp., united with *Syzygium cumini*. Note the whiteness of the trunk of the *Ficus* sp.; water table : 40 feet.

Table I

Symbiotic plants as hydrologic indicators in Varahamihira's *Brihat Samhita*

Sl. No.	Sloka No.	Symbiotic plants	Position of the aquifer			Subsurface features
			Direction	Distance	Depth	
1.	17	Palasa and Badari	West	1·37 m (4'–6")	7·43 m (24'–4")	Nonpoisonous snake at a depth of 2·20 m (7'–6").
2.	18	Bilva and Udumbara	South	1·37 m (4'–6")	6·86 m (22'–6")	Black frog at a depth of 1·14 m (3'–9").
3.	72 73	Badari and Rohita	West	1·37 m (4'–6")	36·58 m (120'–0")	Tasty water. First a southerly flowing aquifer, next a pasty rock, next white clay, scorpion at a depth of 1·14 m (3'–9").
4.	74	Karira and Badari	West	1·37 m (4'–6")	41·15 m (135'–0")	Abundant water with north-easterly flow.
5.	75	Peelu and Badari	East	1·37 m (4'–6")	45·72 m (150'–0")	Inexhaustible, brackish water.
6.	76	(*a*) Kakubha and Karira or (*b*) Kakubha and Bilva	West	1·37 m (4'–6")	57–15 m (17'–6")	..
7.	83	Palasa and Sami	West	2·29 m (7'–6")	137·16 m (450'–0")	Snake at a depth of 1·14 m (3'–9"); next yellow clay mixed with gravel.
8.	96	(*a*) Nyagrodha, Palasa and Udumbara ; or (*b*) Nyagrodha and Pippala	..	1·37m (4'–6")	..	Aquifer with northerly flow.

Table II

Morphological and physiological features of vegetation as hydrologic indicators in Varahamihira's *Brihat Samhita*

Sl. No.	Sloka No.	Morphologic features of vegetation	Position of aquifer: Direction	Distance	Depth
1.	49	Extensively occurring, short trees ; glossy trees ; trees with elongated branches hanging down	..	..	..
2.	49	Hollow and rough trees with shattered leaves	No aquifer in neighbourhood	..	..
3.	52	Grassy patch on grassless ground or *vice versa*	..	..	..
4.	53	Thorny tree in the midst of thornless trees or *vice-versa*	West	1·37 m (4′–6″)	8·57 m (28′–1″)
5.	55	Tree with a branch lying low	Below the branch	..	6·86 m (22′–6″)
6.	56	Tree with unusual fruits and flowers	East	1·37 m (4′–6″)	9·14 m (30′–0″)
7.	57	Thornless *Kantakari* with white flowers	Below the tree	..	8·00 m (26′–3″)
8.	58	Date palm with two crowns	West	..	6·86 m (22′–6″)
9.	59	*Karnikara* or *Palasa* bearing white flowers	South	0·91 m (3′–0″)	4·57m (15′–0″)
10.	61	Perishing of grown crops	..	..	4·57 m (15′–0″)
11.	61	Glossy and extremely white vegetation	..	..	4·57 m (15′–0″)
12.	85	White thorny *Sami*	South	2·28 m (7′–6″)	171·45 m (562′–0″)
13.	92	Glossy trees	South	..	9·14 m (30′–0″)
14.	92	Tree in the midst of thick vegetation with unusual features	South	..	9·14 m (30′–0″)
15.	101 102	Tree with latex flow or glossy trees, shrubs, and creepers with densely covered foliage	..	..	6·86 m (22′–6″)
16.	105	Coarse shrubs and creepers with leaves full of pores	Aquifer far away	..	..
17.	106	*Kurba* with red laticiferous sprouts	..	..	..

Table III

Sanskrit names of the plants and their botanical equivalents

Sl. No.	Sanskrit name	Botanical name
1.	Badari	Zyzyphus jujuba ; Mucuna prurita; M. pruriens.
2.	Bilva	Aegle marmelos.
	Durva	Desmostachya bipinnata; Panicum dactylon ; Cynodon dactylon.
4.	Kukubha	Terminalia arjuna ; Bauhinia tomentosa
5.	Kantakari	Solanum xanthocarpum; Celastrus montana; Gymnosporia spinosa.
6.	Karira	Capparis decidua ; C. aphylla.
7.	Karnikara	Pterospermum acerifolium.
8.	Kharjura	Phoenix dactylifera.
9.	Nyagrodha	Ficus benghalensis; F. indica
10.	Palasa	Butea monosperma; B. frondosa; Erythrina indica.
11.	Peelu	Salvadora oleoides; Careya arborea; S. persica.
12.	Pippala	Ficus religiosa.
13.	Rohita	Andersonia rohitaka; Tecama undulata.
14.	Sami	Prosopis specigera; Acacia suma.
15.	Udumhara	Ficus racemosa; F. glomerata.

2. The main root, reaching the water table, shows preferred direction of physical orientation with respect to the trunk.

Zimmerman and Brown[8] (p. 56) have stated that "both primary and lateral roots will grow around an impenetrable object after which the root tips tend to reorient to their original direction of growth". Varahamihira's work reveals that the primary root of the phreatophyte exhibits 'polarity', *i.e.*, an universally occurring phenomenon resulting in oriented behaviour,

3. Morphological and physiological features of plants as hydrologic indicators

The occurrence of an aquifer in a waterless tract results in an environmental heterogeneity with a microclimate characterised by high relative humidity on the ground overlying the ground water reservoir. A rise in water table raises the relative humidity. The most important characteristic of the environmental heterogeneity involves the fact that variations in the supply of moisture become relatively widest at places where its quantity is the least; and not only are the variations widest here, but also the plant is more sensitive to it[10]. Clarke[11] (p. 117) has stated that " the concept of microclimate is particularly important in relation to moisture because relative humidity varies widely within short distances in any irregular habitat ".

High relative humidity decreases transpiration in plants[12]. *Various hydrologic indicators, suggested in this ancient Sanskrit work, are the plant responses resulting from high relative humidity and reduced transpiration, consequential to ground water occurrence in arid and semiarid regions.* These plant indicators (Tables I and II) of ground water include :

a. Symbiotic plants with commensal interaction;
b. Plant responses in relation to soil-water;
c. Features resulting from plant exudates;
d. Foliage;
e. Branching pattern;
f. Disorders in flowers and fruits;
g. Thorns; and
h. Knots.

In modern practice, geobotanical prospecting involves recognition of such morphologic and physiologic changes in vegetation. Brooks[13] (p. 38) has stated that " morphologic changes in plants under the influence of mineralization are very varied and includes such factors as dwarfism, gigantism, mottling or chlorosis of leaves, abnormally shaped fruits, changes in the colour in the flowers, disturbances in the rhythm of the flowering period, changes in growth form, and a large number of other indications ".

Modern literature does not contain any reference to morphologic or physiologic features of vegetation as ground water indicators and the present author during the course of his extensive geologic field work in different parts of South India has found innumerable cases in support of the observations made in this ancient Sanskrit work; a few of the photographs representing such cases are included in this paper.

4. Symbiotic plants

Varahamihira suggested that a tree united with another of different species was a hydrologic indicator. Thus he described eleven species of trees in ten different combinations

FIG. 8. *Ficus religiosa* united with *Phoenix sylvestris*; water table : 35 feet.

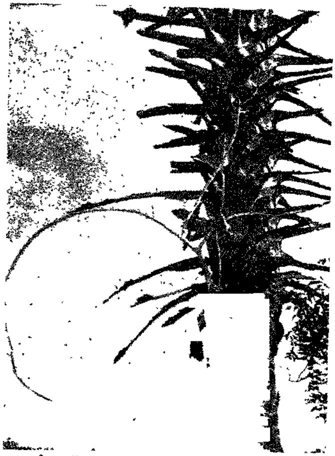


FIG. 9. *Ficus benghalensis* as epiphyte on *Borassus flabellifer*.

FIG. 10. (Right) : *Ficus religiosa* which started as an epiphyte sends down the roots establishing soil connection; (Left): on further growth the roots become thick tightly winding the trunk of the host tree till it is completely enclosed as shown in Fig. 5.

FIG. 11. *Ficus benghalensis* (right) sending out aerial roots as anchorage organs around the adjoining trunk of the neem tree (left). On continued growth, the roots enclose the neem trunk giving rise to a combined form as shown in Fig. 4. This plant community includes a liana. The arrow shows the occurrence of a termite mound in the foreground. Water table : 40 feet.

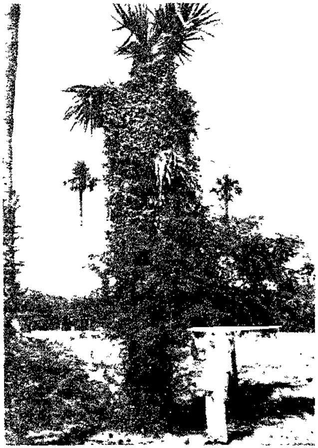
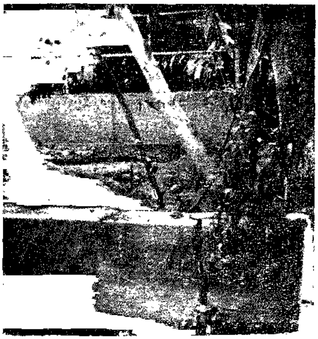


FIG. 12. Different types of lianas, *viz.*, *Tinospora cardifolia*, *Asparagus racemosa*, and *Albizzia amara* supported by *Borassus flabellifer*.

FIG. 13. Short, *Memecylon umbellatum* with an average height of 8 feet in the northern part of a coastal island; the same species, in the middle and southern parts of the island grows to an average height of 15 feet.

FIG. 14. Conspicuous whiteness on the trunks of the *Borassus flabellifer* which support varied types of lianas; water table: 18 feet.



FIGS. 15–17. Eucalyptus trees at the water tank. Note the low-lying branch developed for the tree on the extreme left (the branch was cut off and the remnant marked by an arrow) and whiteness of the trunk of the tree in the middle (Fig. 15). The trees of the same age and of the same species, grown away from the tank are dark-coloured (Fig. 17).

to locate sources of ground water at depths varying from 6·86 m (22′–6″) to as much as 137 m (450′) (Table I). It may be noted that the trees involved in the development of the combined forms are those for which the dispersal of seeds is by birds and animals. These combined forms of plants, according to McDougall[14], constitute 'social conjunctive symbiosis', *i.e.*, dissimilar organisms living in contact with each other. Some of the combined forms, recorded as hydrologic indicators, are shown in Figs. 4–8. Many of them, in the initial stages, occur as epiphytes (Fig. 9) which are augmented by warm humid climates (Daubenmire[10], p. 306). The epiphytes, on continued growth, establish soil connection (Fig. 10) and, on further growth the roots become profuse, thick, and woody tightly winding and ultimately enclosing the trunk of the host tree (Fig. 5). The symbiotic form of the neem and *Ficus* sp. is very common because the dispersal of the seeds of both these trees is by birds. When they grow together, *Ficus* sp. sends out, during its juvenile stage, the aerial roots from its trunk as anchorage organs winding around the adjoining trunk of the neem tree (Fig. 11); on continued growth the lower part of the trunk of the matured neem tree is completely enclosed giving rise to the development of such a combined form as shown in Fig. 4. In all these cases the ecologic interaction between the two species is commensalism.

4.1. *Lianas*

Varahamihira suggested, in *sloka* 87, that lianas (Fig. 12) are a hydrologic indicator. Further *slokas* 102–103 also state that the lianas associated with termite mounds are hydrologic indicators.

Daubenmire[10] (p. 304) has stated that the "abundance of lianas varied directly with the humidity and warmth of the climate, so that this ecologic class is most conspicuous in the moist tropics". The association of lianas and termite mounds suggests similar environmental conditions for their development. The termites, in general, are very susceptible to desiccation and the maintenance of a constant high humidity in their mounds is an essential prerequisite for the very survival of the species, especially of those that live in arid and semiarid regions. As a matter of fact, the physical connection between the termite mound and ground water, through subterranean termite shafts, has been shown by several workers[15–17]. Thus both lianas and termite mounds are the surface features which reflect high relative humidity to serve as ground water indicators.

4.2. *Responses in relation to plant-soil-water*

Sloka 52 states that a grassy patch on grassless tract and *vice-versa* are indicators of ground water. Capillary water is the source of almost all the water plant extracts from the soil. For all practical purposes only the upward movement of capillary water is important, and movement in this direction is significant only within a few feet of the water table.

Grassy patch in a grassless tract is due to the availability of soil moisture above the aquifer zone, while its surrounding area, due to physical dryness, develops into a grassless terrain. The reverse case, *i.e.*, a grassless patch in a grassy area, is a case of water-logged condition and the consequent physiological dryness due to the occurrence of water table at a shallow depth. When the pore spaces of the soil are filled with water, the plant roots which are suffocated due to suboptimal aeration do not flourish in much the same way as if the soil were too dry. In this regard, the case cited by Treshow[18] is significant : while digging footings for an apartment building, an underground spring was tapped inadvertantly and the water table was raised to within 2 feet of the soil line. Then the birch, maple and cottonwood trees with roots in the water-logged areas soon declined and ultimately died over three year period. The sensitivity and tolerance of a plant species to water-logged condition varies widely.

Varahamihira stated that perishing of grown crops (*sloka* 61), absence of germination, or withering of vegetation (*sloka* 95) are ground water indicators.

All these are again the cases of unfavourable conditions due to water excess as a consequence of the occurrence of an aquifer at a shallow depth. Perishing of grown crops reveals that environmental conditions favourable for the welfare of a plant differ at different stages of its life cycle. LeBarron and Neetzel[19] have found that the seeds of certain bog-inhabiting trees find conditions most favourable for germination on habitats that are distinctly too wet and unfavourable for the best growth of the matured trees.

4.3. *Short trees*

Sloka 49 states that extensively occurring short trees indicate ground water. This is another case arising from water-logged condition due to the occurrence of an aquifer at shallow depths. In such a soil condition, the root system is suffocated due to suboptimal aeration resulting in the suppression of growth. Bryant[20] and Doneen and MacGillivray[21] have shown that the shoots occupy less space due to suboptimal aeration. Reduced terminal growth due to water-logged condition of the soil has been observed both in small plants and forest trees.

4.4. *White vegetation*

Sloka 61 states that the vegetation serving as hydrologic indicator to be white. Further, it has been pointed out in *sloka* 77 that *Durva* grass, colonizing the termite mound, is white.

Whiteness is an imbalance symptom of water excess in vegetable and field crops. In the initial stages, the symptom is " white spot " [22] which occurs, in its mildest form, as bleached patches, and in its severest form, the entire leaflet is bleached. This is a consequence of hydration resulting from rapid absorption of water accompanied by increased humidity and reduced transpiration.

Whiteness in vegetation may also be due to 'guttation'. Water, containing copious amounts of dissolved solutes, is exuded through the hydathodes along the leaf margin ; when the water evaporates, the salts deposited on the leaf surface impart whiteness. Curtis[23] has cited that under cloudless, cool nights, grass guttated profusely, and lawns took on a whitish cast.

4.5. *Whiteness in trees*

The hydrologic indicator plants, *Rohitaka* (*sloka* 84) and *Sami* (*sloka* 85) have been described to be 'white'. It refers to the whiteness of the trunks of the trees. Under conditions of high relative humidity and reduced transpiration, root pressure manifests resulting in the exudation, on the trunks, of the sap which turns white. It is a common observation to find the trunks of certain species developing whitish cast when large branches are cut off. Ladefoged[24] has observed the independent relationship between the growths of shoot and root in that roots of stumps of felled trees began growing at the same time as those of the neighbouring in tact trees. The sap, exuded due to root pressure, often gives white appearance due to the evaporation of the sap and consequent deposition of the mineral salts.

Alternatively, the whiteness of trunks may be explained as follows : xerophytes are often characterised by dense hair or pubescence which bring about a decrease in transpiration. The covering hair is usually dead and, at maturity, is occupied by air ; such dead hair often appear white showing that large proportion of the light falling upon them is totally reflected.

White trunks of palmyra (Fig. 14), *Ficus* sp., etc., developed in areas of ground water existence, are of common occurrence. An interesting case of the development of whiteness is recorded from the botanical garden of the Sri Venkateswara University. The eucalyptus trees, grown adjacent to a water tank (Fig. 15), developed white trunks (Fig. 16), with the development of an elongated low lying branch which also serves as a ground water indicator (See Sec. 4.9.2). The eucalyptus trees, of the same species and of the same age, developed away from the water tank, have dark-coloured stem (Fig. 17). Obviously the development of whiteness on the trunk is due to high relative humidity resulting from the water tank.

4.6. *Latex flow*

Varahamihira pointed out (*slokas*: 100–102 and 106) that latex flow is a hydrologic indicator.

Dehydration of the trees causes withdrawal of water from the latex vessels leading to a decrease in the rate of latex flow which is the result of increased transpiration and decreased relative humidity[26]. Buttery and Boatman[27] have also shown that loss of water is responsible for decrease in latex flow. Conversely, high relative humidity causes increase in latex flow, which, therefore, serves as a hydrologic indicator.

4.7. *Glossy trees*

Varahamihira, in *slokas* 49, 50, 51 and 61, described the hydrologic indicator plants to be glossy.

Abundant hair, especially in leaves of certain trees in semiarid regions, produce resinous secretions[28] which have transpiration-retarding effect (Volkens, cited in Oppenheimer[29]). Waxes are also excreted by submicroscopic pores out to the leaf surface[30]. Such waxy and resinous substances which reduce transpiration impart glossy appearance to the trees.

4.8. *Foliage*

Varahamihira, in *slokas* 100–102, pointed out that the trees with densely covered foliage is a hydrologic indicator.

Plant canopy is formed of many layers of leaves (Fig. 18). The activity of the growth-promoting auxins is stimulated by high relative humidity resulting in the development of a full-fledged crown with profuse growth of branches and foliage. Such a tree exerts pronounced ecologic effects. The overlapping of the leaves result in a closed canopy in which shade is increased, wind velocity lowered, air temperature changed, humidity increased and CO_2 content of the air is lowered[31]. Daubenmire[10] (p. 344) has pointed out that "an experiment in fertilizing forest soil resulted in increasing the density of the tree canopy, which in turn had a marked effect on the epiphytic flora". It may be noted that the development of epiphytes, like plant canopy, is the result of high relative humidity.

4.8.1. *Sparse foliage*

Sloka 49 states that "hollow and rough trees with shattered leaves do not indicate water in the neighbourhood".

These are some of the important morphogenetic aspects of water on growth and form of the trees. These structural characteristics of the tree species in waterless tracts are collectively referred to as 'xeromorphy'. Zimmerman and Brown[8] (p. 162) have stated : "Any one who has observed trees growing under moisture stress in semiarid regions or on locally severe sites such as dry ridges, deep sands, or precipitous slopes, has noticed the crown becoming knarled and grotesque because of repeated dieback of terminal and lateral branches during recurrent years of severe moisture stress." Denmead[32] has pointed out that when the plant canopy is open, *i.e.*, with sparse foliage, a considerable amount of water may be lost by direct evaporation from the soil.

4.9. *Branching*

Varahamihira described different patterns of branching as hydrologic indicators which include : (1) tree with elongated branches hanging down (*sloka* 49) (Fig. 19); (2) tree

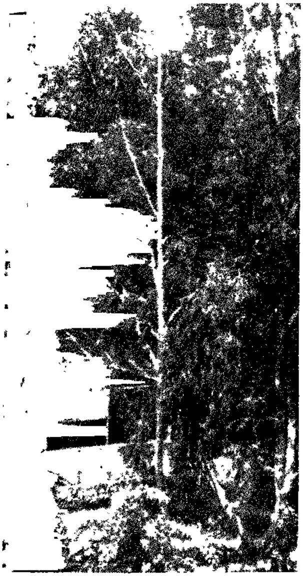


FIG. 16.

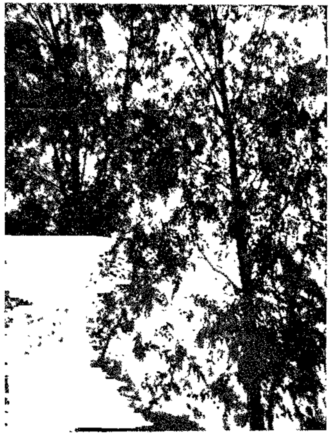


FIG. 17.

FIG. 18. Plant canopy formed of many layers of leaves in *Anacardium occidentale*; water table : 15 feet.

FIG. 19. Elongated branches of *Azadirachta indica* hanging down. In between the walls occurs a flight of steps leading to a well; water table : 50 feet.

FIG. 20. An elongated branch of *Mangifera indica* lying low; water table : 10 feet.

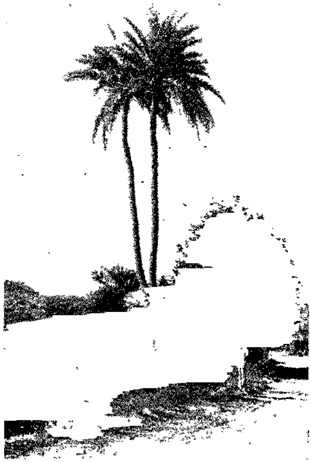


FIG. 21. *Phoenix sylvestris* with two crowns; note the plant canopy of *Tamarindus indicus* on the right; in its vicinity occurs a termite mound; water table: 30 feet.

FIG. 22. Coconut tree with two crowns. Some of the leaves were cut off to expose the branching.

FIG. 23. Thornless *Sami* (*Prosopis specigera*): In the foreground is the wall of a well which is situated at 10 feet distance from the tree; water table : 50 feet.

with an elongated branch lying low (*sloka* 55) (Fig. 20); and 3. *Kharjura* with two crowns (*sloka* 57).

4.9.1. *Elongated branches hanging down*

Zimmerman and Brown[8] have pointed out that the branches of a tree do not grow randomly in various directions but are regulated in their direction of growth by the interaction of gravity and light on internal hormonal mechanism. High relative humidity stimulates the growth promoting auxins resulting in the release of the buds from inhibition and elongation of the internodes. It is a common observation to find the trees, developed on the banks of streams, rivers, tanks, and other surface water bodies, having their branches conspicuously elongated and drooping towards the water surface while the landward branches have normal length and attitude. The regulation and positioning of lateral organs (shoots and roots) in space is termed 'plagiotropism'. The inclined position of lateral branches is the result of two opposing forces : (1) negative geotropism which tends to erect the branch, and (2) epinasty which tends to depress it. Drooping of the elongated branches is primarily a curvature response caused by epinasty brought about by the lateral or unequal growth of the branches for which the term 'gravimorphism' has been used by Waring and Nasr[33]. Varahamihira's work and the supporting field evidence reveal that the lateral branches become distinctly elongated and graviomorphic due to hydrotropism.

4.9.2. *Elongated branch lying low*

In certain trees a branch lying low is conspicuously elongated (Fig. 20) and such a morphologic feature was also cited as a hydrologic indicator; but in this case it does not droop; in spite of the elongation and massive size, the low-lying branch remains more or less horizontal. This feature is also commonly seen in trees developed on the banks of the surface water bodies, the elongated, low-lying branch extending over the water surface. The horizontal position of the elongated branch is interpreted in terms of strong apical control whereby the terminal leader exerts a pronounced epinastic response to counteract the negative geotropic response of the branch (Zimmerman and Brown[8], p. 137).

4.9.3. *Kharjura with two crowns*

Kharjura is an arborescent monocotyledon in which the vegetative lateral buds are absent leading to the columnar growth habit where unbranched stem simply terminates in a crown consisting of a tuft of leaves. Such a columnar form is an expression of the strongest apical dominance as the terminal main stem or leader maintains absolute control during its growth. But it is important to recognize that the final form and shape of tree crowns result from many inherent and environmental influences. An environmentally-induced modification, resulting from high relative humidity, involves development of lateral buds which may escape inhibition and develop into a lateral branch near the upper portion of a rapidly elongating terminal shoot and become organized with the same general pattern as that of the main axis to form a separate crown. Development of two crowns in *Phoenix sylvestris* (Fig. 21) and other arborescent monocotyledons, such as coconut (Fig. 22) and palmyra trees, grown on the ground underlain by aquifers, is not uncommon.

4.10. *Fruit disorders*

Trees with disordered fruits are said to be hydrologic indicators (*sloka* 56).

Under certain conditions, fruits act as reservoir of water for the rest of the plant[35]. Rupture of the outer portions of fruit, variously termed as splitting, cracking, or checking, is a common disorder in a number of fruits; and in nearly every case such fruit disorder is related to high relative humidity as shown in the case of apple, avocado, cherry, lemon, grape berries, and orange.

4.11. *Flowers*

Varahamihira suggested that white flowers borne by thornless *Kantakari* (*sloka* 57), *Karnikara* or *Palasa* (*sloka* 59) as hydrologic indicators.

The colour development in flowers often accompanies the accumulation of sugars and is stimulated by intense transpiration and strong illumination[35]. In other words reduced transpiration and weak light inhibits colour development. White flowers in *Kantakari*, *Karnikara*, and *Palasa* represent inhibition of colour development due to reduced transpiration following high relative humidity.

4.12. *Thorns*

Thorns of the trees have been utilised as hydrologic indicators. Varahamihira, in *sloka* 57, claimed the occurrence of ground water at a depth of 8·0 m (26′–3″) with the aid of thornless *Kantakari*.

Many xerophytes possess thorns as structural adaptations to decrease transpiration. Variations in the development of thorns occur due to variations in environmental conditions. Fritsch and Salisbury[35] (p. 507) cite the examples of the Gorse and Furze in which thorns are not developed when grown in a humid atmosphere. The absence of thorns in an otherwise thorny *Kantakari* is the result of high relative humidity. Fig. 23 is a thornless *Sami* in an area where ground water occurs at a depth of 50 feet.

Sloka 53 states that a flourishing thornless tree in the midst of thorny trees and *vice-versa* indicate ground water at a depth of 8·57 cm (28′–1″).

The existence of a thornless tree in the midst of thorny trees is due to high relative humidity as explained above. But Varahamihira also stated that the occurrence of a thorny tree in the midst of thornless trees is a hydrologic indicator. Such a case is said to be paradoxical and perplexing and classified, in modern science, as one of the

FIG. 24. *Azadirachta indica* with profusely developed knots; water table: 20 feet.

'obsolete adaptations '[10]. Thorns are mostly an expression of the tendency to increase woody tissue to serve as a transpiration check under conditions of high relative humidity.

4.13. *Knotty trees*

Sloka 81 points out that knotty *Sami* is a hydrologic indicator. Increase in woody tissue, forming a knot, like thorns, is a transpiration check under conditions of high relative humidity. Figure 24 shows the neem (*Azadirachta indica*) which is profusely knotty. A well dug nearby to this tree provides a perennial supply of water.

5. Varahamihira : The founder of hydrology

Meinzer[36], referring to the French physicist, Edmie Moriotte (c. 1620–1684), has stated that he " probably deserves more than any other man the distinction of being regarded as the founder of hydrology ". Tolman[37] who is the author of the pioneer text book dealing with ground water has stated : " Ground water is hidden in sub-surface interstices and escaped the serious attention of the father of all sciences, scientific curiosity, until intensive investigations beginning about forty years ago revealed the importance of ground water and many of the interesting phenomena accompanying its occurrence. " Wisler and Brater[38] have stated that " hydrology is a relatively new branch of the natural sciences ··· one need not go back many years to find a time when there was practically no literature on the subject". Such wrong notions are prevalent among the modern workers for the obvious reason that Varahamihira's work so far has not come to light. Certain other modern workers[6,39,40] dealt with historical development of hydroscience; but in these works also reference to Varahamihira's work is conspicuous by its absence. It may be pointed out that Varahamihira deserves more than anybody else the distinction of being regarded as the founder of hydrology.

6. Conclusions

Varahamihira described various plant responses, in a ground water ecosystem, as hydrologic indicators applicable to arid and semiarid regions. All the plant responses are those developed due to high relative humidity and reduced transpiration. The most significant aspect of this ancient work is that only those plant responses which are very obvious were employed as hydrologic indicators.

However the following points need emphasis :

1. The hydrologic indicators, in this Sanskrit work, are environmentally-induced variations acquired only as a result of continued exposure during prolonged period of the life cycle. Hence it should be noted that all morphologic features, employed as hydrologic indicators, are in relation to matured trees. These indications are not applicable to seedlings and very young plants.

2. The geobotanical indicators described are those which occur in natural surroundings. Man can create an atmosphere characterised by high relative humidity. For example, it is a common observation to find abundant epiphytic flora, lianas, termite mounds, etc., on the bunds of paddy and such other agricultural fields where high relative humidity prevails due to irrigated waters.

3. Sometimes a single morphologic or physiologic feature cannot be employed as a hydrologic indicator since the plant response is often similar to deficit and excess of water.

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