Description of rainfall variability in *Br hat -samhita* of Varâha-mihira

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Br hat -samhita of Varâha-mihira (5–6th century AD*) provides valuable information on the approach in ancient India towards monsoon rainfall, including its measurement and forecasting. In this context, we come across a description of the expected amount of total seasonal rainfall depending on the first rains under the 27 naks atras of Indian astronomy. This provides a rough statistical picture of what might have been the rainfall and its variability in the region around Ujjain, where Varâha-mihira lived. The coefficient of variation of the model, described by him, is 37%. This value is close to the present-day climatic variability of station-level monsoon rainfall in and around Ujjain, Madhya Pradesh.*

Monsoon variability may be defined as the tendency of seasonal rainfall to fluctuate about its long-term climatic normal value. When year-wise sample observations are available, one can find the normal value as the time average of the data series. The standard deviation of the sample provides a simple characterization of the variability. It is the usual practice to represent this deviation, as a percentage of the normal or mean value, and refer to it as the coefficient of variation. For example, the all-India (southwest) monsoon rainfall has a mean value of 85.24 cm with a standard deviation of 8.47 cm. This gives the coefficient of variation over a period of 130 years (1871–1990) to be nearly 10%. This would be higher for a smaller region such as a district or a State. It would be of interest to know whether this variability remains constant over time in a statistical sense. If this parameter were to be stable, it would hint that floods and droughts have been part of this normal climatic variability. There is considerable anecdotal description in ancient literature, to believe that the monsoon phenomenon was well known in India since early Vedic period (*c.* 4000–3000 BC). However, on the quantitative side, descriptions are meagre and sketchy. Information is available on how rainfall was measured, but the outcomes of the measurement are missing, except for some brief numbers. Interestingly enough, what little is available has reference to variability of rainfall in an obscure statistical fashion. With this in view, this note presents a brief review of available information followed by an interpretation of a set of statements appearing in the *Br hat -samhita* (*BS*) of Varâha-mihira (VM) from a modern perspective.

Artha-ú âstra

A review on measurement of rainfall in ancient India has been previously written by Srinivasan[1] and hence will not be repeated here. The earliest reference to rain gauges and regional distribution of rainfall is contained in the *Artha-ú âstra*[2], a treatise on statecraft authored by Kaut ilya in the 4th century BC. Kaut ilya states that rainfall over forest districts was 16 *Dron a* (*D*) and over Avanti it was 23 *D*. Since the above rainfall values are mentioned in an administrative manual, these might have been some kind of averages observed over a length of time. The ancient connotation of Avanti stands for the region of that name with its capital at Avanti City, generally identified with Ujjain (23°11′N 75°47′E). The extent of this region is not precisely known, except that it overlaps with the present-day subdivision no. 19 of the India Meteorological Department (IMD). From available data for 100 years (AD 1901–2000), the mean value of the June–September monsoon seasonal rainfall of this subdivision is 86 cm. If the months of October and November are also included, the six-month average increases marginally to 91 cm. The modern values cannot be compared with the figures of Kaut ilya, since he mentions his gauge to be a bowl with its mouth being about 40 cm (in diameter), with no information on the height. Thus, instead of comparing absolute values of rainfall, it would be worthwhile to compare the past with the present, in terms of a dimensionless parameter. It is in this context that the set of 27 rainfall quantities mentioned by VM in his *BS* acquires significance.

Br hat -samhita

There are several editions available for this ancient Sanskrit classic, with commentaries and translations in various languages. Here, the text edited by Ramakrishna Bhat[3] is used for further reference. *BS* devotes eight chapters to discuss rainfall, including measurement and forecasting. In chapter 23, a statement on the amount of rainfall to be forecast for the season, depending on the first rains in the month of *Jyes t ha* is given. The text reads,

Hastâpya-saumya-citrâ-paus n a -dhanis - t h âsu s od aú a dron âh |
Œatabhis ag -aindra-svâtis u catvârah kr ttik âsu daú a ||
Œravan e magh â'nurâdhâ-bharan î-mûles u daú a caturyuktâh |
Phalgunyâm pañcakr tih punarvasau vimœatirdron âh ||
Aindrâgnyâkhye vaiú ve ca vimú atih sârpabhe daœa tryadhikâh |
Âhirbudhnyâryamn a -prâjâpatyes u pañcakr tih ||
Pañcadaú âje pus ye ca kîrtitâ vâjibhe daœa dvau ca |
Raudre as t âdaú a kathitâ dron â nir u-padraves vete || *(ch.23.6-9)*

The rainfall quantified in terms of *Dron a,* stated in the verses is depicted in column 2 of Table 1. The *naks atra* s are proxies for the position of the Moon. This is an ancient Indian method of calendar reckoning, which is still popular. VM is categorical that rainfall measurement should start after the full moon in the month of *Jyes t ha* (June–July). Thus, he appears to have been particular about the onset of monsoon, which he has placed after the *Jyes t ha* full moon, spread over the next 27 days. Even though VM starts chapter 23 of *BS* with a qualitative prognosis based on first rains in the asterism of *Pûrvâs âd hâ* , he states the expected (or forecast) seasonal rainfall in terms of the values given in Table 1. Obviously, he was aware that the first rain could happen under any of the 27 stars. Hence, the above may be taken as an ancient way of describing what is presently known as variability of rainfall. The numbers themselves would have come from observations, which were definitely in vogue as understood from the details given by Kaut ilya and other ancient writers on the subject.

Since there is no connection between the first rains and the seasonal total (except to the extent the former is included in the latter), the rainfall given in *Dron a* should be interpreted as the climatic normal value, in a statistical sense. The day on which the rain starts is a random variable and over a long period, this would be under any one of the 27 *naks atra* with equal probability. Thus, if the rainfall amounts mentioned are meaningful, they may represent values observed with a probability of 1/27 for each *naks atra* . For example, in modern notation, probability of rainfall equal to 10*D* will be the same as probability of first rains in *Kr ttik â*, which will be 1/27. Similarly,

Probability ($R = 15$) = Probability (first rains in *Pus y a*) + Probability (first rains in *Pûrvâbhâdra*)
= 1/27 + 1/27 = 2/27.
Probability ($R = 4$) = 3/27;
Probability ($R = 25$) = 4/27.

Rainfall in cm and such associated probabilities are listed in the last two columns of Table 1. This provides a rough statistical picture of what might have been the climatic variability of rainfall in the region surrounding Ujjain, where VM lived during 5–6 century AD. Rainfall with the above discrete probability distribution has a mean value (m) of 15.59 *D* and standard deviation (σ) of 5.73 *D*. This gives the dimensionless coefficient of variability (σ/m) as 37%. This value is close to the present-day variability figures in the western part of Madhya Pradesh, including Ujjain (Table 2).

So far, no units have been invoked in discussing variability, which is the ratio of the standard deviation to the mean value. However, the close match of this quantity makes one wonder whether it is possible to convert the values stated in *BS* into modern-day equivalents. There are many difficulties in converting *Dron a* to metric units. Srinivasan[1] states that a *Dron a* is equal to about 5.1 cm of rainfall. But, Balkundi[4], a meteorologist, has found this conversion factor to be 6.4 cm. In Table 1, rainfall figures of *BS* are converted with $1D = 6.4$ cm and shown for easy reference. Average rainfall, according to this ancient text, will be 99.78 cm with a standard deviation of 36.67 cm. In Table 2, a few current average and standard deviation values for Ujjain and nearby stations are presented. Keeping in view the uncertainty involved in converting the ancient *Dron a* measure into modern figures, the present-day rainfall values seem to be broadly in the same range as the figures in *BS*. During ancient times, some parts of present Rajasthan and Gujarat were included in the geopolitical region of Avanti/Ujjain. Quite clearly, the coefficient of variation increases as one proceeds from Ujjain towards Jaipur in Rajasthan. Thus, the model of VM is consistent with the present-day understanding of rainfall distribution over the target region.

Time-series and probability distribution

The mean (m) and standard deviation (σ) are not efficient in reflecting extreme values. For this purpose, it is expedient to represent time-series data in the standard form $y = (R - m)/\sigma$ to visualize fluctuations about the mean and beyond the one-sigma level. For Ujjain town, the modern rainfall data are available for short lengths only. However, for Indore near Ujjain, reliable time-series data are available. These two stations have comparable coefficients of variability, as seen from Table 2. With this in view, station data of Indore are standardized and presented for the period 1901–2002 in Figure 1. For the ancient model of VM, a time-series has been artificially simulated according to the probability distribution of Table 1. This is also shown in Figure 1. This simulated time series has been based on a sequence of independent, uniformly distributed random numbers from 1 to 27. This is done to see how the two data compare, about their mean levels, when equal sample lengths are considered. Evidently, the simulated sample has no specific starting year and is devoid of any natural inter-annual variability pattern. Nevertheless, visual comparison of the two time series highlights the similarity of the variations therein. This can be better seen by constructing the relative frequency diagram or the probability density function for the two series on the same scale, as in Figure 2. It is observed that in the central parts of the distribution, the probabilities are comparable. Towards the right tail, indi-

Table 1. Rainfall variability model of VM

Serial number of 27 *naksatra* starting with *Krttik â*	Rainfall in *Drona*	Rainfall in cm (1 *D* = 6.4 cm)	Probability of occurrence
1	10	64	1/27
2, 9, 10, 24	25	160	4/27
3, 11, 12, 18, 21, 25	16	102.4	6/27
4	18	115.2	1/27
5, 14, 19	20	128	3/27
6, 23	15	96	2/27
7	13	83.2	1/27
8, 15, 17, 20, 27	14	89.6	5/27
13, 16, 22	4	25.6	3/27
26	12	76.8	1/27

Table 2. Monsoon seasonal rainfall over central Indian stations (1901–1980)

Station	N	E	Mean (cm)	Standard deviation (cm)	Coefficient of variability (%)
Ujjain	23°11′	75°47′	82.57	28.13	34
Indore	22°43′	75°48′	86.45	26.22	31
Guna	24°39′	77°19′	97.83	32.27	33
Dhar	22°36′	75°18′	85.74	25.92	30
Jaipur	26°49′	75°48′	55.57	22.61	42

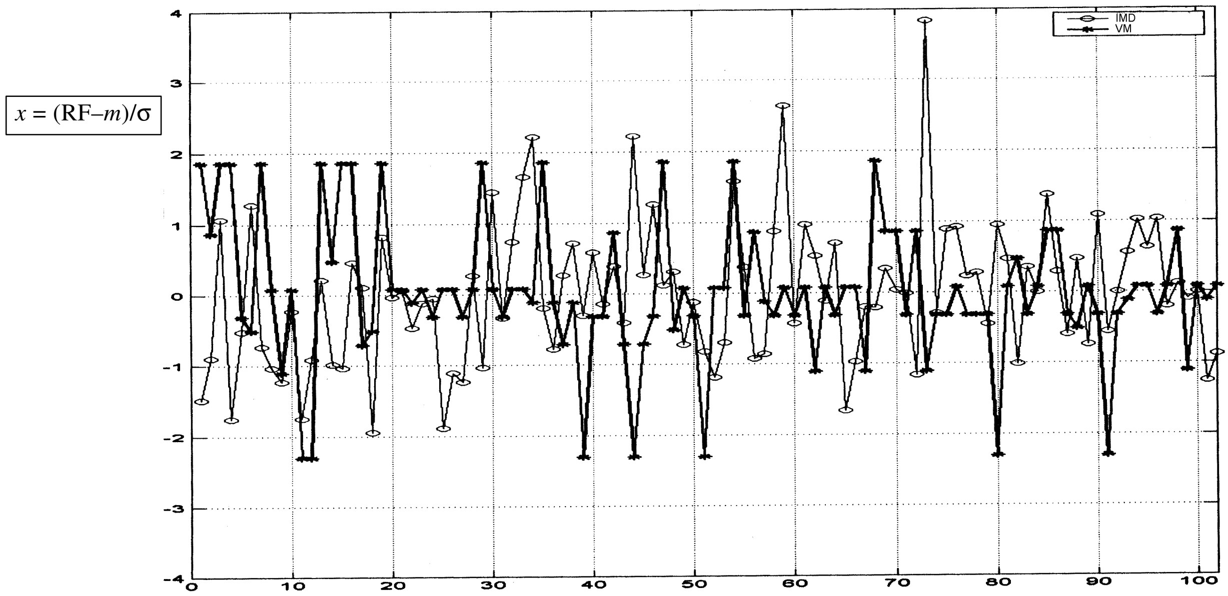

Figure 1. Standardized actual (IMD) and simulated (VM) rainfall time-series at Indore.

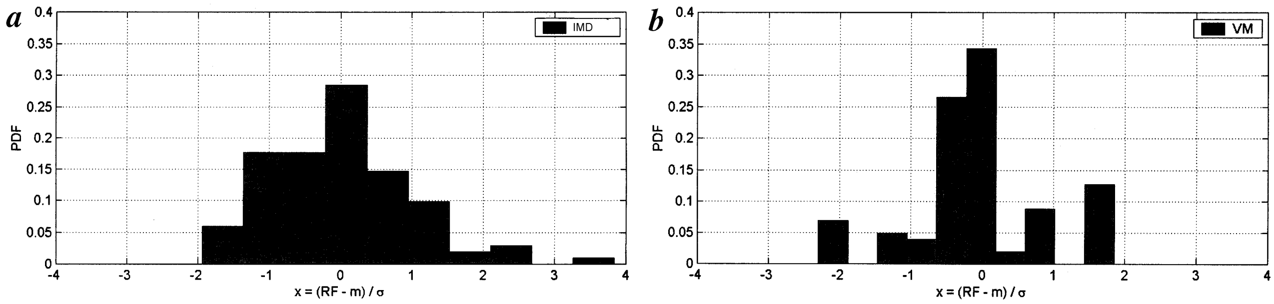

Figure 2. Comparison of probability density functions at Indore. ***a***, IMD (actual); ***b***, VM (simulated).

cating floods, the model of VM appears curtailed or saturated. The reason for this is traceable to the 27 number of states used by him. Had he used another calendar, he would have come out with 30 or more states resulting in a more spread-out distribution. However, on the left side of the distribution, the two probabilities again appear to be comparable. Conclusions that are more specific are not possible.

Conclusion

Ancient texts such as *Artha-ú âstra* and *BS* written before 6th century AD preserve vague, but definitively quantitative information on the amount of monsoon rainfall. It appears that VM had recognized that monsoon rainfall had considerable yearly variation. The list of 27 expected rainfall values, based on the occurrence of first rains, as stated in the *BS* is amenable for statistical investigation. Since, the conversion of *Dron a* measure to present-day linear measure is not conclusively established, it is not possible to directly compare the present-day average rainfall with the ancient value. However, the non-dimensional variability, defined as the ratio of standard deviation to climatic mean, of rainfall in the central part of India has perhaps remained stable over a long period.

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4. Balkundi, H. V., Commentary in '*Kr s i - Parâú ara*', translated by Sadhale, N., Agri-History Bulletin No. 2. Publ. Asian Agri-History Foundation, Secunderabad, 1999.

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