Biswas, A. K. (1970). The Post-Aristotelian Period. In A. K. Biswas, *History of Hydrology*, (pp. 52–57). Amsterdam: North-Holland Publishing.

Contents

4

The post-Aristotelian period

INTRODUCTION

After Aristotle, the headship of the Lyceum was taken over by his pupil and almost contemporary Theophrastus (371/370–288/287 B.C.). According to Diogenes Laertius he was called Tyrtamus in his early days but Aristotle was so impressed with his eloquence that he named him Theophrastus (the divine speaker). He was a voluminous writer and Diogenes ascribed the authority of some 227 treatises to him on all sorts of subjects. Nearly all his works are lost but one can draw some conclusions from what are available at present – fragments of treatises on *De signis tempestatum* (*pluvarium*, *ventorum*, *tempestatis* et *serenitatis*), *De ventis*, and *Meteorologica*.

Somewhere around the time of Theophrastus, the first ever quantitative measurements of rainfall were being taken in India. The credit for the measurements goes to a resourceful Chancellor of Exchequer, Kautilya, who decided to tax the land according to the precipitation it received which presumably would be an indirect form of taxation on agricultural products.

THEOPHRASTUS ON HYDROLOGY

The original work of Theophrastus on meteorology is lost. It was, however, translated into Syriac, and was later retranslated into Arabic by an anonymous Arab who also made an abstract of his translation. Bergsträsser[1] believed that the abstract was made in 1446 or 1447 A.D. by an unlearned and careless scribe from an Epicurean source of Theophrastus' work on meteorology. On the whole, it is presently accepted that the four pages of the available abstract are of Theophrastian origin.[2] It indicates that the meteorological concepts of Theophrastus followed the conventional pattern of that time, and probably begins at the point from which his great master left off. Some of the statements from his abstract, with brief discussions, will follow.

Snow falls when the clouds are frozen as they pass through cold before they have a chance to discharge their load of water. Present in the cloud are very small drops of water separated by air, and when freezing takes place snowflakes are formed with the drops containing some air caught in the process. When squeezed and compressed, snow turns into water but its bulk is reduced as the air escapes. The lightness and whiteness of the snow further supports the contention as it is due to the presence of the entrapped air. Frost and ice are produced due to congelation of dew through cold. Air again is the cause of whiteness of the ice and it is in fact a combination of snow on frost. Hail is caused when drops of water are congealed owing to moisture, and are round in shape either because the corners are broken off and smoothened as they fall (compare with Seneca's concept in chapter 5) or else due to the cold which at once compresses it into that form.

It can be said, with some justification, that Theophrastus was the first man to have a correct understanding of the hydrologic cycle,[3] and that the Roman architect Vitruvius later restated his ideas. In the abstract, the reason for the vapour to depart from water surfaces is attributed to the wind: 'the air often contracts, sometimes in the cast, sometimes in the west, or the north or the south; if it gathers there and finds no empty space, the air flows from one region to another lying opposite to it, because the empty space attracts it and with it withdraws vapour from the water and from the earth until there is no empty space left'.[1] Later Proclus in his commentary on *Timaeus* of Plato credited Theophrastus with saying, 'this ... is one cause of rain, viz. the pressure of clouds against a mountain'.[4] Still later, exactly the same reasons were expressed in almost the same words (see chapter 5) by Vitruvius who stated that he too had studied the works of Theophrastus carefully. It makes one strongly suspect that the concept of hydrologic cycle was first postulated by that Greek, and Gilbert [5] has made a strong case for such a suspicion.

In the beginning of his treatise *De ventis* (On winds), Theophrastus stated categorically that the causes and origin of winds have already been considered, and hence he will only deal with the effect of winds and the forces and conditions associated with them. He was probably referring to his own treatise *Meteorologica* (or conceivably to a work of the same name by his illustrious master). The third book, entitled *De signis tempestatum* (*pluviarum*, *ventorum*, *tempestatis* et *serenitatis*), or 'On weather signs (rain, wind, storm, and fair weather)', is a collection of notes concerning weather forecasting.

A typical one reads: 'If cranes fly early and in numbers there will be an early storm; but if late and for a long time, the storm will come later. And if they wheel in their flight they indicate a storm'.[6]

HYDROMETEOROLOGICAL OBSERVATIONS

Probably the Greeks were the first people to make systematic hydrometeorological observations. Theophrastus stated that many men were interested in meteorological observations in Greece as well as in Asia Minor. Such observations were not intended to include quantitative measurements of weather, but rather to present a more statement of fact such as 'it rained on such and such a date'. At times the hydrometeorological observations were publicly exhibited in the form of *parapegma* (astronomic tables or almanacs). This practice can be traced from the time of Meton and Euctemon in Athens around the fifth century B. C. A typical *parapegma* reads:[7]

September 5 – Rising of Arcturus. South wind, rain and thunder.
September 12 – The weather will likely change.
September 14 – Mostly fine weather for seven days, thereafter easterly winds.

The first quantitative hydrometeorological measurement (that of rainfall) however, dates back to the fourth century B.C. – to the celebrated minister of Chandragupta, founder of the Maurya dynasty of India.

RAIN GAUGE OF KAUTILYA

The earliest reference to a rain gauge was made by Kautilya in his book entitled *Arthasastra* (the science of politics and administration), which was probably written towards the end of the fourth century B.C. It is stated therein that: 'In (front of) the store house, a bowl with its mouth as wide as an *aratni* shall be set up as a rain gauge'.[8] He also stated in a later chapter entitled 'The superintendent of agriculture' that:

'The quantity of rain that falls in the country of jangala [forests] is 16 dronas, half as much more in moist countries; as to the countries which are fit for agriculture – 13½ *dronas* in the country of asmakas [Maharastra]; 23 *dronas* in avanti; and an immense quantity in Western countries, the borders of the Himalayas, and the countries where channels are made use of in agriculture. When one-third of the requisite quantity of rain fails both during the commencement and closing months of the rainy season and two-thirds in the middle, then the rainfall is [considered] very even.'[9]

Aratni was a normal unit of measure comparable to the cubit in length, about 18 in. – the distance from the elbow to the fingertips. The unit is still in use in certain parts of rural India but is now known as *hath* (hand). Unfortunately, Kautilya does not say anything about the shape of the rain gauge. In a comparatively recent translation of *Arthasastra*, the translator stated in a footnote that 'On the basis of about 511 cubic inches in a *drona* and a cylindrical rain gauge with a surface area of about 254.3 sq. inches, 16 *dronas* amount to be about 32 in. of rain; if the gauge-mouth is understood to be square (18 in. x 18 in.) they would amount to be about 25 in.'[10] According to Webster's dictionary, 1 *drona* is equivalent to 16.5 litres, and assuming 1 litre to be about 61.02 cubic inches, 1 *drona* would be equivalent to 16.5 x 61.02 = 1007 cubic inches. Under the circumstances the translator's figures represent only approximately one-half of the amount computed from the dictionary's definition.

Kautilya believed that forecasts of rainfall could be made from observations of the planets Jupiter and Venus, and of the Sun. His classification of clouds is of considerable interest.[11, 12]

‘Three are the clouds that continuously rain for seven days; eighty are they that pour minute drops; and sixty are they that appear with the sunshine – this is termed rainfall. Where rain, free from wind and unmingled with sunshine, falls so as to render three turns of ploughing possible, there the reaping of good harvest is certain.’[9]

The need for rain gauges arose for two reasons – lands were taxed according to the amount of rainfall[13] they received every year, and the fact that the Superintendent of Agriculture should have, of necessity, a good knowledge of rainfall for planting crops.[14]

The next quantitative measurements of rainfall were made in Palestine around the first century A.D.

CONCLUSION

Two obvious major developments during this period are the development of the concept of the hydrologic cycle, and the first quantitative measurements of rainfall on a rational basis. It is evident that Kautilya maintained a series of rain gauges over the subcontinent of India, and it is a great pity that the system was not continued after his time.

Philo of Byzantiuml[15] lived sometime after Ctesibius, who flourished around 283–247 B.C.(?), but before Vitruvius. He was aware of the need for repeating experiments[16] when formulating concepts of scientific progress.

‘And the ancient did not succeed in determining this magnitude by test, because their trials were not conducted on the basis of many different types of performance. But the engineers who came later, noting the errors of their predecessors and the results of subsequent experiments, reduced the principle of construction to a single basic element . . .’[17]

Philo was an ‘ordinary’ engineer and a practical man, not a philosopher. It is consequently not surprising that his idea did not get the support it deserved. Had Philo’s concept become popular, and had the philosophers accepted his recommended procedure, the history of the development of hydrology or in fact that of any other science would in all probability have been quite different.

REFERENCES

1. LUCRETIUS CARUS, TITUS, De rerum natura, vol. 3, edited by Cyril Bailey. Oxford, Clarendon Press (1947) pp. 1745–1747.
2. STAHL W. H., Roman science. Madison, University of Wisconsin Press (1962) p. 99.
3. MIDDLETON, W. E. K., A history of the theories of rain. London, Oldbourne Press (1965) p. 10.

4. PROCLUS, DIADOCHUS, Commentary of Proclus on Timaeus of Plato, translated by T. Taylor. London (1820) p. 101.
5. GILBERT, O., Die meteorologischen Theorien des griechischen Altertums. Leipzig, B. G. Teubner (1907) pp. 425–427.
6. THEOPHRASTUS, On winds and on weather signs, translated by J. G. Wood. London, Edward Stanford (1894) p. 67.
7. HELLMANN, G., The dawn of meteorology. Quarterly Journal of the Royal Meteorological Society 34 (1908) pp. 221–232.
8. KAUTILYA, Arthasastra, translated by R. Shamasastry. Bangalore, India, Government Press (1915) p. 64.
9. STAHL W. E., *op. cit.*, p. 143
10. KAUTILYA, Arthasastra, translated by R. P. Kangle. Bombay, University of Bombay Press (1963) p. 171.
11. SAMMADAR, J. N., Indian meteorology of the 4th century B.C. Quarterly journal of the Royal Meteorological Society 37 (1912) pp. 65–66.
12. ANONYMOUS, The antiquity of the raingauges. Scientific American 144 (1912) 236.
13. ANONYMOUS, Irrigation in India through the ages. Central Board of Irrigation of India (1951).
14. BISWAS, ASIT K., Development of raingauges. Journal of Irrigation and Drainage Division, ASCE 93 (1967) pp. 99–124.
15. CLAGETT, M., Greek science in antiquity. London, Abelard – Schuman Ltd. (1957) p. 76.
16. EDELSTEIN, L., Recent trends in the interpretation of ancient science. Journal of the History of Ideas I3 (1952) pp. 573–604.
17. COHEN, M. R. and I. E. DRABKIN, A source book in Greek science. Cambridge, Harvard University Press (1948) p. 318.