

**INTERCEPTION, INFILTRATION AND  
EVAPOTRANSPIRATION**

In the hydrological cycle, water which falls as rain reappears as infiltrated water, runoff, surface and underground water storage. This is also called as rainfall partitioning in modern hydrologic literature. The surface and ground water reservoirs are constantly getting replenished by recharge (precipitation) and depleted by evapotranspiration. The concepts related to the various components of rainfall partitioning were well conceived by the ancients Indians. This chapter briefly discusses about the ancient knowledge in this field as available in the Vedas and other ancient Indian literature.

**Interception and Infiltration**

Interception is the part of the rainfall that is intercepted by the earth's surface and which subsequently evaporates. Interception can amount to 15-50% of precipitation, which is a significant part of the water budget. One can distinguish many types of interception, which can also interplay with each other (Geritts, 2010). The term infiltration is used to describe the process involved where water soaks into or is absorbed by the soil (Horton, 1933) and it is one of the important components of the hydrologic cycle. In the hydrologic cycle, water from the oceans and various surface bodies on the land evaporates and becomes part of the atmosphere. The evaporated moisture is lifted and dispersed in the atmosphere until it precipitates on the land or in the ocean. The precipitated water may be intercepted and used in transpiration of the plants or may run over the ground.

Some references to interception are found intermixed with other topics in ancient Indian literature, such as explaining the effect of forests and vegetation on rainfall, cloud formation and environmental purification. Taithiriya Samhita mentions the effect of forests on causation of rainfall (TS. II, 4.9.3)

सौभययैवाहुत्या दिवो वृष्टिमव रुन्धे मघुषा सं यौत्यपां  
वा एष ओषधीनां रसो यन्मध्वभदय एवौषधीभयो वर्षत्यथो  
अद्भय एवौषधीभयो वृष्टिं नि नयति ॥ TS,II,4.9.3 ॥

The verses 184.15-17 of Mahabharata state that the plants drink water through their roots. The mechanism of water uptake by plants is explained by the example of water rise through a pipe. It is said that the water uptake process is facilitated by the conjunction of air. This clearly reveals the knowledge of capillary action of soil in movement of water up and down as:

पादैः सलिलपानाच्च व्याधीनां वापि दर्शनात् ।  
व्याधिप्रतिक्रियत्वाच्च विघते रसनं द्रुमे ॥ MB.XII,184.15 ॥

वक्त्रेणोत्पलनालेन यथोद्ध्वं जलमाद्देत ।  
तथा पवनसंयुक्तः पादैः पिवति पादपः । MB.XII,184.16 ॥

As far as infiltration is concerned, the scholar, Varahamihira clearly reveals it in the opening shloka of the Vrhat Samhita. Verse 1 tells us that at some places water table is higher and at others it is lower as:

पुंसां यथादेन शिरास्तथैव क्षितावपि प्रोन्नतनिम्नसंस्थाः (Vr.S,54.1)

It implies that the water veins beneath the earth are like veins in the human body, some higher and some lower. Verse 2 reads like this.

एकेन वर्णेन रसेन चाम्भश्च्युतं नभस्तो वसुधाविशेषात् ।  
ननारसत्वं बहुवर्णतां च गतं परीक्ष्यं क्षितितुल्यमेव ॥ Vr.S.,54.2 ॥

It says that the water falling from sky assumes various colours and tastes from differences in the nature of earth. Thus, it implies that the infiltration of rainwater is the source of groundwater. The ground water is a complex function of rainwater. Rainwater originally has the same colour etc., but assumes different colours and tastes, after coming down to the surface of the earth and after percolation.

Three verses quoted by Bapudeva Sastri (in Sindhanta Siromani by Bhaskaracharya, Part II, Goladhayaya, Tripathi, 1969) belonging to an era prior to 1200 A.D., provide scientific details of the phenomena of fog or mist (for which the term रजः संहति has been used). The verses purport to say that at the end of rainy season dissipated clouds (moisture) hang near the surface of the earth and eclipse mountains, trees, vegetation cover or gardens and disappear through the activity

of air and heat from these surfaces. This clearly reveals the fact of interception by earthy materials, vegetation etc. and its disappearance with time by the activity of air and heat.

### **Evapotranspiration**

The phenomena of evaporation and evapotranspiration and its interrelation with other hydrological processes were well understood by ancient Indians as evidenced by Vedic and other ancient literature. In Rig Veda (I, 6.10) it is mentioned that the sun ray breaks the water contained in the earth and other materials into minute particles, then these minute particles ascend by air and form clouds as:

इतो वा सात्तिमीमर्हे दिवो वा पार्थिवादधि ।

इन्द्र महोवार जसः ॥ R.V. I,6.10 ॥

नव्यं तदुक्थ्यं हितं देवासः सुप्रवाचनम् ।

ऋतमर्षन्ति सिन्धवः सत्यं तातान सूर्यो वित्तं मे अस्य रोदसी ॥ R.V.I,105.12 ॥

The verse I,105.12 of Rig Veda says that the water from the sea etc., evaporates due to the heat of Sun rays, which is the primary cause of rain formation. The same fact is revealed in the verse IV, 58.1 of Rig Veda as:

समुद्रादूर्मिर्मधुमां उदारदुपांशुना समृतत्वमानट् ।

घृतस्य नाम गुह्यं यदस्ति जिह्वा देवनाममृतस्य नाभिः ॥ R.V.IV,58.1 ॥

The verse VIII, 72.4 of the Rig Veda says that the atmospheric air gets heated due to Sun, then this heat reaches the Earth and converts the humidity into vapour and collects it as clouds, which is the cause of the rain and food production as:

जाम्यतीतये धनुर्वयोधा अरुहद्वनम् ।

धर्दे जिह्वायवधात् ॥ R.V.VIII,72.4 ॥

Like Rig Veda, the Yajur Veda also contains some knowledge about evaporation along with transpiration as:

देवो वनस्पतिर्देवमिन्द्रं वयाधसं देवो देवमवर्धयत् ॥ Y.V.,28.43 ॥

देवो देवैर्वनस्पति हिरण्ययर्णो मधुशाखः सुपिप्पलौ देवमिन्द्रमवर्धयत् ॥ Y.V.,28.20 ॥

It says that the vegetation attracts water from Earth and evaporates it to the atmosphere due to heat, wind etc. to form clouds. Similarly, Atharva Veda (IV, 25.2 and IV, 27.14) says that due to universal Sun and air, the water goes to the sky and comes back as rain. The evapotranspiration is caused due to Sun rays and wind as:

ययोः संख्याता वरिमा पार्थिवानि याभयां रजो युपितयन्तर्क्षे ।

ययोः प्रायं नान्वानशे कश्चन तौ नो मुञ्चतमंहसः ॥ A.V. IV.25.2 ॥

अपः समुद्राद दिवमुदवंहन्ति दिवस्पृथिवीमभि ये सृजन्ति ।

ये अभिदरीशानां मरुतश्चरन्ति ते नो मुञ्चन्तंहसः ॥ A.V. IV,27.74 ॥

The verse I, 173.6 of the Rig Veda states that the atmosphere encompasses the Earth.

प्र यदित्था महिना नृभयो अस्त्यरं रोदसी कक्ष्ये नास्मै ।

सं विव्य इन्द्रो वृजनं न भूमा भर्ति स्वधावां ओपशमिव घाम् ॥ R.V. I,173.6 ॥

The solar phenomena are associated with the vault of the sky or heaven, while lightning. Rain and wind are referred to as occurring in the atmosphere (R.V., IV, 53.5, III., 56, I., 108.9-10) but it is doubtful whether the Rig Veda knew or guessed exactly the limit or the vertical height of the atmosphere, from these verses:

यदिन्द्राग्नी परभस्यां पृथिव्यां मध्यमस्यामवमस्यामुत स्थः ।

अतः परि वृषणावा हि यातमथा सोमस्य पिवतं सुतस्य ॥ R.V. I,108.9-10 ॥

षड् भारों एको अचरन्विभर्त्युतं पर्षिष्ठमुप गाव आगुः ।

तिस्त्रो महीस्परास्तस्थुरत्यागुहा द्वे निहिते दश्येका ॥ R.V. III, 56.2 ॥

त्री षधस्था सिन्धवास्त्रिः कवीनामुत त्रिमाताविदयेषु सम्राट् ।

ऋतावरीर्योषणास्तिस्त्रो अप्यास्त्रिरा दिवो विदये प्रत्यमानाः ॥ R.V.,III,56.5 ॥

त्रिखारिक्षं सविता महित्वना त्री रंजासि परिभूस्त्रीणि रोचना ।

तिस्त्रो दिवः पृथिवीस्तिस्त्र इन्वति त्रिभिन्नैरभि नो रक्षति त्मना । R.V.,IV,53.5 ॥

We read “Savitr (the Sun) encompassing them by magnitude pervades the three divisions of the firmament, the three world, the three brilliant spheres, the three heavens, the three-fold Earth. In

this connection a very significant question comes in to mind whether the three divisions of firmament denote troposphere, stratosphere, and ionosphere? Again in the triple divisions of the earth are we entitled to identify frigid, temperate and torrid zones, for different schools regarding Aryan home do recognize the Rig Vedic Aryans' knowledge about frigid and temperate zones and, it is just possible that in course of their ocean voyages and advances for habitat, they might have known torrid zone also.

The Vedic people were well aware that plants (or forests) had some influence on the loss of water and causation of rainfall (TS., II,4.9.3).

सौभययैवाहुत्या दिवो वृष्टमव रुन्धे मघुषा सं यौत्यापां वा एष ओषधीनां  
रसो यन्मध्वभदय एवौषधीभयो वर्षस्यत्यथो उद्भय एवौषधीभयो वृष्टिं नि नयति ॥ TS.,II,4.9.3 ॥

The concept and role of insolation is also referred to in the Taithiriya Samhita. Agni (Insolation) causes the rain to arise (T.S., II,4.10.2) as:

अहोरात्राभयां पर्जन्यं वर्षयतो ग्नेये धामच्छदे पुरोडाशमष्टाकपालं निर्वयेन्मारुतं  
सप्तकपालसौर्यमेककपालमग्निर्वा इतो वृष्ट मुदीरयति मरुतः सृष्टां नयन्ति यदा खलु  
वा असावादित्यो न्यङ्. रष्मिभिः प्यावर्ततेथ वर्षति धामछदिवि खलु वै भूत्वा  
वर्षत्येता वै देवता वृष्टया ईशते ता एवं स्वेन भागधेयेनोप धावति ता ॥ TS.II,4.10.2 ॥

The epic Ramayana also furnishes a lot of information regarding the atmosphere, its conditions and cosmic regions, up to the distance of the Moon from the Earth. Entire atmospheric cosmic stretch was divided into nine regions, where last one is the longest. Ramayana (I.47.4) describes mythically the origin of the atmospheric regions.

वातस्कन्धा इमे सप्त चरन्तु दिवि पुचक ।  
मारुता इति विख्याता दिव्यरुपा मामात्मजाः ॥ Ramayana.I,47.4 ॥

Intensive insolation and high temperature work as an agency of destruction or dispersion of the existing clouds is spoken of in VI.43.29 of Ramayana as:

निर्विभेद शरैस्तीक्ष्णैः करैर्मैघमिवांशुमान् ॥ Ramayana.VI,43-29 ॥

In the Ramayana, we read about evaporation by the Sun's rays in general verse (II.105.20), and about the formation of clouds due to solar heating of the ocean (VII,32.68) as:

आयूर्षि क्षपयन्त्याशु ग्रीष्मे जलिमवांशवः ॥ Ramayana,II,105.20 ॥

उद्भूत आतपापाये प्योदानामिवाम्बुधौ ॥ Ramayana,VII,32.68 ॥

The insolational heating of the ocean water is also referred to in the Verse VII.25.30 of Ramayana.

दौदात्म्येनात्मनोद्धतस्ताप्ताम्भा इव सागरः ।

ततो ब्रवीद दशग्रीवः कुद्रः संरक्तलोचनः ॥ Ramayana.VII,25.30 ॥

In the twelfth skanda of epic Mahabharata, the atmosphere is divided into seven regions (Skanda, Spheres) and they are discussed in considerable detail. The wind named as आवह (M.B.XII, 328.37), blows with a loud noise. Another wind which drinks up water from the four ocean and having sucked it up gives it to the clouds in the sky and subsequently to rain god is called उद्धह (MB. XII, 328.38-39) as:

अम्बरे स्नेहमभयेत्य विधुदा भयश्च महाधुतिः ।

आवहो नाम संवाति द्वितीयः श्वसनो नदन ॥ MB.XII,328.37 ॥

उदयं ज्योतिषां शश्वत सोमादीनां करोति यः ।

अन्तर्देहेषु चोदानां यं वदन्ति मनीषिणः ॥ MB.XII,328.38 ॥

यश्चतुर्म्यं समुद्रेभ्यो वायुर्धारयते जलम् ।

उद्धत्याददते चापो जीभूतेभ्योम्बरे निलः ॥ MB.XII,328.39 ॥

Apart from the wind, the sun was realized as the main cause of evapotranspiration. The Vana Parva tells us that the Sun evaporates moisture from all plants and water bodies and causes rainfall (MB.III.3.49). The epic informs us of various types of clouds and atmospheric layers as well.

त्वमादायांशुमिस्तेजो निदार्षो सर्वदेहिनाम् ।

सवौषाधिरसानां च पुनर्वर्षासु मुञ्चसि ॥ MB.III.3.49 ॥

संदहत्यैकार्णवं सर्वं त्वं शोषयसि रश्मिभिः ॥ MB.III.3.59 ॥

Kanada in his Vaisesika Sutra (Vais. Sutra., 5.2.5) explains the cause of evaporation of water thus, “the Sun’s rays cause the ascent of water, through conjunction with air”:

नाइयो वायु संयोगादारोहणम् ॥ Vais.Sutr.5.2.5 ॥

Kanada was also acquainted with convection currents in the atmosphere which he refers to in very scientific terms as:

नोदनापीडनात्संयुक्त संयोगाच्च ॥ Vais.Sutr.5.2.6 ॥

Author and commentator Sankara Misra (1600 AD) has beautifully explained this and illustrated it with the example of a kettle of water heated from below (Tripathi,1969). It conclusively proves that the great philosopher Kanada knew that the Earth is heated by sun’s rays through radiation and convection currents in the atmosphere.

Various Puranas inform us that there are seven regions or layers (वातस्कन्ध) in the atmosphere or there are seven types of winds (Vayu. 49.163). Narada Purana speaks of seven air channels (60.13) viz. सप्तैतेवायुमार्गाः, Kurma Chapt. 41.6-7 also reveals same thing with little variations as described here:

रसातलतलात्सप्त सप्तैवाध्वतलाः क्षितौ ।

सप्त स्कन्धास्तथा वायोः सब्रह्मसदना द्विजाः ॥ Vayu.49.163 ॥

आवहः प्रवहश्चैत ततैवानुवहः पुनः ।

सम्बहो विवहश्चैव तदूर्ध्वं स्यात्परावहः ॥ Kurma.41.6 ॥

तथा परिवहश्चैव वायोर्वे सप्त नेमयः ॥ Kurma. 41.7 ॥

The phenomena of evaporation, cloud formation and their relationship with winds or regions of atmosphere (वातस्कन्ध) are quite satisfactorily described in several Puranas (Brahamand Vol. II, Chapt. 9., Vayu. Chapt. 51, Linga, I,41, Matsya, I,54) and a full-fledged separate chapter has been devoted to them in these topics, which positively evinces that due importance of this branch of meteorology was realized. Some of the verses are quoted here as:

नावष्टया परिविश्वेत वारिणा दीप्यते रविः ।  
तस्मादयः पिबन्वो वै दीप्यते रविरंबरे ॥ Brahmand, Vol.II,9.138 ॥

तस्य ते रश्मयः सप्त पिबंत्यंभो महार्णवात् ।  
तेनाहारेण संदीप्ताः सूर्याः सप्त भवंत्युत् ॥ Brahmand, Vol.II,9.139 ॥

वर्षाघर्मो हिमं रात्रिः संध्या चैव दिनं तथा ।  
शुभाशुभं प्रजानां च ध्रुवात्सर्वं प्रवर्तते ॥ Vayu. 51.11 ॥

ध्रुवेणाधिकृतांश्चैव सूर्योपावृत्य तिष्ठतिः ।  
तदेषदीप्त किरणः स कालीग्निर्दिवाकरः ॥ Vayu. 51.12 ॥

सूर्यः किरणजालेन वायुमुक्तेन सर्वशः ।  
जगतो जलमादत्ते कृत्स्नस्य द्विज सत्तमाः ॥ Vayu. 51.13 ॥

Above lines of Vayu Purana explain that the sun rays along with the air, extract water from earth. The Linga Purana (I,41.11,21 and 30), specifically recognizes the roll of sun rays in evaporation of water, which gets converted to clouds and subsequent rainfall.

वैछुतो जाठरः सौरावारिगर्भास्त्रयोनियः ॥ Linga. I,41.11 ॥

याश्चासौ तपने सूर्यः पिवन्नभो गभस्थिभिः ।  
पार्थिवाग्निविभिश्चसौ दित्यः शुचिरिति स्मृत ॥ Linga. I,41.11 ॥

वसंते चैव ग्रीष्मे च शनैः स तपते त्रिभिः ।  
वर्षास्वथो शरदि च चतुर्भिस्यं प्रवर्षति ॥ Linga. I,41.30 ॥

ध्रुवेणाधिष्टताश्चापः सूर्यो वै गुह्य तिष्ठति ।  
सर्वभूतशरीरेषु त्वापो हयानुश्चताश्चियाः ॥ Matsya. I,54.29 ॥

तेजोभिः सर्वलोकेभ्य आदत्ते रश्मिभिर्जलम ॥ Matsya. I,54.31 ॥

समुद्राद्वायुसंयोगात् वहन्त्यापो गभस्तयः ।  
ततस्त्वृतुवशात्कालेपरिवर्तन दिवाकरः ॥ Matsya. I, 54.321 ॥

The celebrated Jain treatise 'Surya Prajnapti' has dwelt upon at length on insolation, radiation and reflection of the sun's light and energy and heating of the earth and various surfaces. Its conception of a contribution to "albedo" appears to be something wonderful, when we take into account the fact that the work was composed at least nearly half a millennium B.C. The concept of albedo is an important aspect of modern hydro-meteorology. The evapotranspiration process is greatly affected by the albedo.

In Prabharta 4, Sutra 25, detailed discussions are there dealing with insolation or heat of the Sun (तापक्षेत्र), Prabharta 5, Sutra 26 (designated as लेखा प्रतिहति, reflection of sun's light), presents a detailed discussion on the phenomena of scattering of sun's light, radiation, insolation, reflection and albedo and gives accurate scientific details. First, it mentions twenty theories on reflection of the sun's light held by the adherents of other sects (परतीर्थिकानाम). Then, it refers to another important fact that unseen (invisible) objects also possess reflective capacity.

In aphorism, 30 of the 9 Prabharta, discusses about the nature of convection and radiation heating through the sun's ray with reference to earth surface, water bodies and its objects and atmosphere and its continents. The author of the Surya Prajanapti also speaks that slanting rays of the sun give lesser heat and vertical ones greater heat. This is discussed with reference to the rising of the sun, noon and evening and different places (or latitudes). This shows that during Jain period, the Indians were well known about the heat exchange processes with in-depth technical theories.

## **Epilogue**

The various references and discussions presented in the chapter show the ancient Indians had developed significant understanding about the processes of interception, and infiltration. The interception of water by vegetation and hanging of water particles near the surface of Earth on other materials was also observed, which disappear through the activities of wind and heat. The modern soil science tells us that the soil is composed of interconnected pore spaces. This was clearly realized by the ancient Indians and was compared with the veins in the human body, through which infiltration takes place, which is the source of ground water. Ancient Indians also developed a very scientific knowledge about evaporation and transpiration. That sun rays, wind, humidity, vegetation etc. are the major causes of evapotranspiration, was known to them. The ancient Indians had realized the importance of evapotranspiration as an important facet of water cycle, energy circulation and food production and, for maintaining the natural eco-system. Solar phenomena, lightening, wind, cloud formation etc. take place in lower layer of the atmosphere.

Atmosphere was divided in troposphere, stratosphere and ionosphere and globe in torrid, temperate and frigid zones which is comparable to modern meteorology. Plants drink up water through roots which is facilitated by the conjunction of air is alluded to in Mahabharata which fully corroborates the modern concept of capillarity in soil, water and plant relationship. The fact that plants and forests have some influence on water loss, differential rate of heating of the continents and water bodies, formation of convection currents and their effects were well understood. However, it is point of further research in the ancient hydrologic literature whether there were specific instruments/techniques to quantify the processes of interception, infiltration and evapo-transpiration?