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Effect of tropical dry and wet forest on convective precipitation – A case study of Ranchi Region, Jharkhand, India

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ABSTRACT

Tropical deforestation on many scales influences local, regional, and even global climate. Equatorial climate has characteristics of local convective rainfall event. In the recent past, convective rainfall pattern in Ranchi region of Jharkhand, India is observed to be changed. Tropical storm intensity and numbers of dry days are probably more sensitive to the degree of forest cover than annual precipitation. In the present research work, an attempt has been made to determine the extent of contribution of local forest in local cumulonimbus cloud formation and convective precipitation. Transpiration is an important characteristic of ecosystem. Transpiration rate of some important tree species found locally in Ranchi plateau forest was measured by using CI 340 hand held photosynthesis measuring equipment. The forest cover map of the Ranchi district was prepared for the year of 2018 for pre monsoonal season using Arc-GIS. The total dense forest cover area was estimated at 1508.819 km^2 which were 30.165% of the total study area, which is slightly more than the data (28.42%) available on the Forest, Environment and Climate Change Department of Jharkhand. Average transpiration rate from the local vegetation was obtained around 800 mL/m^2 of vegetation area for 5 hour duration of the day. Total approximate transpiration per day helpful in convective cumulonimbus cloud formation from the whole dense forest cover of study area was obtained around 1210 million of liter. Study shows that local green cover have significant role in local convective rainfall. Study also shows that the local green cover of Ranchi district may contribute maximum up to 27.48% in the pre-monsoonal local convective precipitation.

Key words : *Convectional rainfall, Cumulonimbus cloud formation, CI340, Transpiration rate.*

Introduction

Tropical deforestation would seriously modify local microclimates and, if sufficiently extensive, could change the climate of large regions in the vicinity of the deforested areas. If huge areas of rain forest disappear, even the global heat balance could be affected significantly. It is warned that deforestation combined with carbon dioxide released by the combustion of fossil fuels would add so much carbon dioxide to the atmosphere that it would worsen the situation at a global scale and regional changes following deforestation would be of greater magnitude (Dickinson, 1980). The disappearance of tropical forests would at most modify local climates and any effect on global climate would probably be swamped by natural changes and through an increase in the carbon dioxide content of the atmosphere (Lockwood, 1980). Different values of contribution have been attributed to the forest in aug-

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menting rainfall. It was asserted that forest increased rainfall by 3%, 1% due to the trees of 30 m or higher obstructing air movement and 2% due to the effect of the friction of the canopy (Kittredge, 1948). In a similar study, it was ascribed rainfall increase due to forest as 6% for the Germany. Several research workers have studied and suggested an increase of 10 to 12% in the plains and up to 25% in the hills (Luna, 1981; Nicholson, 1929; Hursh and Connaughton, 1938; Fedorov and Burov, 1967). Effect of land use change on regional climate especially rainfall, is best elaborated by (Dickinson, 1980) who argued that the differences are due to scale: hydrologists consider small areas and use limited observational data, whereas, the effects of vegetation change on atmospheric processes would be detected in case of area to be in the range of several hundred square kilometers. Also, in the tropics, crop yields and water resources over a large area are affected by what appears to be a negligible change of rainfall amounting to a few percentages. Moreover, convective rainfall (thunderstorms) is so variable that it is difficult to detect even moderate changes. The principal source of water vapor is evaporation from the sea; during a typical monsoon day, it is estimated that about 75 tons of water vapor are transported across the west coast of India (Das, 1968). The second largest source, about one fifth of the former, is evaporation from water masses on land and transpiration from vegetation. Warm air containing water vapor rises; with an increase in altitude, pressure decreases resulting in an expansion of the air mass; the rising air cools as it expands at the rate of 1° C for every 100 m rise in elevation. A stage is reached when the air is cooled beyond its saturation point and it can no longer hold all the water vapor in the gaseous phase, the surplus vapor condenses to form raindrops. A saturated cubic meter of air contains 39.4 g of water vapor at 35°C; at 20°C, 17.3 g; at 10°C, 9.4 g; at 0°C, 4.8 g; and at -10°C only 2.1 g (Das, 1968). The condensation of the excess vapor releases latent heat to the air mass so that it rises still higher and the process continues. The rising air will continue to ascend only as long as it remains warmer than the surrounding atmosphere at any level. Rising air tends to accumulate at higher altitudes preventing the upward motion of the air from below, unless wind at the higher level carries away the rising air (Homji, 1980a).

The higher rainfall of Assam, compared to the intensively cultivated Ganga valley, was attributed to the extensive forest mantle of the former, not to the physiographic differences (Blanford, 1888). In another example from central India, where the ban imposed on shifting cultivation in certain parts in 1875 had supposedly led to an increase in precipitation at 14 stations during the following decade (Blanford, 1888). No such increase was noted where shifting cultivation continued. In a report "Improvement of Indian Agriculture" pointed out that at Udhagamandalam (Ootacamund), the number of rainy days (excluding those of June, July, and August when the rains are not of local origin) increased during the five year period, i.e. 1886-1890 to 416 when the area was wooded (Von Lengerke, 1977). During an earlier five year period, 1870-1874, when the area was treeless, there were only 374 rainy days. Tritiated water was used to measure actual transpiration in a variety of individual trees (Kline *et al.,* 1970; Kline *et al.,* 1972a). Tritiated water was injected into the base of a tree, then twigs were sampled periodically, analyzed for tritium, and a curve of radioactivity as a function of time was plotted. Transpiration of the tree was found to be proportional to the area under the curve (Kline *et al.,* 1970; Kline *et al.,* 1976) had described a method of estimating the transpiration of an entire Douglas fir forest using the tritiated method, based on the finding that transpiration was a linear function of sapwood area (r = 0 98). Transpiration of the entire forest could therefore be estimated from estimates of the sapwood area of the forest and the measured relationship between transpiration and sapwood area.

In India, flora of Jharkhand mostly consists of dry and moist deciduous forests. It is noteworthy in this context that Jharkhand possess a semi-arid landscape, which suffers an acute shortage of water during the hot summer months: therefore, dry deciduous trees are common in the territory of Jharkhand. Among the important trees that form an important part of the fauna at Jharkhand are sal (*Shorea robusta*), jackfruit (*Artocarpus heterophyllus*), jamun (*Syzygium cumini*), kendu (*Diospyros melanoxylon*), gambhar (*Gmelina arborea*), shisham (*Dalbergia sissoo*), mahua (*Mahua longifolia*), lac, mango (Mangifera Indica), pipal, bamboo etc. The decline in rainfall of the pre-monsoon months (May and June) over the Ranchi plateau was attributed to the degradation of forests over an extensive area. The thunderstorm activity of the pre-monsoon season provides showers at the crucial moment when the water supply is rapidly dwindling towards the end of the long dry season. During the prevalence of long droughts during the (summer) monsoon season in weak monsoon years, conditions resemble those of the pre-monsoon months with high temperatures and no rains. Under such conditions the wooded areas are likely to benefit from the convective rains which may not be high in amount but are sufficient to maintain the crops and water supply for the local economy; the regions devoid of Forests may not derive any benefit from the convective showers. The normalized difference vegetation index (NDVI) data was used to analyze the spatial-temporal changes of vegetation and the correlation of vegetation and climatic variables over the period of 1982–2012 in Central Asia by using the empirical orthogonal function and least square methods [18]. The results showed that the annual NDVI in Central Asia experienced a weak increasing trend overall during the study period. The annual NDVI was positively correlated with annual precipitation in Central Asia, and there was a weak negative correlation between annual NDVI and temperature. [18] carried out a study of spatio-temporal variability of the properties of mesoscale convective systems (MCSs) during 1998–2012 over a complex terrain (20°–30°N; 80°–100°E). The most intense MCSs were found during pre- monsoon over the region of the plains of Gangetic West Bengal, Bangladesh and Chota Nagpur Plateau with significant reduction in intensity in monsoon. The eastern Himalaya foothills and Pegu Yoma highland showed relatively weak MCSs with marginal changes in their intensity from pre- monsoon to monsoon. They observed a significant spatio- temporal variability in the properties of MCSs, which is associated with distinctly different thermo-dynamical, dynamical and microphysical processes.

Recent observation shows that increasing urbanization in the district also affected the environment adversely. Summers are faced by heavy water scarcity. The place is losing its identity of pleasantness because of rising number of dry days in the summer. Rain fall comes in patches with extremities creating heavy loss to the agriculture and the livelihood. Deforestation is also a main factor for depleting ground water level as it act as a suction medium to bring water table above its normal level. Although recent government data shows the rise in forest cover of the district but the fact is that it is the overall green cover rise, not the rise in dense forest cover. As dense forest covers are decreasing year by year, there is a need to focus on the rise in dense forest cover of the district to regain its originality and loosing identity. In this research paper, a rough volume of transpirated water from the local tropical dry and wet forest of the Ranchi district, Jharkhand, India was estimated by using the modern CI340 hand held photosynthesis equipment. The mainstay of the paper is to highlight the importance of the local forest in maintaining the local climate at Ranchi, Jharkhand. Effort was made to estimate the maximum level of contribution of the forest in local convective cumulonimbus cloud formation in the pre-monsoonal season.

Materials and Methods

Description of Study area

Ranchi is the capital of Jharkhand state, India. The district is located between latitude 133 23°222N and longitude 85°202E near to the Tropic of Cancer. The district is located at southern part of the Chotanagpur plateau of east India. The average elevation of the district from mean sea level is 651m. Ranchi has a combination of hilly topography and dense tropical forests which produces a relatively moderate climate compared to the rest of the state. Study area is featured by tropical dry and wet forest cover. The annual rainfall is about 1430 mm. From June to September, the rainfall is about 1,100 mm. Ranchi has a humid subtropical climate (Koppen Climate Classification: Cwa), but its location and the forests surrounding it combine to produce the unusually pleasant climate for which it is well known. The location of study area is shown in Fig. 1.

Preparation of spatial data

The forest cover of the Ranchi district was mapped using Arc-GIS. The Normalized Differential Vegeta-

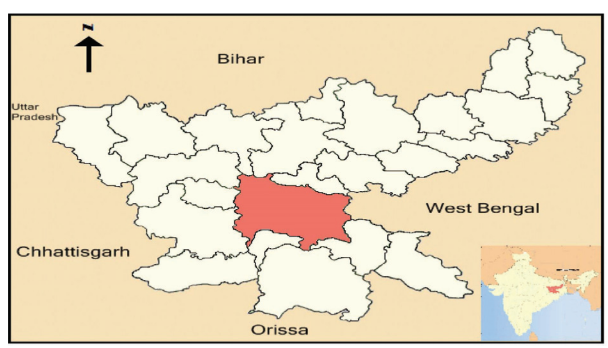

Fig. 1. Location of Ranchi District, Jharkhand, India

tion Index (NDVI) is standardized vegetation cover index for extracting the vegetation cover areas. The NDVI extracts the vegetation cover by measuring the difference between Near-infrared (NIR) and Red band. NIR band is basically reflects the vegetation and Red Band is absorbs the vegetation cover areas. The value of NDVI is ranging from -1 to +1, the positive value indicates the vegetation cover areas and negative values indicates the other features such as water bodies, built up areas, waste land etc. The NDVI is uses the NIR and Red Band images in equation for extraction the vegetation and is given by

$$NDVI = \frac{NIR-R}{NIR+R} \quad .. (1)$$

NIR is the reflectance in the near infrared band (760-900 nm), which is strongly reflected by leaf cellular structures; while, R is the reflectance in the red band (630-690 nm) which is characterized by chlorophyll content absorption at the canopy. In present research, Landsat 8 satellite imagery of the year 2018 was used for extracting the vegetation cover areas. The Landsat 8 satellite image was downloaded from USGS earth explorer website (https:// earthexplorer.usgs.gov/). The satellite image was processed and atmospheric corrections were carried out with QGIS. All the bands of satellite imagery were layerstack into a single image by using the ERDAS Imagine 2014. Different maps were prepared by using ArcGIS 10.3.

Estimation of Transpiration rate

Ranchi plateau have moist deciduous kind of forest. Total amount of rainfall during the season was obtained from POWERNASA. Average daily premonsoonal rainfall was obtained. Locally available sample tree like Sal (*Shorea robusta*), Mango (*Mangifera indica*), Mahua (*Mahua longifolia*), Jamun (*Syzygium cumini*), Pipal etc. were taken for estimation of transpiration rate from the green cover in the region with the help of CI340 hand held transpiration measuring equipment. These tree species are largely found in the region. The transpiration rate was estimated from leave surface of different plants/trees by using the following equations.

$$E = \frac{e_0 - e_i}{P - e_0} * W * 10^3 \quad .. (2)$$

$$e_0 = \frac{hr_0 * e_s}{100} \quad .. (3)$$

$$e_i = \frac{hr_i * e_s}{100} \quad .. (4)$$

$$e_s = 6.13753 * 10^{-3} * e^{T_a * \frac{18.564 - \frac{T_a}{254.4}}{T_a + 255.57}} \quad .. (5)$$

Where;
$e_0(e_i)$: Outlet (inlet) Water vapor (bar)
P: Atmospheric pressure (bar)
e_s: Saturated water vapor at air temperature (bar)
T: Air temperature (degree celcius)
$hr_0(hr_i)$: Outlet (inlet) relative humidity (%)

The observations were recorded during pre-monsoonal season, i.e. from January to June 2018. Experiment was carried out separately for each tree, multiple numbers of times to get an approximate weighted average of the transpiration rate from the leave surface. Experiment was conducted every sunny day during 10 AM in the morning to 3 PM in the afternoon to get maximum transpiration rate because sun is over head during this time span. The readings of each sample tree were tabulated and average transpiration rate/m^2 of leave area from that individual tree was calculated. Similar calculation was done for each individual sample tree. Finally weighted average of all different sample trees was calculated to get a weighted approximate transpiration rate per meter square green cover of the local forest. Transpirated volume of water was calculated by multiplying the obtained value in mol by 18 mL (molecular weight of water molecule). Volume obtained in liter per meter square per second was multiplied by the total green cover area to obtain total transpiration loss during one day. 5 hours span was chosen because this the period which is considered significant for considerable transpiration rate, otherwise during morning and late afternoon, sun's inclination is low which is not helpful for conducting the experiment. Considering the entire rainfall event to be local convectional rainfall throughout the season, the percentage 193 contribution of the forest was calculated in the local convective rainfall.

Results and Discussion

The NDVI map is shown in Fig. 2 which shows the pre-monsoonal vegetation and non- vegetation cover area of Ranchi, Jharkhand for the year 2018. The green color depicts the vegetation cover in the study area. Total area observed under green cover was estimated as 1508.819 km^2 which was around

30.16% of the total study area. The area of vegetation and non-vegetation cover of study area in pre-monsoonal season of 2018 is presented in Table 1.

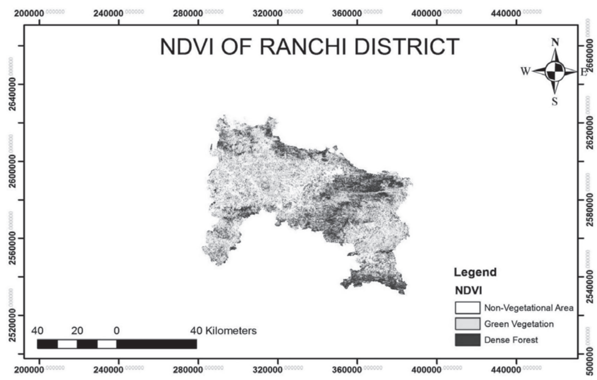

Fig. 2. Pre-monsoonal vegetation and non- vegetation cover area of Ranchi, Jharkhand in 2018

Transpiration rate was obtained throughout the season from the dominant tree species of the study area (i.e. Sal (*Shorea robusta*), Mango (*Mangifera indica*), Mahua (*Mahua longifolia*), Jamun (*Syzygium cumini*), Pipal etc) using CI340 hand held photosynthesis measuring equipment. Timing of the experiment was kept every day between 10 a.m. in the morning to 3 p.m in the afternoon because of the overhead condition of the sun. For each 5 sample trees, 6 readings were taken each month alternatively on different days. All the monthly obtained data was averaged to obtain average transpiration rate from each particular sample. Obtained result is tabulated in Table 2, 3, 4, 5 and 6.

Using the calculated average of the transpiration rate for different sample tree and assuming the weighted area of all the species chosen to be same in the study area, the average transpiration rate from the whole green cover was obtained by averaging the obtained seasonal average of each individual sample tree. The calculation is presented in Table 7. The volume of water transpirated from whole vegetation cover of study area (1508.819 km^2) per second was obtained 46884.23 l. For one day, the volume of water transpirated was found to be as 843916160 l. The transpirated volume of water from the whole vegetation cover area per day in pre-monsoonal season 2018 is 215 depicted in Table 8.

Average pre-monsoonal rainfall of Ranchi district was 0.88 mm per day. Therefore the total approximate volume of precipitation in whole of study area was found to be as 4401653520 liter of water per day. This is the quantity of water which contributes in local cumulonimbus cloud formation helpful in convective precipitation in pre-monsoonal season. Assuming all the water transpirated from the whole green cover to be precipitated back in form of convectional rain, the maximum contribution of the green cover of the study area towards rainfall formation was found to be as 27.48%, which is quite significant. Fig. 3 shows the maximum possible contribution of the local green cover in total convective precipitation.

Table 1. Area of vegetation and non-vegetation cover in pre monsoonal season of 2018.

Year	Features	Count	Area (KM^2)	AREA%
2018	Non-Vegetation cover area	1467986	1321.187	26.41382
	Light Vegetation cover area	2413192	2171.873	43.42114
	Dense Forest cover area	1676465	1508.819	30.16504
	Total		5001.879	

Table 2. Transpiration rate (mmol/m^2/s) from pipal leaf, in pre-monsoonal season 2018.

Pipal sample No.	January	February	March	April	May	June E	July
1	2.002	2.14	2.106	2.345	4.003	4.308	2.304
2	1.873	2.623	2.324	2.896	3.876	3.958	2.566
3	1.622	1.875	2.364	3.689	3.88	4.001	2.154
4	2.002	1.004	1.984	4.001	2.972	3.425	2.012
5	1.358	3.127	2.004	3.859	3.461	2.967	2.184
6	1.266	2.306	1.806	2.904	4.228	3.782	3.434
Average 2.73797619	1.687167	2.179167	2.098	3.282333	3.736667	3.740167	2.442333

Table 3. Transpiration rate (mmol/m^2/s) from Jamun (*Syzygium cumini*) leaf, in pre-monsoonal season 2018.

Jamun sample No.	January	February	March	April	May	June	July
1	0.982	1.342	1.592	2.13	1.231	1.004	0.89
2	0.813	0.983	1.353	2.315	1.498	1.902	2.05
3	1.327	0.628	1.802	1.983	1.21	1.008	0.88
4	1.642	1.586	1.217	1.894	1.89	1.723	1.64
5	1.003	1.638	1.563	2.736	2.045	0.98	1.25
6	0.631	1.007	2.003	2.034	2.32	1.342	1.66
Average	1.066333 1.4935	1.197333	1.588333	2.182	1.699	1.3265	1.395

Table 4. Transpiration rate (mmol/m^2/s) from Mango (*Mangifera indica*) leaf, in pre-monsoonal season 2018.

Mango sample	Jan	Feb	March	April	May	June	July
1	1.218	2.002	3.614	2.527	3.547	2.346	1.408
2	1.116	1.629	2.989	4.432	2.969	2.831	1.902
3	0.683	1.118	3.449	4.448	3.964	1.986	1.248
4	0.881	0.997	4.002	4.231	4.615	3.994	4.132
5	1.114	2.314	3.653	3.863	4.338	4.552	3.122
6	1.265	1.436	3.886	4.226	4.441	2.945	1.884
AVERAGE	1.046167 2.793262	1.582667	3.598833	3.9545	3.979	3.109	2.282667

Table 5. Transpiration rate (mmol/m^2/s) from Mahua (*Mahua longifolia*) leaf, in pre-monsoonal season 2018.

Mahua sample	January	February	March	April	May	June
1	1.003	1.226	3.832	4.205	2.994	3.12
2	0.932	1.993	2.443	4.002	3.207	2.94
3	0.883	1.621	2.661	3.668	3.552	3.11
4	1.255	1.739	2.005	2.904	3.829	3.694
5	1.882	1.881	1.982	3.412	3.451	2.984
6	1.994	1.571	1.884	2.993	3.667	3.163
Average	1.324833 2.602278	1.671833	2.467833	3.530667	3.45	3.1685

Table 6. Transpiration rate (mmol/m^2/s) from Sal (*Shorea robusta*) leaf, in pre-monsoonal season 2018.

Sal sample	Jan	Feb	March	April	May	June
1	1.992	2.586	3.165	4.003	3.543	2.83
2	1.004	1.984	2.994	4.281	2.948	1.59
3	1.447	1.004	2.847	3.884	3.661	3.47
4	2.041	0.932	1.771	2.947	3.88	3.856
5	1.296	2.55	2.79	3.537	3.025	2.472
6	1.941	2.415	3.216	3.663	3.051	3.221
Average	1.620167 2.717694	1.911833	2.797167	3.719167	3.351333	2.9065

Table 7. Average approximate transpiration rate from green vegetation of study area (assuming weighted area of all the sample tree to be the same)

Sample tree	Transpiration rate (mmol/m^2/s)
Pipal	2.73797619
Jamun (*Syzygium cumini*)	1.4935
Mango (*Mangifera Indica*)	2.793262
Mahua (*Mahua longifolia*)	2.602278
Sal (*Shorea robusta*)	2.717694
Average	2.468927

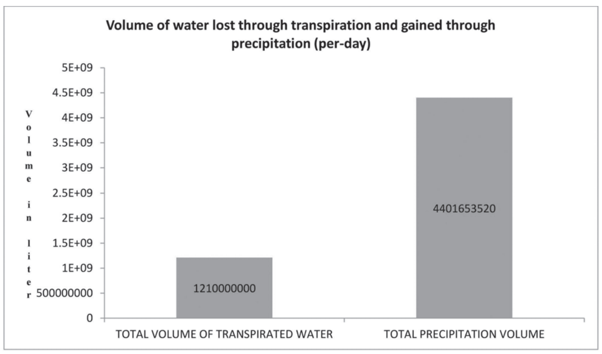

Fig. 3. Comparison of the Total pre-monsoonal precipitation and the total transpiration from local green cover per day

Upon observing the phenomenon of transpiration throughout the pre monsoonal period, i.e. January to June, the monthly averaged maximum transpiration from the species under consideration was observed in the month of April and May. The monthly averaged maximum transpiration rate observed in month of April was 2.182, 3.53, and 3.179 (mmol/m^2/s) for *Syzygium cumini, Mahua longifolia, Shorea robusta*, respectively. While it was averaged maximum 3.97 (mmol/m^2/s) for Mangifera Indica in the month of May and 3.74 (mmol/m^2/s) for Pipal in the month of June. April and May is considered as the hottest and driest months in the region. The humidity remains quite low, this allow leaves to transpire more. Hence trees contribute more and more in local cloud formation during these months which ultimately results into convectional rainfall.

Although major part of the transpirated volume is helpful in maintaining the local atmospheric humidity. Still this has a crucial role in local convective precipitation. Fig. 4. shows the trend of transpiration in different species during pre-monsoonal season of 2018.

Conclusion

Forest have significant role in local convective rainfall. In fact the local convective rainfall is the result of total evapotranspiration from the same local region. Total green cover in the district was obtained 1508.819 km^2 which was 30.17 % of the total study area. Total approximate volume of water transpira-

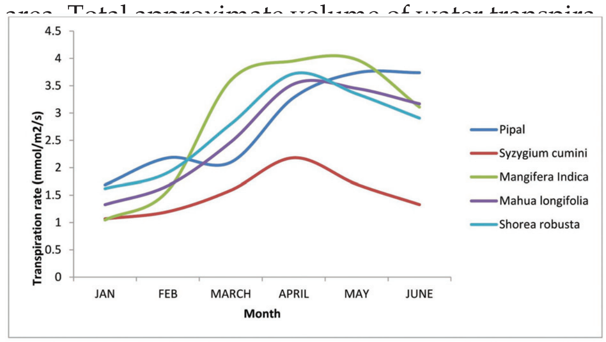

Fig. 4. Trend of transpiration in different species during pre-monsoonal season of 2018

tion per day is helpful in convective cumulonimbus cloud formation and maintaining the humidity from the total dense forest cover of study area was obtained around 1210 million of liter. Study also shows that the local green cover of Ranchi district may contribute maximum up to 27.48% in the pre-monsoonal local precipitation assuming that whole volume of transpirated water from the local green cover precipitated back in form of rain. The results would have been more accurate and fine if the area under each sample tree was known because that would have given more accurate weighted transpiration rate from the vegetation covered zone of the study area. Similarly error arising because of averaging the transpiration rate for whole of the season can also be improved by focusing on every day situation.

Table 8. Transpirated volume of water from the whole vegetation cover area per day in pre-monsoonal season 2018

Transpiration rate (mmol/m^2/s)	Transpiration rate (l/m^2/s)	Transpirated volume of water from total vegetation cover per day (5 hours). (liter)
2.468927	4.44407×10^{-5}	1210000000

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