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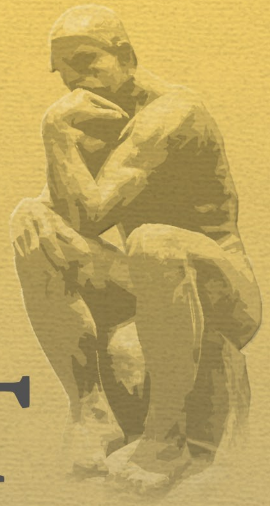

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RESEARCH ARTICLE

Water scarcity in *Sohra* (Cherrapunjee): A paradox

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ABSTRACT

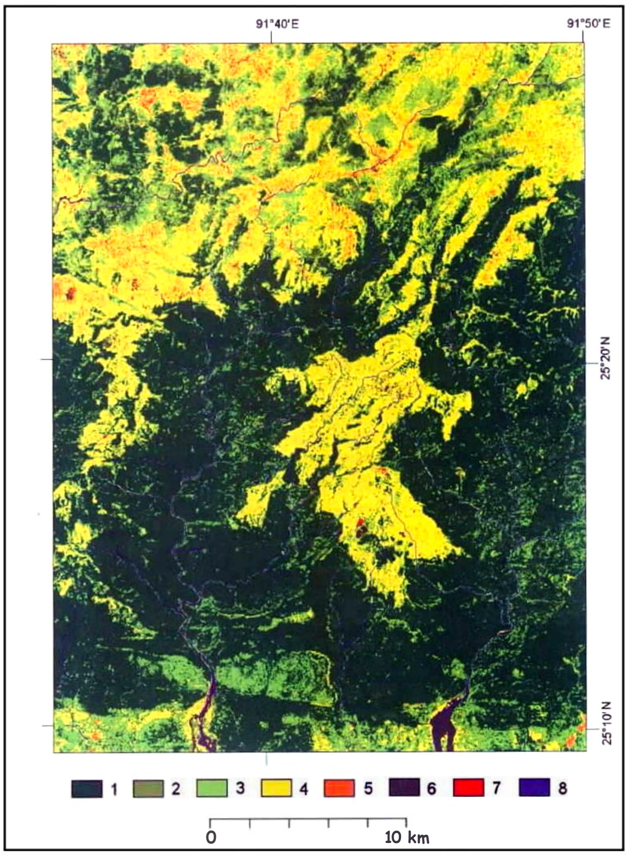
Sohra (Cherrapunjee) the erstwhile region with the highest amount of rainfall and still among the heaviest rainfall receiving region in the world is beset with persistent domestic water shortage with households in the area getting drinking water only once in three days. This shortage can be attributed to both access issues (distance to the source, availability of storage facilities, socio-economic status, etc.) and geo-environmental conditions of the study area. The present paper tries to understand the role of the climatic factors, viz., rainfall and temperature in determining natural water availability in Sohra and find out the water resource potential in a qualitative manner. In terms of rainfall the study area is characterized by periods of surplus water availability (March to September) accompanied by period of intense water scarcity (November to February) as well. Apart from rainfall, temperature is also a very important element for the development of water resources in the study area. January is the coldest month and June is the hottest month. This variation in temperature plays a very important role in determining water resources development in the study area. In the present work potential *evapotranspiration* has been determined, using the Thornthwaite and Mather's method for calculating potential *evapotranspiration* to understand the water balance in the study area. The water balance is found very high, (>1000 mm) with the highest values during the peak monsoon months of June and July (>2000 mm). On the other hand, the lowest values occur during the lean season months, i.e., November, December and January. These months experience a deficit of more than –20 mm. These two periods thus can be consequently identified as water-surplus (monsoon and pre-monsoon season) and water-deficit (lean season) periods respectively.

Keywords: Water resource potential, evapotranspiration, water-surplus, water-deficit, water balance

INTRODUCTION

The position of *Sohra* (Cherrapunjee) as the area receiving the highest amount of rainfall may have been usurped by Mawsynram which is located 16 km to the west, but it is still among the heaviest rainfall receiving region in the world. During the period 1980-2012 Sohra received an average annual rainfall of 1140.24 cm. However, at the same time the people in the area suffer from severe shortages of domestic water (Dohling, 2003). In 2010, because of the drinking water crisis in Cherrapunjee, the Greater Sohra Water Supply Scheme at a cost of Rs. 4.13 crore with the aim of providing drinking water to about 25,000 families in Sohra was started. However, shortage of domestic water persists with households in the area getting drinking water only once in three days (PTI, 2010). A part of this shortage can be attributed to access issues (distance to the source, availability of storage facilities, socio-economic status, etc.) but a degree depends on natural water availability.

Natural water availability in any region depends on geo-environmental factors that can be divided into two Categories, viz., climatic and non-climatic factors. It is the interaction between these two groups of factors that determine natural water availability. The present paper tries to understand the role of the geo-environmental conditions in determining natural water availability in Sohra and find out the water resource potential in a qualitative manner. In this paper the focus is on the climatic factors, viz., rainfall and temperature.



1 – Sub-tropical deciduous forest; 2 – sub tropical pine forest; 3 – scrub; 4 – grassland; 5 – cropland; 6 – rock outcrop; 7 – built up area; 8 – water.

Source: Prokop and Walanus, 2003

Fig. 1. Land use/land cover map of Cherrapunjee spur and surrounding areas (compiled by P. Prokop on the basis of satellite image IRS-ID).

STUDY AREA AND METHODOLOGY

The study area for this study is the Sohra/Cherrapunjee region, which is located along the southern slopes of the Meghalaya Plateau. The curious case of 'scarcity in the midst of plenty' was what attracted the choice of the study area. It includes the Cherrapunjee spur and the surrounding canyons and deep gorges merging with the alluvial plains which are part of the great Sylhet plain. Apart from rainfall there are other features that can be used for delimitation of this region, horizontally bedded sandstone formations, dissected plateau surfaces, deep gorges, thin soil, highly degraded landscape, etc. All of these in conjunction make up the Cherrapunjee region.

The study is based on secondary data, rainfall and temperature, which was extracted from the website of Cherrapunjee Holiday Resort which has more than 100 years of meteorological data. This data was analysed using SPPS V17. Parametric as well as non-parametric tests were conducted using the software to test the validity of the results. Final results were then collated and presented with explanation.

RESULTS AND DISCUSSION

Climatic factors

The climatic factors that are important for determining natural water availability are rainfall and temperature. Rainfall determines the amount of water an area gains while temperature determines water loss through the process of evaporation and transpiration known in conjunction as *evapotranspiration*. The surplus/deficit that occurs as a result of the operation of these two factors determines natural water availability of an area.

Rainfall

Rainfall over the Cherrapunjee Plateau is the highest in the world. Such a peculiar phenomenon has not gone unnoticed and much work has been done in the recent past in understanding the climatological, hydrological and geomorphological significance of such a phenomenon. Most of the authors (e.g., Kingdon-Ward, 1955) agree that orography is the main cause of the enormous rainfall at this station (Prokop & Walanus, 2003). The extreme wet conditions prevailing in the southern slopes of the Meghalaya Plateau (Cherrapunjee) are because of the orographic effects and wind-ward movements of the South West Monsoon (Singh & Syiemlieh, 2004). There are some however, who attribute the heavy rainfall in the area to factors other

Table 1. Annual rainfall and annual rate of change in Sohra/Cherrapunjee during 1970-2012.

Year	Annual rainfall (in mm)	Rate of change (%)
1970	17200	0
1971	8469	-50.76
1972	11656	37.63
1973	10910	-6.4
1974	24555	125.07
1975	11961	-51.29
1976	9019	-24.6
1977	12110	34.26
1978	6950	-42.61
1979	12095	74.02
1980	9133	-24.49
1981	9418	3.12
1982	10381	10.23
1983	9764	-5.94
1984	16761	71.66
1985	11816	-29.5
1986	8140	-31.12
1987	13153	61.6
1988	17930	36.32
1989	13460	-24.93
1990	11598	-13.84
1991	13506	16.45
1992	8357	-38.13
1993	12801	53.19
1994	11205	-12.47
1995	14210	26.82
1996	12897	-9.24
1997	8994	-30.26
1998	14537	61.64
1999	12503	-13.99
2000	12262	-1.92
2001	8972	-26.84
2002	12262	36.68
2003	10499	-14.38
2004	14791	40.88
2005	9758	-34.03
2006	8734	-10.49
2007	12647	44.8
2008	11415	-9.74
2009	9070	-20.54
2010	13472	48.54
2011	8732	-35.18
2012	13364	53.05

Source: Cherrapunjee.com

than just the orography (Dhar & Farooqui, 1973). For example, according to Tang et al., 1999 the heavy rainfall in Cherrapunjee is due to the strong heat source from the Daxiawan Hot Spot (DHS) (a special region with high ground temperature, low density, low magnetism, negative gravity abnormality, frequent earthquake and strong tectonics) in the Yarlung Zangbo River. With the heating of the Tibetan Plateau being very influential on the occurrence of monsoon in the South Asian region, it was observed that the moisture flux around Tibet Plateau is transported to the centre of heat low over

Table 2. Difference in the mean annual rainfall in Cherrapunjee during 1970-1980, 1981-1990, 1991-2000 and 2001-2012.

Period	Mean rainfall (in mm)	σ (in mm)	Levene's Test of Equality of Error Variances		ANOVA		Kruskal Wallis	
			F	Sig.*	F	Sig.*	χ^2	Sig.*
1970-1980	12187	4906	1.151	0.341	0.294	0.83	1.555	0.67
1980-1990	12242	3164						
1990-2000	12127	2058						
2000-2012	11143	2137						

* Significance level at 0.05

Source: Cherrapunjee.com

Tibet, except for the Gauhati station (Cherrapunjee), which is transported to DHS and the moisture flux is the strongest one around the plateau (Gao et al. cited in Tang et al., 1999). This means that it is the DHS that induces the heavy rainfall in the area (Tang et al., 1999).

The present study analyses the trend of rainfall in Cherrapunjee from 1970 to 2012. The highest rainfall during the period was recorded in 1974 when the area received more than 20000 mm of annual rainfall, followed by 1988 and 1970 when the area received more than 17000 mm of annual rainfall. At the lower end of the spectrum, the minimum amount of rainfall was recorded in 1978 - 6950 mm, which is almost 60% less than the average annual rainfall received during the whole period. In general about a third of the study period received rainfall of less than 10000 mm with the remaining years getting more than 10000 mm. The minimum rainfall recorded during the study period was found to be < 2 standard deviation while the maximum rainfall was > 3 standard deviation implying that the difference between years experiencing greater than average annual rainfall is bigger than years receiving lesser than average annual rainfall.

The average annual rainfall during the study period is 11895 mm with 21 years receiving more than average rainfall and 22 years less than average rainfall (i.e. almost equal). Among the years receiving more than the average rainfall around 60 percent of them fall in the post-1990 period; while for the period receiving less than the average rainfall, both pre-1990 and post-1990 period have equal number of years (11 years each). In conjunction with a low measure of dispersion (standard deviation = 3195 mm and CV (%) = 27), it indicates that the annual absolute amount of rainfall in Cherrapunjee has not experienced a great deal of variation. In fact stable precipitation regime is a characteristic feature of the whole eastern region of the country (Starkel, 1972).

However, analysed in terms of rate of change, a slightly different picture emerges. Around 60 percent of the selected time period experienced a negative rate of change with almost 60 percent of them belonging to post-1990 period. On the other hand, post-1990 and pre-1990 period have equal number of years that experienced a positive rate of change (nine years each). In contrast to the pattern of absolute annual rainfall, a greater degree of variability is observed in the annual rate of change of rainfall (standard deviation = 40.67%, CV (%) = 625.15). Thus, though the average rate of change is 6.51 percent the actual rate of change varies greatly from -34.16 percent to + 47.18 percent. This means that although the absolute amount of rainfall has not greatly varied, in relative terms the rainfall pattern has experienced a significant change over the years. To analyse the direction of change, the linear regression method of Ordinary Least Square method is used.

The linear trend of rainfall in Cherrapunjee showed declining trend. For Dhar and Farooqui, 1973 the analysis of the trends in the annual and rainfall data of Cherrapunjee for 1903-1959 showed no linear trend, but some oscillations of the order of 10 years or so. An abrupt rise in totals from 1944 to 1954 was also observed. Prokop and Walanus, 2003, on the other hand, after analysing the instrumental rainfall data for the period 1871-1999 of North Assam sub-division and four meteorological stations of North-East India, found that though, rainfall in Cherrapunjee may show periodic fluctuations but analysed over a long period of time the trend is very stable, i.e., neither increased nor decreased.

The difference in results, compared to the latter study which is more comprehensive, could be due to the shorter time period taken in the present study (only 40 years). Also the present study considers rainfall after 1999 when the trend line goes below the average annual rainfall. The decline, though, is not very high, just 30.38 mm, which is less than one percent of the annual average rainfall of the study period. The decline, therefore, does not seem to be very significant. In order to test whether the decline is statistically significant, both parametric (One Way ANOVA) and non-parametric (Kruskal-Wallis test) tests are used.

The entire study period of 1970-2012 is divided into four parts, viz., 1970-1980, 1981-1990, 1991-2000 and 2001-2012. Except for 1981-1990 when the area received 55 mm more rainfall from the previous period, the remaining periods, 1991-2000 and 2001-2012 experienced a consistent decline in

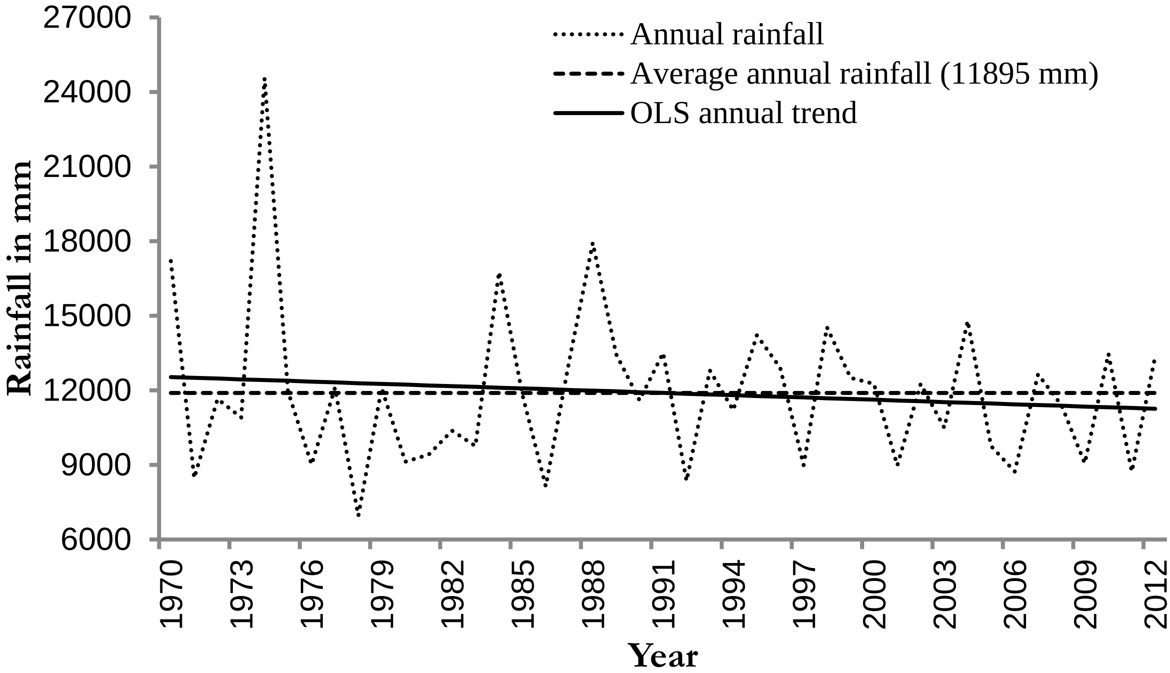


Fig. 2. Pattern of annual rainfall in Sohra/Cherrapunjee during 1970-2012.

rainfall, 115 mm and 984 mm less than the preceding periods. Both the ANOVA and Kruskal Wallis tests have revealed that the difference between the means of the different periods is not statistically significant. Hence, the decline is not significant. This low statistical significance is due to the very high absolute amount of rainfall that Cherrapunjee receives.

Rainfall being the primary source of water resources (both surface and ground-water) on the

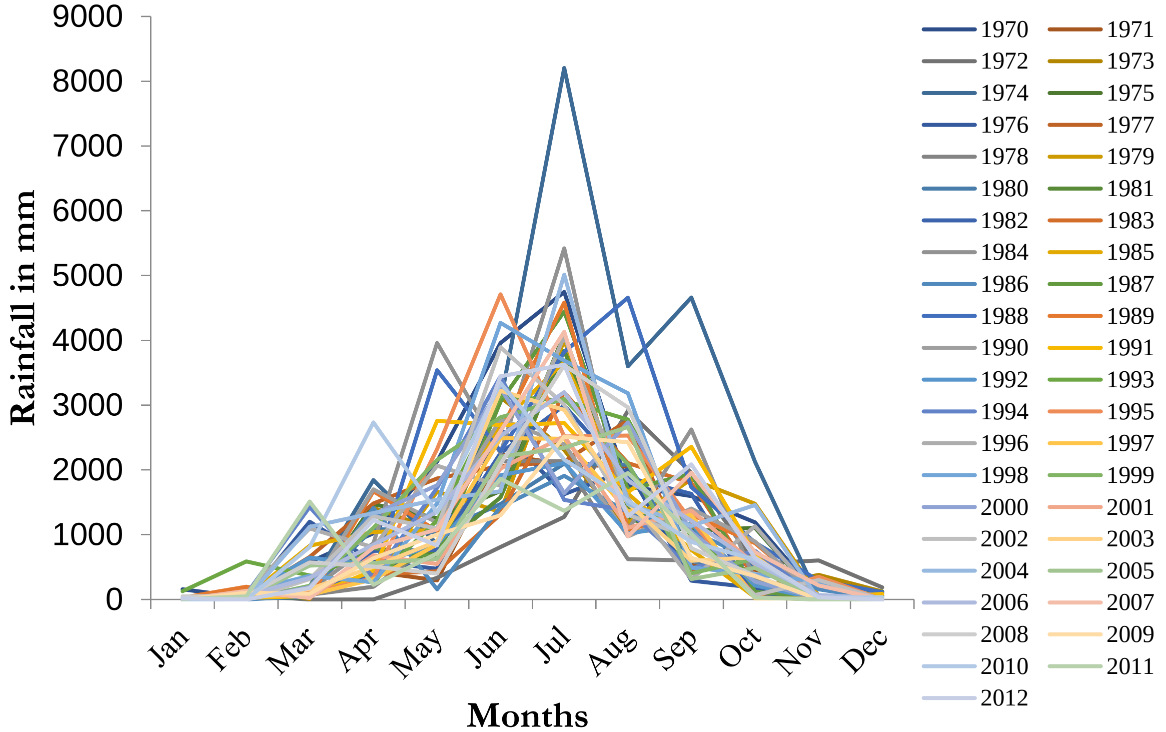


Fig. 3. Distribution of monthly rainfall from 1970 to 2012.

Earth, annual rainfall is crucial for water resources availability. Due to the very high amount of rainfall Cherrapunjee's potential annual renewable water resource is very high. The potential annual renewable water resource for Cherrapunjee (taking the total area and 2001 population of Shella Bholaganj C.D. Block) based on annual average rainfall is to the tune of 126419 m^3 $capita^{-1}$. This figure is much higher than the 17000 m^3 $capita^{-1}$ identified by Falkenmark, 1997 and Gleick as the threshold below which water stress condition develops (Brown & Matlock, 2011).

Table 3. Pattern of monthly rainfall in Cherrapunjee during 1970-2012.

Season	Month	Average monthly rainfall (mm)	σ (mm)	CV (%)
Pre-Monsoon	March	355	405	114
	April	844	561	67
	May	1258	810	64
Monsoon	June	2499	862	34
	July	3124	1305	42
	August	1869	821	44
	September	1225	794	65
	October	551	451	82
Post-Monsoon/ Lean	November	82	136	166
	December	25	44	175
	January	18	30	165
	February	61	94	155

Source: Cherrapunjee.com

However, the seasonal distribution of this high amount of rainfall is highly skewed creating conditions of surplus and scarcity. This is in keeping with the general nature of the Monsoon type-climatic system where more than 2/3rd of the annual rainfall is concentrated in just a few months of the year (Dhar & Farooqui, 1973; Singh & Syiemlieh, 2004). The maximum amount of rainfall in this period is received during the month of July that records an average monthly rainfall of 3124 mm followed by June with an average monthly rainfall of 2499 mm. Rainfall declines from July reaching the average minimum monthly rainfall of 551 mm in October. Around 78% of the annual rainfall is received by Cherrapunjee during the five months of June to October. This leads to the re/emergence of the many waterfalls in the area. For e.g., the arrival of the monsoon rejuvenates the Nohsngithiang Falls (also known as Sister Falls) which has very little discharge in the lean season. The amount and intensity of rainfall during this season is very high. In fact, one of the reasons of the observation of high rainfall in Cherrapunjee is the positive intensity-duration relationship (Singh & Syiemlieh, 2004). It is during this season that the 'break monsoon' phenomenon occurs when the axis of the season monsoon trough shifts northwards from its normal position and lies close to the foothills of the Himalayas causing extreme rainfall in the North East (Cherrapunjee) but dry conditions elsewhere in the country (Dhar & Nandargi, 2003). This high rainfall affects not just the geo-hydrology of Cherrapunjee but also of downstream Bangladesh (Murata, Hayashi, et al., 2007; Murata, Terao, et al., 2008). The highly disastrous floods of 1988 in Bangladesh was caused by the heavy monsoon rainfall in the north-east of Bangladesh and Meghalaya (Cherrapunjee) causing the Meghna and Brahmaputra (in Bangladesh) to flow above the danger level (Brammer, 1990; Mirza, 2003). Except for 1984, the severe flood years in Bangladesh correspond to the top five largest annual rainfalls at Cheerapunjee (Murata, Hayashi, et al., 2007). Water sources get recharged but unless they are protected there is a high likelihood of contamination. The potential water resources during this season is 19700 m^3 $capita^{-1}$ which is still very high compared to the annual threshold. This season is the water surplus period.

Table 4. Water status in different seasons based on water barrier differentiation proposed by Falkenmark, 1997 according to rainfall distribution.

Seasons	Potential water availability (m^3 $capita^{-1}$)		Water status
	Seasonal	Monthly	
Pre-Monsoon	8701	2900	No stress
Monsoon	19700	3940	No stress
Post-Monsoon/ Lean	374	94	Stress

Source: Cherrapunjee.com

Apart from the rainfall received during the Monsoon months, significant amount of rainfall, 21 percent is also received from April to June. The average monthly rainfall increases from 355 mm in March to reach a maximum of 1258 mm in May. The highest intensity of rainfall is also recorded during this season, i.e., pre-monsoon period Singh and Syiemlieh, 2004. In fact, a typical feature of Cherrapunjee is the heavy downpours during the pre-monsoon months every year with their intensity passing 1 mm h^{-1}. Annually these pre-monsoon rains reach 7.7 days for rainfall above 100 mm and 1.6 days for rainfall above 300 mm (Soja & Starkel, 2007). These rains are mostly due to the local convection activity and the effects of the tropical cyclones in the Bay of Bengal. Sometimes storms with very high wind speed are experienced during this period which causes great damage to improperly constructed and weakly protected water sources like small springs. Water tables however start rising and this brings relief to the people and an end to the period of water shortage of the preceding months, i.e., lean season. With a potential water resource of 8701 m^3 $capita^{-1}$ the area is comfortably placed and experiences no water stress problems.

The lean season begins from November when the Monsoon finally retreats from the area and continues to February. This period receives just 1% of the annual rainfall. The highest average monthly rainfall (82 mm) recorded is during November while the minimum average monthly rainfall of 18 mm is recorded during January. Apart from the very low amount it is the very high variability of more than 150% that greatly constraints water availability during this period. Most of the sources become completely dry or greatly reduced in the amount of water they possess. The flow in the smaller streams becomes sluggish and in the larger ones the water level goes down. The water tables, especially in the valley, fall drastically necessitating digging deeper to reach water. Most of the waterfalls, especially the smaller and perennial ones, also disappear. Severe water stresses have been reported during this season (Breitenbach et al., 2010; Soondas, 2013). This period is the water deficit period. The study area thus is characterized by periods of surplus water availability accompanied by period of intense water scarcity as well. However, rainfall is not the only factor that determines climatic natural water availability unless climatic water loss through *evapotranspiration* is also considered. The latter depends on the temperature characteristics and variation in the study area.

Table 5. Monthly variations in Potential Evapotranspiration (PET) and water balance (P-PET) during 2009-2012.

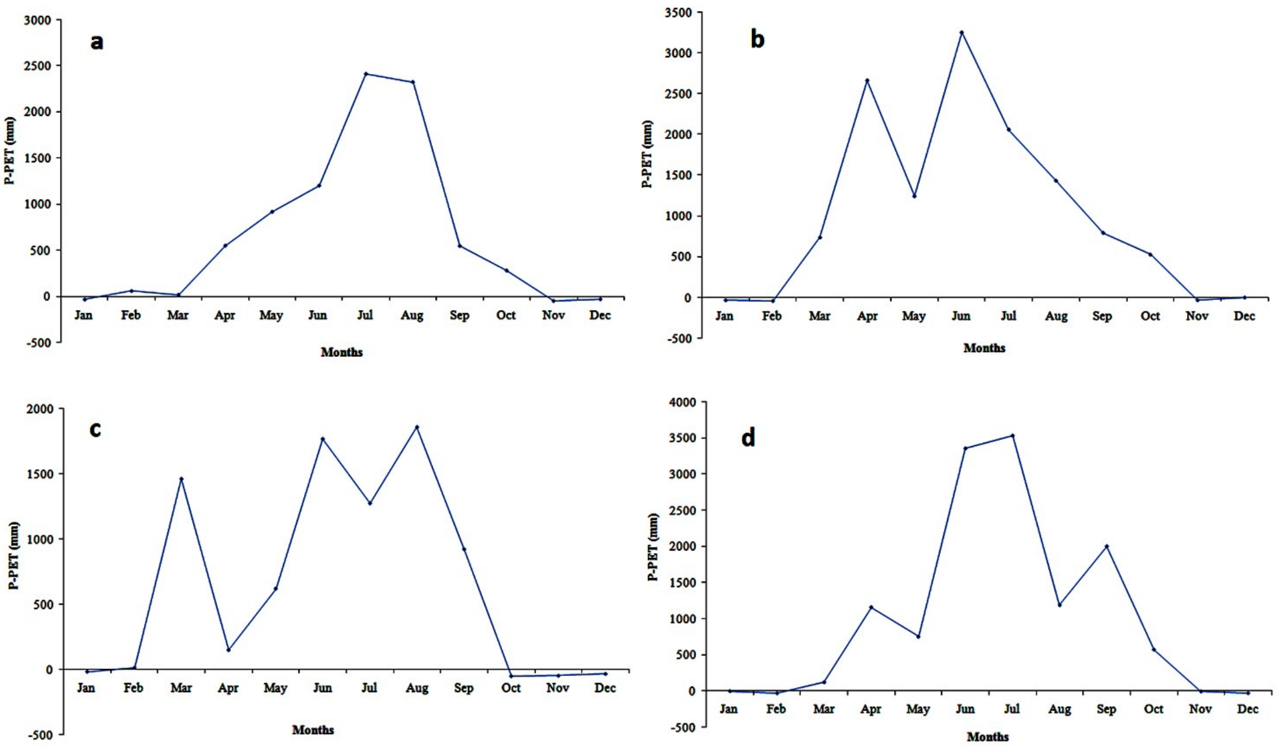
Months	**Temperature (Degree Celsius)**	**PET (mm)**	**P (mm)**	**P-PET (mm)**
January	12.01	29.30	7.20	-22.10
February	14.20	38.05	37.05	-1.00
March	17.22	63.35	645.75	582.41
April	19.05	77.12	1205.00	1127.89
May	19.93	91.43	971.90	880.48
June	20.44	95.76	2487.18	2391.42
July	20.70	98.28	2416.23	2317.95
August	20.97	98.28	1796.93	1698.65
September	21.17	91.04	1155.80	1064.77
October	20.09	80.93	411.75	330.82
November	16.64	51.19	16.50	-34.69
December	13.06	32.76	8.40	-24.36

Source: Cherrapunjee.com

Temperature

Apart from rainfall, temperature is also a very important element for the development of water resources in the study area. The most significant factor controlling the climate in Cherrapunjee is the South-West Monsoon and altitude (Dohling, 2003) with the South-West Monsoon determining the amount of rainfall and altitude determining the temperature conditions. As a consequence, Cherrapunjee experiences cold temperate climate with foggy winter months while the southern part of the terrain along the Bangladesh border experiences hot summer with cool winter (Biswas, 1990). While studying the variations of surface air temperature over the land areas in and around the Bay of Bengal for the time period of 1951-1990, Quadir et al., 2004 found that Cherrapunji has observed a cooling at the rate of $-0.018°C\ year^{-1}$ respectively. Annually, temperature in the study area varies from minimum of 5°Celsius to a maximum of 26°C. The heavy rainfall helps in bringing down the temperature and the average temperature throughout the year is just over 17°C. January is the coldest month with average temperature just above 10°C, although the minimum temperature may drop below than 10°C. June is the hottest month with maximum temperature approaching 25°C. This variation in temperature plays a very important role in determining water resources development in the study area.

The rainfall that falls in a region is transported back to the atmosphere through the process of evaporation and transpiration. The energy that drives these processes is the heat energy of the sun, i.e., the temperature. In conjunction evaporation and transpiration are known as *evapotranspiration*. *Evapotranspiration* is the combined evaporation from the soil surface and transpiration from the plants which represents the transport of water back to the atmosphere, the reverse of precipitation (Thornthwaite, 1948). There are two types of *evapotranspiration*, viz., *potential evapotranspiration* and *actual evapotranspiration*. The former is based on theoretical formulations. It is derived from an understanding of the factors responsible for the process and their relationships that gives a potential value. In actual *evapotranspiration* an attempt is made to find out the amount



Note: a – 2009; b – 2010; c – 2011; d – 2012 **Source:** Cherrapunjee.com.

Fig. 4. Water balance (P-PET) in Cherrapunjee from 2009 to 2012

of *evapotranspiration* that has taken place from an area. This is done by multiplying suitable crop coefficients with the *potential evapotranspiration* (Nokes, 1995). In the present work only *potential evapotranspiration* has been determined as it is considered to be sufficient.

There are many methods available for determining the *potential evapotranspiration*. The present study, however, uses the Thornthwaite and Mather's method for calculating *potential evapotranspiration* which is given below.

$$e = 1.6\left(10\,\frac{t}{I}\right)^{a} \quad (1)$$

where,

e = Monthly *Potential Evapotranspiration* in mm or cm for standardized month of 360 hours of sunshine.

t = Mean monthly air temperature in °C.

I = annual heat index which is summation of the monthly indices, i, which is defined as,

$$i = \left(\frac{t}{5}\right)^{1.514} \quad (2)$$

The 'a' is the location coefficient that has to be determined in the following manner,

$$a = 0.000000675I^3 - 0.0000771I^2 + 0.017921I + 0.49239 \quad (3)$$

Temperature starts increasing by the end of February and continues till September after which temperature starts falling. This subsequently coincides with the rise in PET values (from more than 60 mm to over 90 mm). Cherrapunjee, as has already been discussed, receives very high amount of rainfall. As such the water balance is also very high, (>1000 mm) with the highest values during the peak monsoon months of June and July (>2000 mm of excess water is available after considering *evapotranspiration* losses). On the other hand, by the end of October, the Monsoon fully retreats from the region and as such the lowest values occur during the lean season months, i.e., November, December and January. These months experience a deficit of more than -20 mm, i.e., *evapotranspiration* demand is more than rainfall received. These two periods thus can be consequently identified as water-surplus (monsoon and pre-monsoon season) and water-deficit (lean season) periods respectively. This pattern is found to be consistent over the period undertaken for study, 2009 to 2012 with small variations. During the monsoon and pre-monsoon season excess water is available. Potentially this water can contribute to recharge of the various water sources, surface as well as subsurface, from which people collect water. Water sources recharged during the water surplus seasons could provide water during in the water deficient season.

CONCLUSION

As stated in the beginning, Sohra/Cherrapunjee suffers from the paradoxical situation of 'scarcity in plenty'. The subsequent discussion tried to analyse the role of the geo-environmental factors in understanding this condition. Though annual rainfall is very high, its distribution is highly skewed with lean season receiving very less rainfall. This has important implication in terms of climatic water loss through the process of *evapotranspiration*. Indeed, lean season is found to have deficit water balance values indicating severe water shortage. This seasonal shortage could be overcome if there is proper recharge and storage of rainfall that is available during the water surplus pre-monsoon and monsoon season. The geo-environmental conditions especially climatic factors in Sohra/Cherrapunjee are highly unfavourable for water resources development and this sufficiently explains the condition of 'scarcity in plenty'.

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