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Correlation of Climatic Parameters and Elevation During the Monsoons in Sri Lanka

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ABSTRACT. This paper highlights variations of monthly climatic conditions of highland stations (Matale, Peradeniya, Talawakele, Sita Eliya, Bandarawela, Passara and Girandurukotte) during the monsoons. It also emphasizes the relationship of each climatic parameter and topography (height and aspect of slope) of the selected locations. The climatic elements analysed here are the monthly means of wind speed mean maximum temperature (T_{Max}) mean minimum temperature (T_{Min}) relative humidity at 0830 (RH_{0830}) and 1530 LST (RH_{1530}) monthly rainfall (RF) and the mean daily hours of sunshine and pan evaporation. During the northeast monsoon T_{Min}, RF, RH_{0830} and RH_{1530} show peak values in December. The rainfall values during northeast monsoon on windward side dropped with increasing altitude. Likewise two of the leeward stations Talawakele and Matale show a similar relationship with rainfall as on the windward side while Peradeniya shows a very different RF pattern.

During the southwest monsoon Girandurukotte and Passara have less low clouds than during any other season. Hence, peak values of the maximum temperature are observed in this period. The stations Peradeniya and Passara in spite of having a 628 m difference of elevation recorded nearly the same temperature of 27.5°C in August. It may be due to the higher wind speed at Peradeniya than in Passara during this month. To support this, it can also be mentioned that the maximum temperature at Sita Eliya as the peak station in terms of elevation indicated low values during June and July when wind speeds were high. T_{Max} values fluctuate in all stations with a low amplitude.

INTRODUCTION

Sri Lanka is located within the tropics in the core area of the Asiatic Monsoon region. Hence, she receives most of its rainfall from the two monsoons, the southwest (SWM) and the northeast (NEM) and the weather systems which occur in the Inter Tropical Convergence Zone (ITCZ). In between the two monsoons there are two transitional periods known as the inter-monsoon seasons (Thambyahpillay, 1952).

Sri Lanka provides an ideal setting for climatic studies not only due to its topographic and climatic variations but also due to the presence of two monsoons. The central highlands present a barrier to both monsoons making a special impact on climate. Although, over twenty meteorological stations are present over the country and have data to cover more than hundred years it is regrettable that hardly any systematic study on inter

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relationship of these climatic parameters has been undertaken in the past. The number of meteorological stations within the Central Highlands is only four.

Decrease in temperature with increasing altitude is a well known fact. But how other parameters vary with elevation has not been properly discussed. This study emphasizes these relations and correlation of each climatic parameter.

Thambyahpillay (1952) stated that the recognition locally of three climatic zones; Wet, Dry and Arid purely on the basis of average rainfall is climatologically unsound and inadequate. He suggested that temperature-precipitation relationship be used as the criterion of zonation for classification. He demarcated the Wet Zone, by the 1905 mm (75"), annual rainfall curve or 508 mm (20") SWM rainfall and the dry zone rainfall is below 1905 mm.

The Wet Zone rainfall, while being higher, is more evenly distributed in both winter and summer (Asian Development Bank, 1994). The monsoonal conditions refer to the seasonality of rainfall, from tropical conditions to the temperature patterns which are characterized by large diurnal variations in comparison to the only small and typical seasonal differences. Thus larger diurnal ranges, other than seasonal ranges characterize the tropical temperature conditions of Sri Lanka.

There is a significant vertical temperature gradient (the lapse rate of temperature) in Colombo (7 m a.s.l.) and in Nuwara Eliya (1895 m a.s.l.). Station data for the 1961-90 period indicates that the vertical temperature gradient is 0.604°C for every 100 m.

The annual average rainfall data clearly shows a considerable variation of rainfall in Sri Lanka. The annual maximum of 5700 mm is recorded in the Kenilworth Tea Plantation at Ginigathhena (890 m a.s.l.) and at Watawala which is situated on the western slope of central highlands. The greater annual rainfall is recorded on the western slopes rather than the eastern slopes. The reason for this difference is the amount and regional distribution of the SWM rainfall. During the four to four and a half month period from mid-April/end-May till the end of September, the heavily moisture-laden SWM brings ample orographic rains on the windward, western slopes of the central highlands. During this period, on the eastern slopes, the SWM occurs only as a dry, Katabatic, *Foehn*-like wind that brings very little rain (Yoshino, 1983). The central highlands act as a clear-cut orographic barrier which causes considerably varying SWM rainfall totals on both slopes. The western slopes record in most parts 1500-2500 mm, the eastern slopes around 500 mm only. In no other season of the year can such a remarkable difference of rainfall due to the influence of the central highlands be observed.

The vertical distribution of rainfall is characterized by increasing totals with increasing altitude in the lower parts of the highlands only, whereas in the middle and upper parts of the mountains the rainfall totals decrease with increasing altitude.

The average annual totals of sunshine in Sri Lanka vary between about 2850 (Kankasanturai) and 1500 (Nuwara Eliya) hours. More specifically, the highest totals are recorded in the lowlands of the north and east of Sri Lanka, the lowest in the highlands. The sunshine totals on the western slopes are lower than that of the eastern slopes. The high amount of cloudiness and rainfall results in low sunshine totals on the western slopes compared to the eastern slopes, at the time of the SWM. The lowest monthly sunshine totals occur during the SWM on the western slopes.

Yoshino and Suppiah (1982) analyzed wind conditions based on the monthly values in the 1971-80 period. The southwesterly winds prevail in June and September at the southern-most region and the northern-most region of the island. In addition, it is interesting to note that the relatively strong winds blow in a zonal area north of the northern foot of the central highlands.

Generally, cloudiness is less in the Dry Zone lowlands than in the Wet Zone lowlands and highlands. In the latter areas, a higher amount of cloudiness can be observed on the western slopes compared with the eastern slopes. Annual average cloudiness at 0830 LST is fairly the same for all stations, *i.e.*, five Octas, but different values are indicated in the evening.

In the Dry Zone, class A pan evaporation is around 6 mm/day during dry season, and about 3 mm/day during the wet season (Panabokke, 1996). In the Wet Zone it is between 3.5 and 2.5 mm/day, while in the higher elevations above 2000 m it is between 2.5-1.2 mm/day.

Relative humidity (RH) at 0830 LST for all stations is around 80% but values at 1730 LST vary with location. Annual average RH in stations in the Dry Zone come down to 67% (Vavuniya) and 68% (Maha Illuppallama). But these values in the Wet Zone stations like Colombo, Katugastota, Nuwara Eliya and Ratnapura drop to 75, 70, 82 and 74% at 1730 LST respectively.

The highlands of Sri Lanka act as a clear-cut climatic divide. This causes, in a large and meso-scale sense, different rainfall, temperature, sunshine and wind conditions on both the western and eastern slopes of the highlands.

The results of an analysis of rainfall in Nuwara Eliya to detect the trends for a 112 year period (Madduma Bandara, 1997) indicate a significant decline in annual rainfall amounting to about 500 mm or 20% of the total during the last 100 years. This study shows a decreasing trend of annual rainfall in Nuwara Eliya; around 4.98 mm/year.

Miyashita (1997) has used temperature and rainfall records over 100 years in 14 meteorological stations scattered throughout the island and studied their trends. The annual mean surface air temperatures shows positive trends in all stations except in Kandy (-0.007°C/year). The greatest positive trend indicated in Nuwara Eliya (0.0101°C/year). Puttalam, Ratnapura, Badulla and Anuradhapura shows positive gradients greater than 0.05°C/year. The objective of this study is to identify the relationship between altitude and climatic parameters of inland stations of Sri Lanka.

MATERIALS AND METHODS

This study considered the climate of the inland hill country. The analysis consisted of the available climatic data of the locations in inland stations including those at higher altitudes.

The monthly data and the mean daily data used for this analysis were recorded and compiled at the Department of Agriculture (DA) and the Tea Research Institute (TRI) and they consist of recent figures for NEM and SWM from 1991-1994. The NEM considered from December to February and the SWM was from June to September. The climatic elements analysed were the monthly means of wind speed (WS), mean maximum temperature (T_{Max}), mean minimum temperature (T_{Min}), relative humidity at 0830 (RH_{0830}) and 1530 LST (RH_{1530}), monthly rainfall (RF), the mean daily hours of sunshine (HS) and pan evaporation (PE). The topography, altitude and the seasons were the main parameters, which influence climatic elements. Hence seasonal variations of climate in the agro-meteorological stations and TRI stations were analysed.

Inter relationships of climatic parameters were identified using a graphical presentation for each season. Variation of each climatic parameter at seven locations with time is shown in graphs (Fig. 1-4). These graphs were used to explain the initial relationship among the parameters. The correlation coefficients of climatic parameters were also calculated. The agro-meteorological stations and the TRI stations in the central highlands, together with the data made use of in this analysis are indicated in Table 1.

Table 1. Altitude, aspect and location of selected inland stations for the study.

Station	Latitude (N)	Longitude (E)	Altitude (m)	Aspect
Matale*	7° 30'	80° 37'	365	West facing
Peradeniya*	7° 15'	80° 45'	492	West facing
Talawakele**	6° 55'	80° 40'	1382	West facing
Sita Eliya*	6° 58'	80° 46'	1860	Flat terrain
Bandarawela*	6° 50'	81° 00'	1372	East facing
Passara**	6° 56'	81° 07'	1120	East facing
Girandurukotte*	7° 20'	81° 00'	96	Eastern plain

* Agro. Met. Station ** TRI Station

RESULTS AND DISCUSSION

Results of the correlation analysis are given for the northeast monsoon (NEM) period and the southeast monsoon (SWM) in Table 2 and 3 respectively.

Northeast monsoon period

Variation of monthly average values during January, February and December from 1990-1994 is indicated in Fig. 1. According to Fig. 1a and 1b, the month of February showed high maximum temperatures and low minimum temperatures. However, there was an exception to this in Girandurukotte, Peradeniya and Matale stations, which had considerable differences of elevation. The difference between the T_{Max} values of Sita Eliya and Talawakele was considerable (Fig. 1a). It may be due to the higher wind speed and lower hours of sunshine at Sita Eliya.

Table 2. Correlation coefficients of eight climatic variables and height during NEM (N=90).

	T_{Max}	T_{Min}	HS	WS	RF	PE	RH_{0830}	RH_{1530}
T_{Max}	1							
T_{Min}	0.743 (0.000)	1						
HS	0.1672 (0.152)	-0.378 (0.001)	1					
WS	-0.577 (0.000)	-0.656 (0.000)	0.219 (0.059)	1				
RF	0.002 (0.986)	0.427 (0.000)	-0.598 (0.000)	-0.302 (0.004)	1			
PE	0.349 (0.002)	-0.027 (0.815)	0.606 (0.000)	0.27 (0.016)	-0.458 (0.000)	1		
RH_{0830}	0.282 (0.007)	0.648 (0.000)	-0.635 (0.000)	-0.349 (0.001)	0.484 (0.000)	-0.253 (0.025)	1	
RH_{1530}	-0.445 (0.000)	0.102 (0.338)	-0.679 (0.000)	0.008 (0.944)	0.453 (0.000)	-0.492 (0.000)	0.524 (0.000)	1
H	-0.908 (0.000)	-0.895 (0.000)	0.115 (0.224)	0.571 (0.000)	-0.204 (0.054)	-0.263 (0.019)	-0.515 (0.000)	0.181 (0.087)

The P values are given in Parenthesis.

Table 3. Correlation coefficients of eight climatic variables and height during SWM (N=120).

	T_{Max}	T_{Min}	HS	WS	RF	PE	RH_{0830}	RH_{1530}
T_{Max}	1							
T_{Min}	0.896 (0.000)	1						
HS	0.627 (0.000)	0.505 (0.000)	1					
WS	-0.722 (0.000)	-0.629 (0.000)	-0.27 (0.008)	1				
RF	-0.499 (0.000)	-0.417 (0.000)	-0.631 (0.000)	0.311 (0.001)	1			
PE	0.805 (0.000)	0.716 (0.000)	0.737 (0.000)	-0.339 (0.001)	-0.514 (0.000)	1		
RH_{0830}	-0.798 (0.000)	-0.646 (0.000)	-0.57 (0.000)	0.602 (0.000)	0.428 (0.000)	-0.798 (0.000)	1	
RH_{1530}	-0.852 (0.000)	-0.776 (0.000)	-0.607 (0.000)	0.555 (0.000)	0.4471 (0.000)	-0.859 (0.000)	0.883 (0.000)	1
H	-0.924 (0.000)	-0.962 (0.000)	-0.516 (0.000)	0.685 (0.000)	0.44 (0.000)	-0.732 (0.000)	0.667 (0.000)	0.799 (0.000)

The P values are given in Parenthesis.

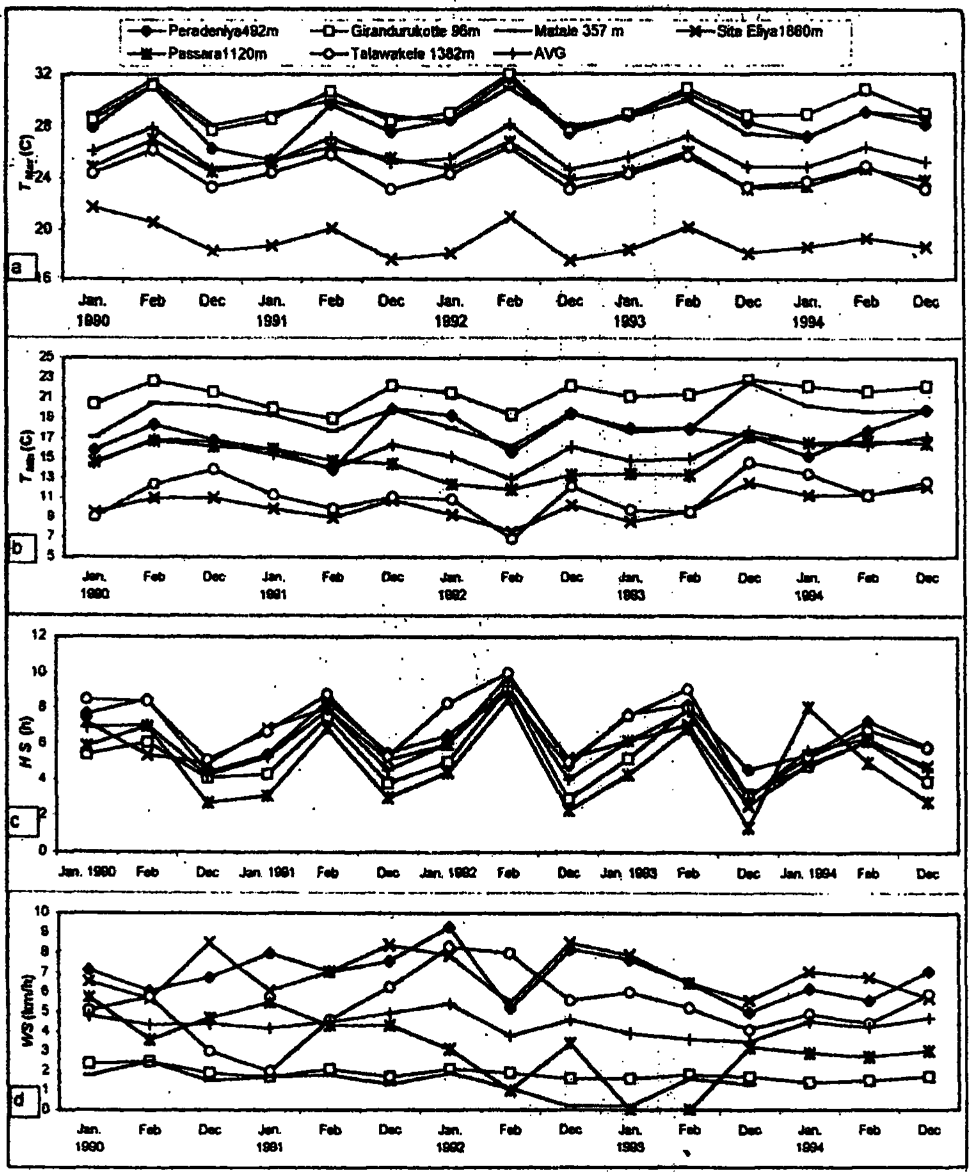

Fig. 1. Variation of maximum air temperature (T_{Max}), minimum temperature (T_{Min}), hours of sunshine (HS), wind speed (WS) during NEM.

During NEM, the maximum temperatures were lower in December than during other months and the minimum temperatures were higher. This is probably due to high cloud cover (Department of Meteorology, 1976). As it shows, the number of sunshine hours has a negative relationship with the minimum temperature and a positive relationship with the maximum temperature. However, the correlation coefficients of maximum temperature and minimum temperatures with hours of sunshine were 0.167 and -0.378 respectively (Table 2). The minimum number of sunshine hours indicated in December and the maximum in February. Again this may be due to high and low cloud cover in December and February respectively (Department of Meteorology, 1975). A marked difference existed in T_{Max} variation based on elevation and not on the aspect of slope (Fig. 1a).

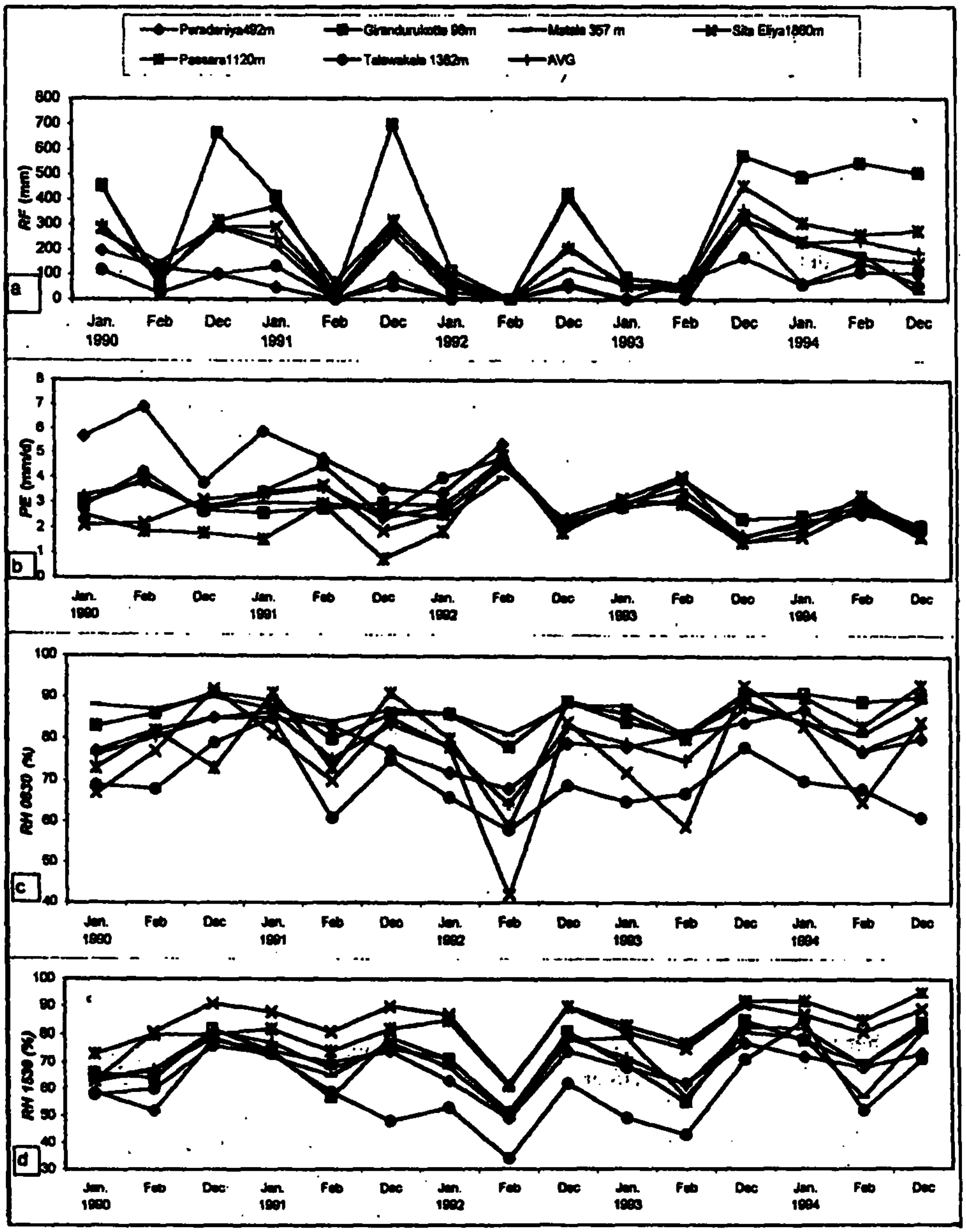

Fig. 2. Variation of monthly rainfall (RF), AVG pan evaporation (PE), relative humidity at 0830 and 1530 LST (RH_{0830}), (RH_{1530}) during NEM.

The decrease of T_{Min} with increasing altitude was clearly indicated on both slopes (Fig. 1b). The lowest mean T_{Min} of 1992 February at Talawakele and Sita Eliya were 6.9

and 7.6°C respectively. Apart from the above, the T_{Min} of Talawakele and Sita Eliya were close to each other even with an elevation difference of 478 m, although the elevation effect gives a marked difference to the T_{Min} at low elevations.

Fig. 1c shows a similar pattern of variation of the HS in most of the stations. The amplitude of fluctuations of HS indicated that it was lowest at Peradeniya (4.5 h) and highest at Passara (7.1 h).

During December, the highest WS was reported at Sita Eliya (8.5 km/h) which decreased along both slopes. This positive relationship of WS with elevation has a correlation coefficient of 0.5719 (Table 2). However, there were exceptionally high wind speed values at Peradeniya (above 5 km/h), the occurrence of which may be attributed to valley winds.

Fig. 2b shows PE rates at the two leeward stations, Peradeniya and Talawakele which are higher than all other stations. This may be due to dryness of the wind (*i.e.*, low RH), high WS and also high HS (Fig. 1c, 1d and 2d). The lowest PE rate during December 1991 was observed at Passara (0.777 mm/d) which is on the windward slope, where hours of sunshine were low (Fig. 1c).

Fig. 2c shows the variation of RH_{0830} at Sita Eliya with high amplitude. The least amplitudes of RH_{0830} were at Matale and Girandurukotte, where high rainfalls prevailed (Fig. 2a). The variation of T_{Min} and RH_{0830} were similar (Fig. 1a).

As leeward stations, Talawakele and Peradeniya showed the least RH_{1530} values due to the dry wind, high WS and HS (Fig. 1c and 1d). This is a good example of having moisture-laden winds on the windward slope and dry winds on the leeward slope due to the *Foehn* effect.

Southwest monsoon period

The variations of eight climatic parameters during SWM from June 1990 to September 1994, are shown in Fig. 3 and 4.

The higher values of T_{Min} were observed from May to June (12.6-12.5°C) during higher mean wind speed. Variations of HS are indicated in Fig. 3c. The highest HS values were recorded at Girandurukotte, which is a low elevation, dry-zone station situated east of the hill country. The reason for higher variations may be less cloud cover on the leeward side. The lowest HS was reported at Talawakele (1382 m) on the western slope. The reason for the lowest HS may be the high cloud cover on the windward (western) slope.

The WS of Sita Eliya had exceptionally high values (maximum 23.9 km/h) and a high range of fluctuations (18.5 km/h). This may be due to the high elevation and full exposure to SWM (Fig. 3d). These high values exceed the long-term average values of Diyatalawa and Nuwara Eliya (Dept. of Meteorology, 1976). The WS of Passara was low due to the location of this station on the leeward slope.

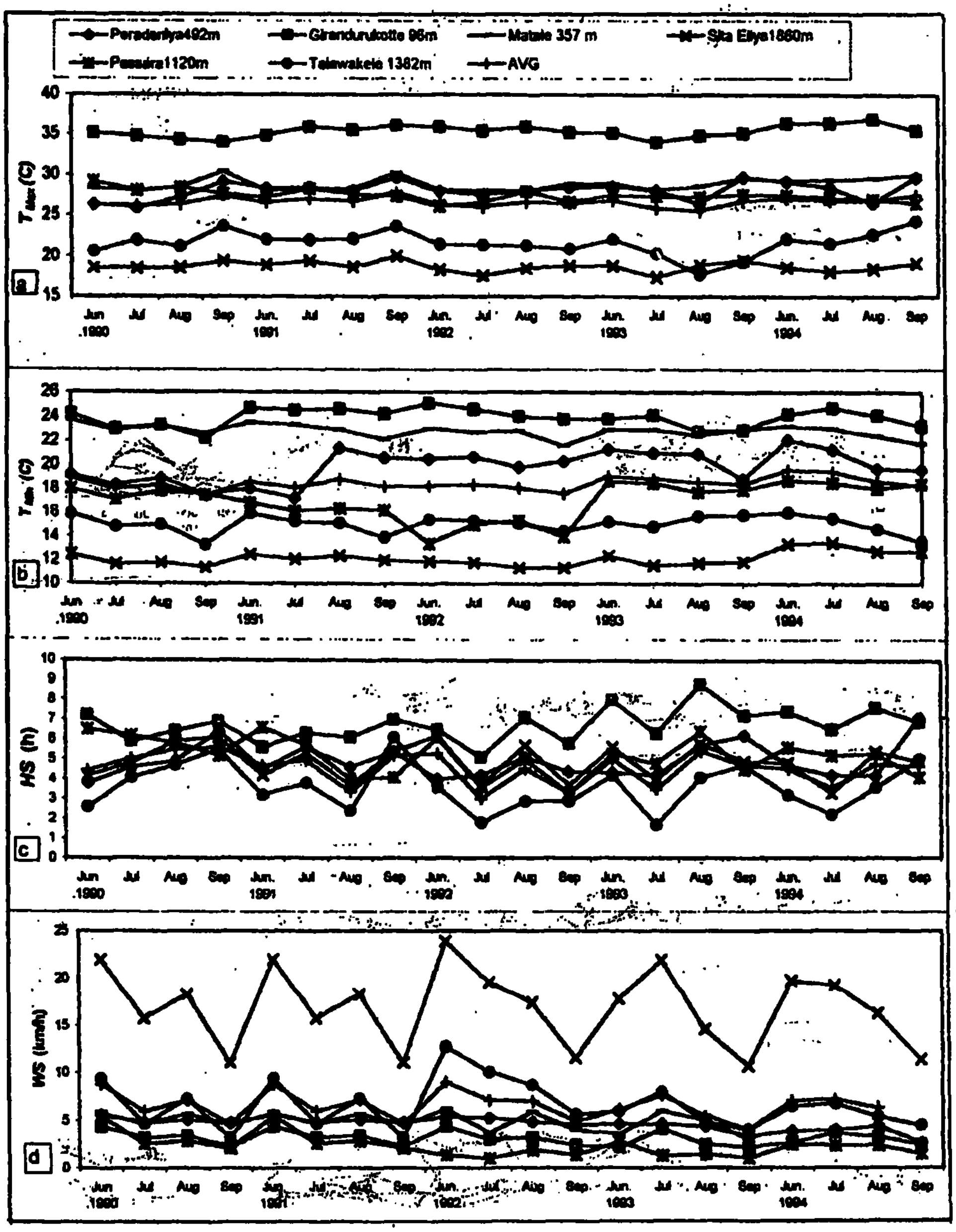

Fig. 3. Variation of maximum air temperature (T_{Max}), minimum temperature (T_{Min}), hours of sunshine (HS), wind speed (WS) during SWM.

Talawakele, as a station on the windward slope received the highest RF (603.5 mm) in June 1992 simultaneously with the highest WS (12.8 km/h) (Fig. 4a and 3d). The RF of Girandurukotte showed the minimum value in June and July with the occurrence of minimum WS.

The lowest PE was observed at Talawakele (Fig. 4b) with one exception from 1990 September to 1991 September. During this period, Passara showed the lowest PE when high RH and low T_{Min} prevailed there (Fig. 4c, 4d and 3b). The lowest PE values were reported at Talawakele on the windward slope surrounded by tea plantations.

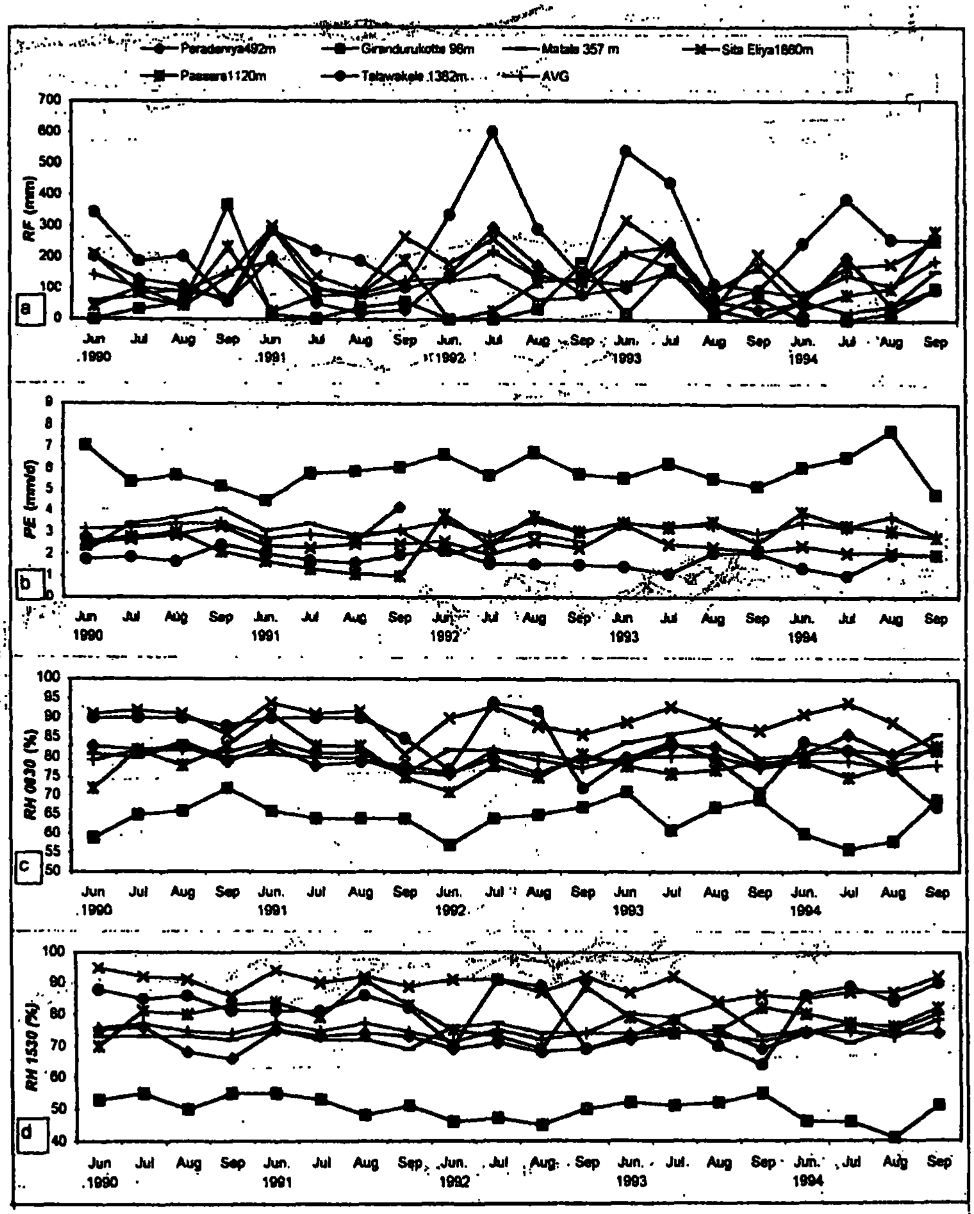

Fig. 4. Variation of monthly rainfall (RF), AVG pan evaporation (PE), relative humidity at 0830 and 1530 LST (RH_{0830}), (RH_{1530}) during SWM.

One interesting feature is the closeness of the PE values of Matale and Sita Eliya despite the fact that there is an elevation difference of over 1500 m between these two stations. The reason for this condition may be the exceptionally high wind speed at Sita Eliya that increases evaporation. The highest RH_{0830} was indicated at Sita Eliya (90%) which is the peak. Girandurukotte (below 70%) which is on the leeward plain, showed the lowest RH_{0830} (Fig. 4c). This also indicates a positive relationship of RH with wind speed (Fig. 4c and 3d). Variation of RH_{0830} and PE at Girandurukotte showed a negative relationship (Fig. 4c and 4b).

Stations on the western slope such as Talawakele, Matale and Peradeniya showed high RH values (above 70%) during SWM because they are on the windward slope which has high cloud cover in the evenings.

CONCLUSIONS

A decrease of the maximum temperature with increasing altitude is clearly indicated on both slopes. The January wind speed, which is higher in Peradeniya (492 m) than in Talawakele (1382 m), contributes to a considerable decrease of the lapse rate. Within this altitudinal range, the highest lapse rate identified is between 357 and 492 m. This study shows that during the SWM most of the climatic parameters shows high correlation with height than NEM. During SWM all climatic parameters show highly significant pair-wise correlation coefficients. The HS, RF and RH_{0830} show opposite values of correlation for NEM and SWM. The relationships for the climatic parameters based on height is more reliable for SWM.

The following conclusions can be given regarding the NEM period. Within the NEM period there is a considerable variation of climatic parameters, which permits the breaking down of the period into three temporal sub-divisions. December for instances shows fairly low T_{Max} values that correlate with less number of HS. Also during this month the high amount of rainfall RF is a general observation that agrees with the expected normal pattern of the NEM. The RH is also generally high during December. On the other hand in January these parameters show moderate values for the NEM. In February, on the contrary, they show a significant difference. For instance T_{Max} becomes higher with maximum HS of the NEM period. This may be due to the weakening of the NEM toward February that brings in less moisture in, reducing cloud cover. This factor seems more important than the increasing of day length towards February. Generally the RH also seems less than in December, which explain the increased PE during February.

During SWM the leeward stations have fewer HS. In this season the temperatures in the stations Peradeniya and Matale are similar to what prevails in the leeward station Passara situated at a higher altitude. The reason may be higher wind speeds in the two windward stations.

HS values are greater in the leeward low elevation station Grandurukotte because of less cloud cover. HS values are less in the windward, hill country station Talawakeke obviously due to the condensation of moisture on the windward side of the hills.

However, even on the leeward side Girtandurukotte and Passara are different. Girtandurukotte has higher PE values than Passara with high T_{Max}, HS and low RH. This explains the effect of elevation on the same slope.

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