Rainfall variation on the windward and leeward side of the Central Highland of Sri Lanka

K.W.G. Rekha Nianthi*

* Department of Geography, University of Peradeniya, Sri Lanka

Abstract
The mountains and highlands in the tropical areas receive more rainfall than the nearby lowlands, in highland areas at least on their windward sides. It is well known that a large part of the heavy rain received on the western side of Sri Lanka is induced by the topographic barriers known as the Central Highland (CH). The objective of this study was to examine whether these orographic rainfall profiles more or less agree with the global figures of the orographic rainfall in the tropical mountains. The orographic effect of the western side of the CH of Sri Lanka has been studied with reference to the annual average rainfall and Southwest Monsoon rainfall using data from 1959-2002. Monthly rainfall data were obtained from the Department of Meteorology in Colombo, Agro-Meteorology Unit, Department of Agriculture, *Peradeniya* and Nakagawa et. al, (1995). The study area consists of nine representative locations of both sides of the CH elevation ranging from 2 to 1667 meters. These locations are *Colombo, Kalutara PWD, Ratnapura, Abergeldie Group, Annifield Estate* and *Sandirigama,* which lie on the western sides and *Badulla, Wewessa* and *Dyraaba* lying on the leeward side of the CH. The precipitation is dependent on the altitude over the western side, which is on the windward side with respect to the southwest monsoon whereas it is independent of the altitude over the eastern side, which is on the leeward side. The analysis showed that, in the western slopes of the CH, the southwest monsoon rainfall increases from the coast to the foothills and then increases up to about 1000 meters from there and decreases above that level. The annual average rainfall also increases up to a height of about 1000 meters and then, decreases above that level. This characteristic may be due to strong differences in water vapor contents between the lower and upper layers of the troposphere. The steep lapse rate frequently present in tropical air masses also tends to reduce the capacity of the air to retain water vapor in the higher parts of the troposphere. Further, the study revealed that the rainfall has been decreasing at some of the locations since 1959-2002. The annual average rainfall has also been analyzed from 1944-1963 for some selected rainfall stations. According to this analysis, the rainfall has been increasing from Colombo (2487 mm) up to *Watawala* (5127 mm) but then again from *Watawala* to *Nuwaraeliya* (1895 m) the annual average rainfall has been decreased rapidly. It is also shown that the rainfall amount is changed in the Uva basin, especially the eastern part. *Welimada* in the *Uva* basin is situated in the lower part of the *Uva* basin and therefore the *Welimada* receive less rainfall (leeward) from both monsoons. These analyses clearly show that the orographic effect of the Central Highland of Sri Lanka shares similar patterns with the global figures of the orographic rainfall in the tropical mountains and highlands.

Index Terms- Rainfall, Orography, Elevation, Windward side, Leeward side

I. INTRODUCTION

The increase in precipitation with elevation on mountain slopes is a worldwide characteristic (Roger, et al 1992). But the actual profile of this pattern can be differed in regionally and seasonally. According to the global mean annual rainfall figures, mountains and highlands receive more rainfall than nearby lowlands at least on their windward sides. This is the result of orographic lifting process which increases rainfall in all climates. But the effects show a significant difference between the tropics and the extra-tropical latitudes or mid-latitudes. Extra-tropical latitudes the amount of precipitation increases with increasing elevation up to the highest levels of the mountains. In the tropics, the increase stops at a level of about 1000-1500 m and above this elevation precipitation generally decreases with height. This characteristic is due to two conditions which frequently prevail in the tropics but are the rather rare in the mid-latitudes. In the tropics and subtropics, the maximum rainfall occurs below the higher mountains summits from which levels it decreases upwards towards the crest (Roger, et al 1992). The first is a strong difference in water vapour content between the lower and upper layers of the troposphere. Tropical air masses are often very humid up to an elevation of about 800-1200 m, but above this level, they are usually rather dry. This may be due to the trade wind inversion but it can also be caused by extremely large water vapor production at the earth's surface in the tropics. The steep lapse rate frequently present in tropical air masses also tends to reduce the capacity of the air to retain water vapor in the higher parts of the troposphere. The second factor is the predominance of vertical air movements in the tropics, where horizontal advection of moisture is often limited. Most precipitation, therefore, originates from the atmosphere directly above the slopes, while in the mid-latitudes water vapor is often transported over large horizontal distance (Weischet, 1965, 1969). A global survey of the vertical profile of precipitation was carried out by Lauscher (1976) analyzing data from about 1300 stations. It is found that the tropical climate shows a clear maximum precipitation between 1000 and 1500 meters above mean sea level. Though this is the general pattern of the annual precipitation of the tropical regions of the globe many local or regional complications may occur (Barry, 1981).

Lauer (1975) has given generalized profiles of the mean annual precipitation against the altitude of various mountains in the tropics. The greatest annual totals of rainfall in the world occur

where mountain barriers lie across the paths of moisture-bearing winds. A famous example is *Cherrapunji* on the Southern margin of the *Khasi* Hills in Assam, India. This station receives averages 1144 cm of rainfall annually. In 1873 the total rainfall was only 719 cm, in 1861, when the annual total was a fantastic 2299 cm; 930 cm rainfall fell in the month of July alone. It is an important factor in triggering the precipitation process and intensifying rainfall on windward slopes, and it, therefore, affects the variations of the aerial distribution.

Thambiyahpillay (1952) has analyzed how annual average rainfall has been changing with increasing elevation taking a cross section from Colombo to *Pothuvil* in Sri Lanka. Domros (1974) also examined the relationship between rainfall and elevation. In this study, he identified that the highest rainfall is received to the western slope of the Central Highland and it is gradually increased from 300 to 1000 m and above this level the rainfall is decreased significantly. Compare to eastern side western side gets higher rainfall. Yoshino et al (1983) pointed out that the location of the Central Highland is one of the main physical structure which the control the climate of Sri Lanka. Horizontal and vertical structure of the physical setting of the Sri Lanka topography creates large diversity to change the rainfall distribution. The Western side of the Central Highland receives more rainfall than eastern side and especially when Southwest monsoon activates. Similarly, when northeast monsoon activate the rainfall is higher on the eastern side but compare to Southwest monsoon Northeast monsoon give less rainfall. Orographic effect of the Central Highlands of Sri Lanka has similar patterns with the global figures of the orographic rainfall in the tropical mountains and highlands (Rekha, 2005).

It is well known that a large part of the heavy rain that falls on the western side of Sri Lanka is induced by the topographic barriers known as the western slopes of the Central Highland. The relief of Sri Lanka characterized by the Central Highland is one of the major factors governing the climate of Sri Lanka. Considerable spatial differentiation of the climate is to be expected in the Southwest as well as in the Northeast monsoon season, as results of the effects of the Central Highlands, which form an orographic barrier across the path of the monsoonal air masses and winds. Thus, not only do the highlands take on the role of a climatic shed, but at the same time, there is also established the regional differentiation of the highlands into a windward side and a leeward side, including the flanking lowlands. Due to opposing wind direction of the Southwest and Northeast monsoon, the windward and leeward sides of the highlands keep changing their role according to the rhythm of the monsoon change: those parts of the highlands on the windward side during the other monsoon seasons and vice versa. The windward and leeward side effect of the Central Highlands on the monsoonal air masses will exercise the greatest effects on rainfall and wind, as also on the other climatic elements though to a lesser degree. So it is interesting to know how the orography of the western sides of the Central Highlands of Sri Lanka influences the monsoon rainfall. An attempt has also been made to find out how far these results agree with the global pattern.

II. MATERIALS AND METHODS

The Central Highland is generally defined as the region above 300 m contour of Sri Lanka. It is located in the South center of the Island with many peaks including the *Piduruthalagala* of 2524 m above the sea level, the highest peak in Sri Lanka. However, within this region, the topography is highly diverse with mountain ranges, valleys, plains and even escarpments and slopes. The study area consists of nine (09) representative locations of both sides of the Central Highland. This is to ensure that a good picture of altitude variation of rainfall over the Central Highland can be obtained with little contribution from latitudinal variation. These locations are *Colombo, Kalutara PWD, Ratnapura, Abergeldie Group, Annifield Estate* and *Sandirigama*, which lie on the western side, and *Badulla, Wewessa*, and *Dyraaba*, which lie on the eastern side of the Central highland.

Table 1: Selected rainfall stations

Stations	Altitude (m)	Monthly average rainfall in mm
(Western slope)		
Colombo	07	200
Kalutara PWD	17	213
Ratnapura	34	297
Abergeldie Group	1098	313
Annifield Estate	1311	225
Sandirigama	1601	183
(Eastern slope)		
Dyraaba	1220	128
Wewessa	914	168
Badulla	670	145

Most of these topographical areas cover both windward and leeward sides of the two monsoons. Monthly average rainfall data of the above locations were obtained from the Department of Meteorology in Colombo, Agro-Meteorology Unit, Department of Agriculture, Peradeniya and Nakagawa et.al, (1995), for the period of 1959-2002. These monthly data were converted to seasonal rainfall using the classification adopted in defining the rainfall year of Sri Lanka. The missing data of each rainfall data series were estimated using normal ratio methods. Annual average rainfall data for the period 1959 to 2002 have been averaged to obtain the mean annual rainfall values for above period. Rainfall is separately computed for the southwest monsoon, northeast monsoon, and annual average rainfall.

The second part of this study also considers another available data set to find out the differences of the orography rainfall of the Central Highland. For this analysis, a cross section is selected from the Western part to Eastern part of Sri Lanka. Along the cross section, the random rainfall stations were selected from *Colombo* to *Panawa tank* based on availability common data period. 16 rainfall stations have been selected from western side to eastern side of CH. Out of the 16 stations, 09 stations are situated on the western slope of the CH and 07 are situated on the eastern side. *Colombo, Awissawella, Eheliyagoda, Norton Bridge, Watawala, Abergeldie Group, Hatton Police Station, Nanu Oya, Nuwaraeliya,* are from western side and *Welimada Gropup, Strathden, Gourukella, Lowe Spring Valley,*

Mousagalla, Kumbukkan, and Panawa tank are from the eastern side have been selected for the study (Figure 1).

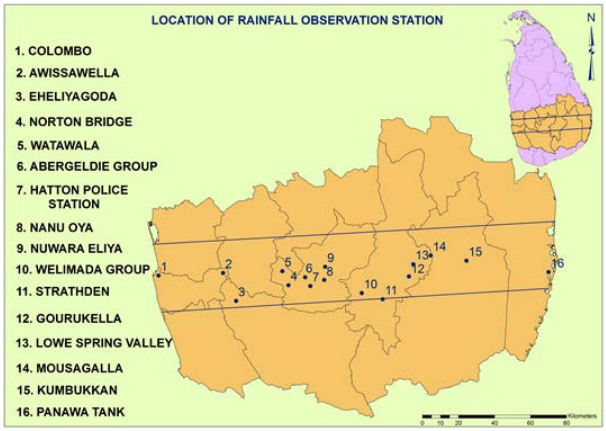

Figure 1: Locations of the rainfall stations on the windward and leeward side of the CH (cross sections of the CH)

III RESULTS AND DISCUSSION

The southwest monsoon rainfall on the western slope increases from about a maximum around 1000 meters and then decreases above this level. In this season, leeward side of the mountain receives less rainfall due to the topographical structure of the Central Highland. On the other hand, the Northeast monsoon rainfall on the eastern sides also shows a similar pattern as above 1000 m the rainfall is decreasing with the elevation. Mountain barriers of the Central highlands of Sri Lanka by forcing ascent of moisture-bearing winds tend to concentrate precipitation on their windward slopes and produce a rain shadow to the leeward sides. It is clearly shown that the more rainfall is received on the western side than the eastern side. According to the results of the analysis, the southwest monsoon air has deposited most of its moisture on the windward side of the Central Highland; there will normally be a great deal less precipitation on the leeward side since on this side the air is much drier and the dew point consequently much lower. The leeward side of the mountain is thus said to be in the rain shadow.

Monthly average rainfall since 1959 to 2002 are shown with selected locations and their attitudes from the both sides of Central Highland (Table 1). Analysis revealed that the annual average rainfall is increasing about up to 1100 m and above that level the rainfall gradually decreases with the height (Figure 2). A similar pattern can be seen in the Southwest monsoon rainfall as well. The southwest monsoon rainfall on the western slope increases from the sea level to about 1000 meters and then the rainfall gradually decrease with the elevation.

Almost similar figures are seen in the northeast monsoon rainfall in the eastern sides. The northeast monsoon rainfall on the eastern slope increases from the sea level to about 1000 meters and then the rainfall decreases gradually with the elevation. Rainfall increases up to 1000 m and then starts to decrease with the height. The western side is on the windward side of the southwest monsoon and the effect of orography in enhancing precipitation is clearly brought out. It is clearly seen that the leeward side receives less rainfall than windward side.

The study also revealed that the southwest monsoon has been decreasing significantly with regard to all the stations since 1959-2002 except *Colombo* and *Ratnapura.* However, southwest monsoon rainfall at *Kalutara PWD, Abergedie Group, Annifield Estate* and *Sandirigama* has been also decreasing since 1959 to 2002.

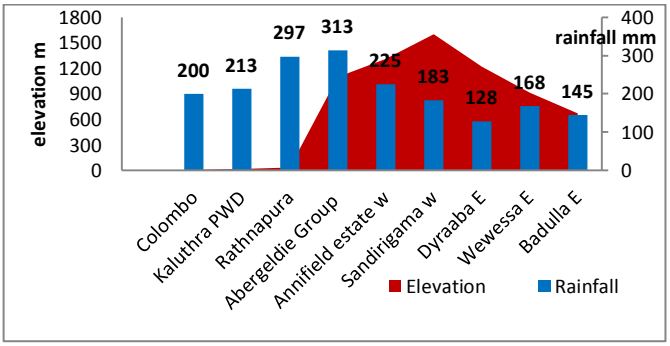

Figure 2: Relationship between monthly average rainfall and elevation

The study also revealed that the monthly average rainfall of the eastern side locations has been decreasing significantly in almost all the stations since 1959-2002 (Table 2). Table 3 shows monthly average rainfall of Northeast monsoon season of selected locations of the periods 1959-2002.

Table 2: Monthly Average Rainfall in mm: 1959-2002 (Eastern side of the Central Highland)

Years	*Dyraaba* (1220 m)	*Wewessa* (914 m)	*Badulla* (670 m)
1959-62	142	186	159
1969-72	148	184	162
1979-82	112	150	132
1989-92	140	132	143
1999-02	96	187	128
1959-2002: average	128	168	145

Source: Calculated by the authors based on rainfall records of Department of Meteorology, Colombo

Table 3: Monthly Averages Rainfall in mm Northeast Monsoon Season: 1959-2002 (Eastern side of the Central Highland)

Years	*Dyraaba* (1220 m)	*Wewessa* (914 m)	*Badulla* (670 m)
1959-62	189	248	229
1969-72	193	287	250
1979-82	70	90	87
1989-92	149	217	191
1999-02	116	248	155
1959-2002: average	144	218	182

Source: Calculated by the authors based on rainfall records of Department of Meteorology, Colombo

The study also revealed that the Northeast monsoon rainfall has been decreasing significantly in all the stations since 1959 to 2002. In general, the greater annual total of rainfall is received on the western slopes than the eastern slopes.

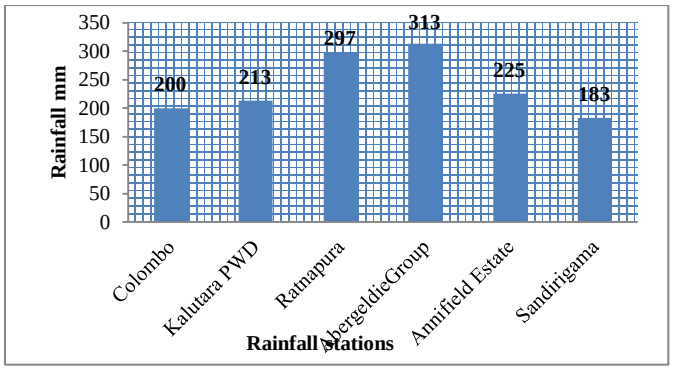

Figure 3: Monthly average rainfall distribution of rainfall stations along the western side

Figure 3 shows the monthly average rainfall distribution along the western slope of the CH. It is also confirmed that the rainfall is gradually increasing up to some certain elevation and above that height, the rainfall is decreased. *Abergeldie* station is situated at the elevation of 1098 m and the *Sandirigama* is situated at the elevation of 1601 m but the rainfall of *Sandirigama* is less compared to *Abergeldie.*

The annual rainfall totals over 5500 mm on the western but the eastern slopes, records less than 2500 mm. The reason for this remarkable difference is the amount and regional distribution of the southwest monsoonal rainfall. During the end-May and until the end of September, the heavily rain loaded southwest monsoonal air masses result in ample orographic rains on the windward, western slopes of the Central Highlands, while on the eastern slopes the Southwest monsoon occurs as a dry, *Katabatic*, *foehn*-like wind which brings very little rain only.

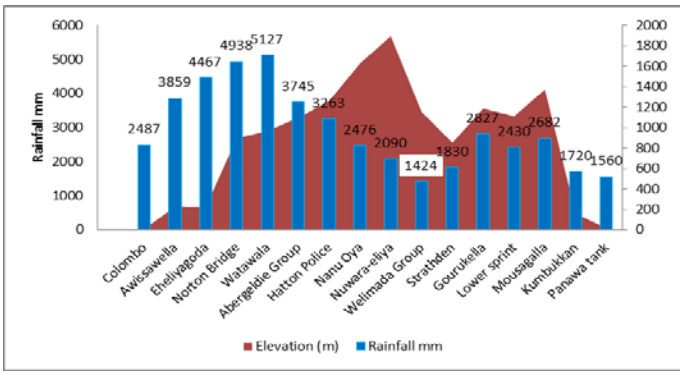

Figure 4: Relationship between elevation and rainfall (1944-1963)

The annual total average rainfall has been analyzed from 1944-1963 for the above stations (Figure 4). According to the analysis, the rainfall has been increasing from Colombo (2487 mm) up to *Watawala* (5127 mm) but then again from *Watawala* to *Nuwaraeliya* (2090 mm) the annual total average rainfall has been decreased rapidly. It is also shown that the rainfall amount is changed in the *Uva* basin, especially the eastern part. *Welimada* in the *Uva* basin is situated in the lower part of the *Uva* basin and therefore the *Welimada* (in leeward) receive less rainfall (1420 mm) from both monsoons (Southwest and Northeast).

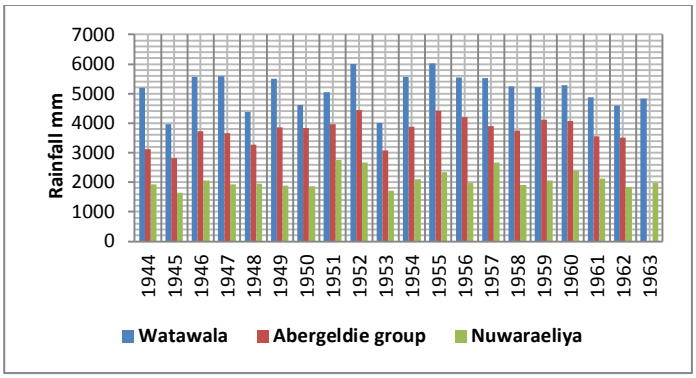

Figure 5: Rainfall difference in *Watawala Abergeldie group,* and *Nuwaraeliya* (1944-1963)

Figure 5 shows the rainfall differences of *Watawala, Abergeldie* and *Nuwaraelya* stations which are lies in the western side of the Central Highland. Annual total averages shows that *Abergeldie and Watawala* station have highest amount of rainfall than the highest elevation of *Nuwaraeliya.*

IV CONCLUSION

This study reveals that the amount of rainfall on the western slope of the Central Highland increases with the altitude to a maximum at a height of about 1000 meters and further up it decrease. A similar pattern can be seen in the southwest monsoon rainfall also. The southwest monsoon rainfall on the western slope increases from the sea level about to 1000 meters then the rainfall is decreasing gradually with the elevation. Almost in a similar manner on the eastern slope of the Central Highland, the rainfall increases to a maximum at about 1000 meters above mean sea level and thereafter decreases continuously. The northeast monsoon rainfall on the eastern slope increases from the sea level about to 1000 meters then the rainfall is decreasing gradually with increases the elevation. These analyses clearly show that the orographic effect of the Central Highland of Sri Lanka has similar patterns with the global figures of the orographic rainfall in the tropical mountains and highlands. However, further studies needed to generalize, that when the rainfall is decreasing an altitude is increased.

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AUTHOR

First Author (Correspondence Author) – K.W.G. Rekha Nianthi, rekhanianthi@yahoo.com , 0812392672