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Statistical Characteristics of Rainfall Intensity of Ogbomoso, South West Nigeria for Microwave Communication Link Budget

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Abstract—Rainfall has long been recognised as one of the atmospheric impairments in the link of electromagnetic wave. Rain rate is one of the most important parameters in the prediction of rain attenuation. Accurate measurement of rain rate is therefore important for link budget estimation. This work presents the results of two-year statistical processing of rain intensity measurement in Ogbomoso, South West Nigeria. A network of rain gauges is strategically sited at three different locations around the town. This analysis is necessitated as a result of increase in population of the town which has attracted some communication companies. This then calls for accurate measurement and statistical analysis of rainfall for adequate microwave link estimation. The results reveal that rain falls more in the hours of (18-24 GMT) and (12-18 GMT) and its characteristic is unpredictable. The worst month in the area falls between June and October. The dependence of percentage of time of the average year P_{AY} on the percentage of time of the average worst month P_{WM} parameters are $a = 0.2573$ and $b = 1.004$. The Q-factor parameter for Ogbomoso is $A = 2.834$ and $\beta =$ -0.08179. This shows a very good agreement with ITU-R recommendation. Therefore, ITU-R 841 (2005) is suitable for use in worst-month analysis for Nigeria and most importantly for Ogbomoso town.

Keywords: rate, worst month, integration time, rain attenuation, Q- factor

1. INTRODUCTION

Rainfall is well known to be one of the atmospheric effects that has serious impacts on communication link at frequency of 10GHz and above [1]. Its effect contributes to reduction in the reliability, availability and performance of the communication link which can be very significant when the propagation path passes through multiple rainfall cell of high intensity [2-4]. Some other propagation effects are depolarization, rapid amplitude and phase fluctuation known as scintillation, cloud attenuation, antenna degradation and bandwidth coherence reduction [5, 6]. These effects must be taken into account in the design of any radio frequency (RF) link as well as systems employing radars. In the recent time, due to high demand for larger bandwidth, higher frequency bands at Ku and above are becoming important for satellite communication and remote sensing application. However, as mentioned earlier, radio wave propagation is more vulnerable to rainfall attenuation at higher frequency. Rainfall rate distribution is an important parameter in the estimation of rainfall attenuation at a specific location. Inadequate knowledge of rainfall pattern coupled with shortage of rainfall data most importantly around this part of the world (Nigeria) makes rain attenuation prediction difficult especially for microwave link budget estimation. Several rain rate and rain attenuation prediction models have been found to be insufficient for tropical rainfall predictions [7-10]. Hence, there is need to carry out this measurement.

This work discusses the statistical processing of rainfall rates in Ogbomoso. The cumulative distribution of average 1-minute and 6-hourly rain intensities, average worst month, the dynamic characteristics of rain events and the dependence of average rain event intensity on rain event duration are presented. The outcome of these analyses will provide useful information for microwave link budget estimation for the area.

2. EXPERIMENTAL SETUP FOR RAIN RATE MEASUREMENT

The most important parameter in the estimation of attenuation due to rain is the rainfall rate. It is the main parameter measured in meteorological centres. The common apparatus used to measure rainfall rate is the rain gauge. A network of rainwise rain gauges was set up at three strategic places in Ogbomoso, Oyo State, Nigeria. One rain gauge was placed at the Faculty of Engineering workshop, LAUTECH, Ogbomoso, another at Ogbomoso High school in the South Local Government area and the last one at Owode police station located in the North Local Government area of Ogbomoso respectively. The positions of the rain gauges were almost on a straight line with distances of 5km apart as similarly suggested by [11-13]. The details of the topographic features of the rain gauge locations are shown in Table 1.

The rainwise rain gauge is set at 0.5 mm tipping bucket type, which records the number of tipping in 1-minute integration time. No data is recorded if the bucket does not tip which means there is no or very little rain i.e. less than 0.5 mm/minute or 30 mm/h. The accuracy of the rain gauge is above 95% and the period of the equipment down time is less than 2%. The accuracy of the rain gauge is measured based on calibration records done at every 6-month interval. The rainlog attached to the rain buckets contains a microcontroller that has a real time clock with EEPROM (Electrically Erasable Programmable Read Only Memory) containing input and serial ports. Once the logger is configured using the RL- Loader software, it goes into standby mode, and remains in this mode until the internal clock reaches the end of a minute. The logger checks for the number of contact closures recorded in the preceding minute, if the count is greater than zero, the logger writes an entry into EEPROM. This entry contains the time, date and number of counts for that minute. The number of close contact per 1-minute integration is recorded in terms of amount of 0.5 mm or 30 mm/hr.

A two-year continuous rainfall measurement from January 2009 to December 2010 was taken at the three locations. The 1-minute integration time was set for all the rain gauges. The readings for one minute were averaged and recorded every minute by the data logging system. Data were extracted from the rain logger into Microsoft Excel for statistical processing. Rain rates at different percentages of time are estimated from the data using Macro Excel program to extract the number of times different rain rate occur. The worst month statistics and its corresponding average worst month are analyzed. The Q-factor estimated for Ogbomoso is compared with the result of other researchers from other parts of the world. The result of the worst month analysis is compared with the ITU-R P 841 recommendations using the figure of merit as provided by the ITU-R P311[14, 15].

3. DATA ANALYSIS

The worst month analysis plays a prominent role in any communication link design. It gives insight to design margin that must be met in any particular month of the year. Worst-month can be applied to quantities such as rain attenuation, cross polarization and rain rate [16, 17]. Worst month

Table 1: The topographic features of the rain gauge locations

Location	Latitude	Longitude	Average Annual Rainfall (mm)	Average Daily Temperature (0°C)
Lautech	8.17	4.27	1362	29.2
Owode	8.12	4.22	1328	29.2
High School	8.11	4.21	1431	29.3

distribution of rain rate is the highest rain rate within a set of individual monthly distribution for a year. The worst month and annual statistics is related by the following ratio:

$$Q = A\gamma^{\beta} \tag{1}$$

where A is the average worst-month probability and γ is the average annual probability for the same threshold. Q-factor is a function of occurrence level and the climatic region. The ITU-R recommendation values for global planning purposes are 2.85 and 0.13 for A and β respectively [14]. The result for Q-factor is derived by plotting the average worst month against average annual percentage of time. The equation for the best line of fit is drawn for the curve. The result for this location is shown in Figure 1.

The dependence of worst month and annual average statistics has been found globally to follow a power law relation as given in (2).

$$P = aP_w^b \tag{2}$$

where P_w and P are the worst month and yearly average cumulative time percentage respectively while a and b are the coefficient for the least root mean square approximation. The ITU-R prediction method recommends the values of $a = 0.30$ and $b = 1.18$ for tropical and sub-tropical regions. The result obtained for this work is presented in Figure 3.

4. RESULTS AND DISCUSSION

4.1. Worst Month Statistics

The worst month statistical analysis for rain rate measured as a function of Q-factor in Ogbomoso is shown in Figure l. The power law equation gives $A = 2.834$ and $\beta =$ -0.08179, which falls in agreement with the ITU-R recommendation. Similar result in this area by other researchers is shown in Table 2. The discrepancy in the results obtained in Ogbomoso, Nigeria as compared with the result of obtained in the Asian part of the world is mainly attributed to terrain/ geographical location of the countries. Although, the countries are located in the same tropical region, however, south west Asian countries experience heavy rainfall throughout the year and rainfall distribution patterns are greatly influenced by seasonal monsoon activities while Nigeria experiences rainfall for seven months and at least three months of complete dry periods. The comparative result revealed that Q-factor is climate and terrain dependent and that the ITU-R proposed value is suitable for use in worst month analysis in Nigeria and most importantly in Ogbomoso town.

4.2. Cumulative Distribution of Rain Intensities for Average Worst Month (AWM)

The obtained cumulative distributions of average 1-minute rain intensities for individual worst months for the three locations are as shown in Figure 2a-2c. The cumulative distribution of average 1-minute rain intensities for AWM for 2009 and 2010 are closely related. Rain distribution in 2010 is a little higher than 2009 but the two years reading follow the same trend. The average rain time is 0.66% and the average rain total is 113 mm. Worst months of 2009 occurred in June with a

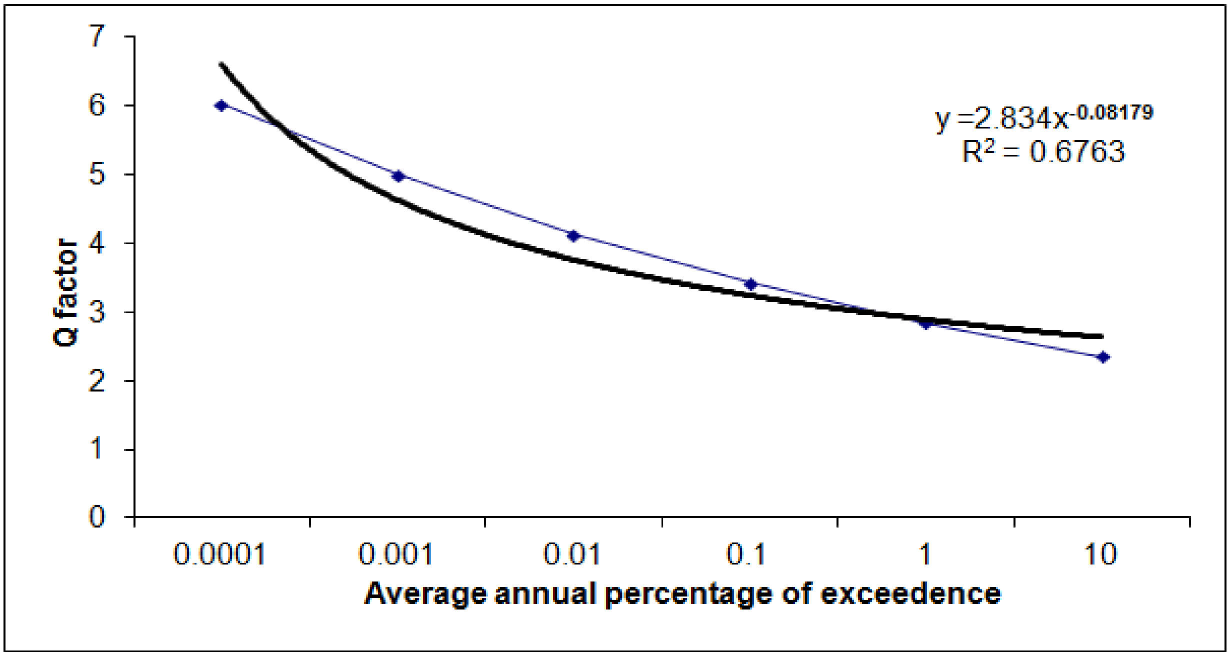

Figure 1: The plot of Q-factor as a function of average annual percentage of exceedence

Table 2: Comparison of A and β values for worst-month analysis

Location	A	β
ITU-R 841 [14]	2.86	0.13
Malaysia [18]	1.3979	0.3041
Malaysia [19]	1.7	0.22
Indonesia [20]	2.834	0.0819
LAUTECH (Nigeria)	2.834	0.0819

highest rain volume of 112 mm and that of 2010 occurred in August with a rain volume of 114mm. This gives a reflection that rain pattern changes yearly and it is almost unpredictable. However, the worst month of any rain period falls between June and October of every year.

4.3. Relation between Average Year (AY) and Average Worst Month (AWM)

The dependence of percentage of time of the average year P_{AY} on the percentage of time of the average worst month P_{AWM} for the same 1-minute rain intensity for the three locations are shown in Figure 3a-3c. The best fitted parameters for LAUTECH, Owode and High school are given in Table 3. The dependence of worst month on average year for Ogbomoso town is given as $a = 0.2573$ and $b = 1.003$. The ITU-R prediction method recommends the values of $a = 0.30$ and $b = 1.18$ for tropical and sub-tropical regions (ITU-R P 841, 2005), which presents a slightly higher value for both parameters than the measured value at Ogbomoso. It is also observed that as parameter a decreases, the difference in yearly and monthly average statistics becomes larger. This observed characteristic is mainly attributed to seasonal variation of monthly cumulative time percentage in the location.

The accuracy of the dependence of worst month average on yearly average cumulative distribution of rain is estimated based on the performance evaluation recommendations given in ITU-R 311. The result is as shown in Table 4. The performance evaluations show that the percentage error and root mean square (RMS) of the proposed parameters from the measured values are quite low compared with the ITU-R model. This shows that ITU-R model in this regard may not be totally accurate for rain attenuation prediction in Ogbomoso.

Table 3: Worst month dependence parameter a and b

Location	a	b
LAUTECH	0.2567	0.9999
Owode	0.2556	0.9933
High school	0.2597	1.008
Average	0.2573	1.0004

Table 4: Performance evaluation of the dependence parameters

	ITU-R	Proposed
Mean error	-37.53	-0.6003
Standard deviation	0.00302	0.000723
RMS	43.32	5.32

4.4. Cumulative Distribution of Rain Intensities for an Average Year

The obtained cumulative distribution of average 1-minute rain intensities is as shown in Figure 4. The probability of rain occurrence for the year is 0.4%. The results obtained are compared with the ITU-R P 837 which shows good agreement close to 0.01% availability time. The result deviated from the ITU-R predicted value at higher availability time. According to the measured value, ITU-R underestimates from 0.01 and below. This could be as a result of short term measurement presently available for this work. However, the authors hope to present the long term measurement result as soon data are available in their next publication.

4.5. 6-hours Cumulative Distribution of Rain Intensities for an Average Year

The obtained cumulative distribution of sampled 1-minute rain intensities for an average year of 6-hour period per day (00-06, 06-12, 12-18 and 18-24 GMT) is as shown in Figure 5. The highest rain intensities occurred in the evening (18-24 GMT) and afternoon (12-18 GMT). The occurrence of rainfall distribution for the hour of 06-12 as shown in the Figure gives an indication that probability of rainfall occurrence in the early morning of the day is quite low. The higher occurrence obtained for 18-24 GMT could be attributed to an enhanced shower activity arising from the convective heating effect during the afternoon and early evening hours.

4.6. Dynamic Characteristics of Rain Events

The total number of rain event from January, 2009 to December, 2010 of observation was '538', the average number of rain events per month is 20, the maximum number of rain events per month was 35 and the minimum number of rain event per month was 4. These revealed that a minimum of 4 rain event is expected during rainy period of the year.

4.7. Duration of Rain Events

The total duration of all events within 24 months was '13104' minutes. The maximum duration of events per day as measured by worst month was 454 minutes and the minimum duration per event was 20 minutes.

4.8. Rain Totals

The rain total over 24 months of observation is 2132.5. The average rain total per month is 125.4 within which 19.4 mm was observed for period 00-06 GMT, 30.2 mm for period 06-12 GMT, 35.6 mm for period 12-18 GMT and 40.2 mm for period 18-24 GMT. The maximum rain total per month is 114.2 mm. It was observed that out of 24 months of rain observation, 262 days are with rain total greater than 0.50 mm per minute. The monthly average number of days with rain total greater that 0.50 mm per minute is 8.73. The scatter plot of probability of occurrence of rain intensity greater than 30 mm/h against rain total is shown in Figure 6. This reflects that rain rate and its corresponding duration are highly correlated with correlation coefficient of 0.813.

5. CONCLUSION

The results of two-year statistical processing of rainfall intensity in Ogbomoso have been presented. The results reveal that rain falls more in the hours of (18-24 GMT) and (12-18 GMT) and its characteristic is unpredictable. The worst month in the area falls between June and October. The measured dependence of percentage of time of the average year P_{AY} on the percentage of time of the average worst month parameters are $a = 0.2573$ and $b = 1.004$. The model test shows -0.6003, 5.32 and -37.53, 43.32 for percentage error and RMS for proposed model and ITU-R 831 respectively. The comparative result revealed that Q factor is climate and terrain dependent and that the ITU-R proposed value is suitable for use in worst-month analysis for Nigeria and most importantly for Ogbomoso town. The results of this work are expected to be useful for quick estimate of microwave link budget and design of quality and reliable communication system for Ogbomoso and its environs.

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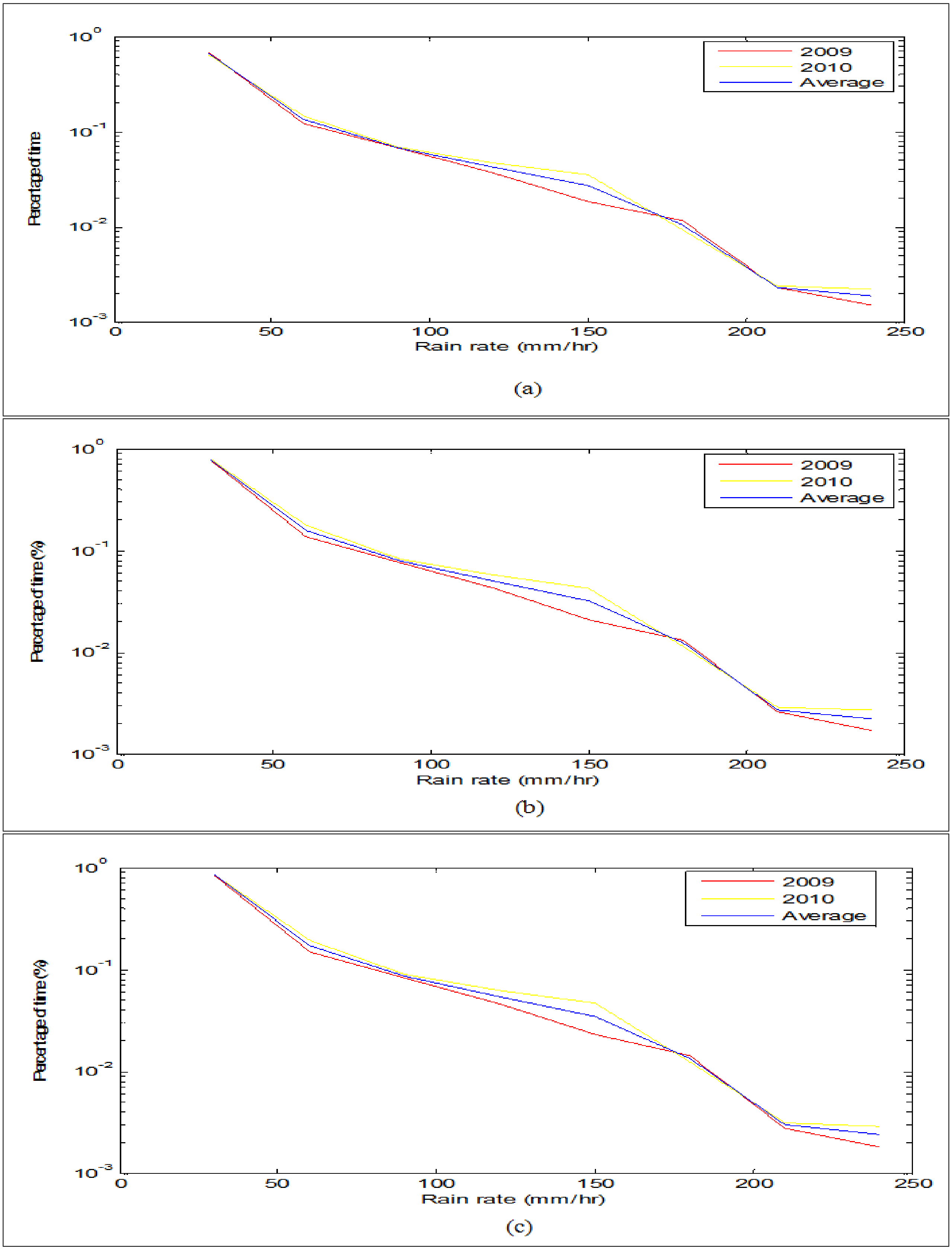

Figure 2: Cumulative distribution of rain intensities for the worst months and AWM: (a) LAUTECH station; (b) High school station; (c) Owode station

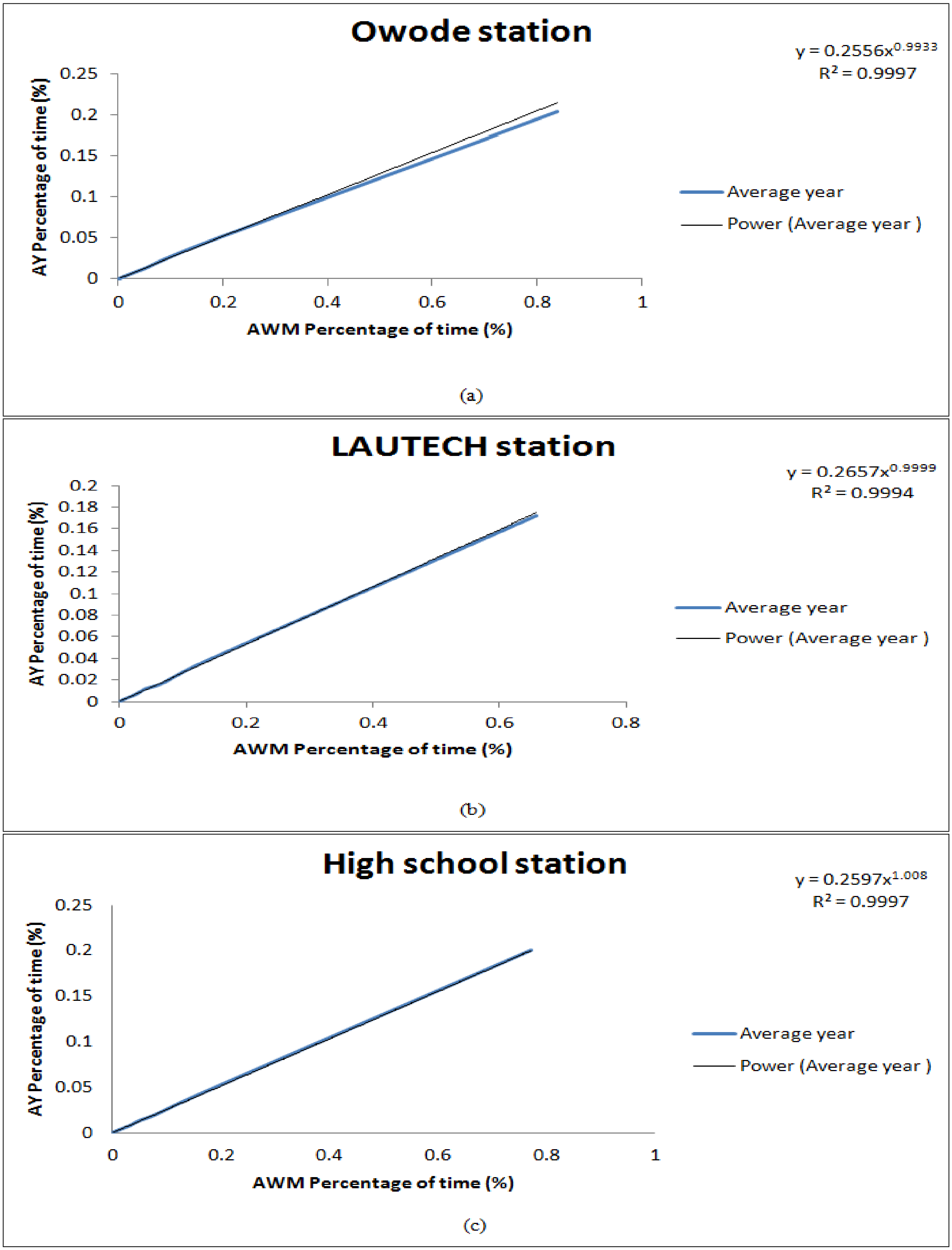

Figure 3: Dependence of P_{AY} on P_{AWM} : (a) Owode station; (b) LAUTECH station; (c) High school station

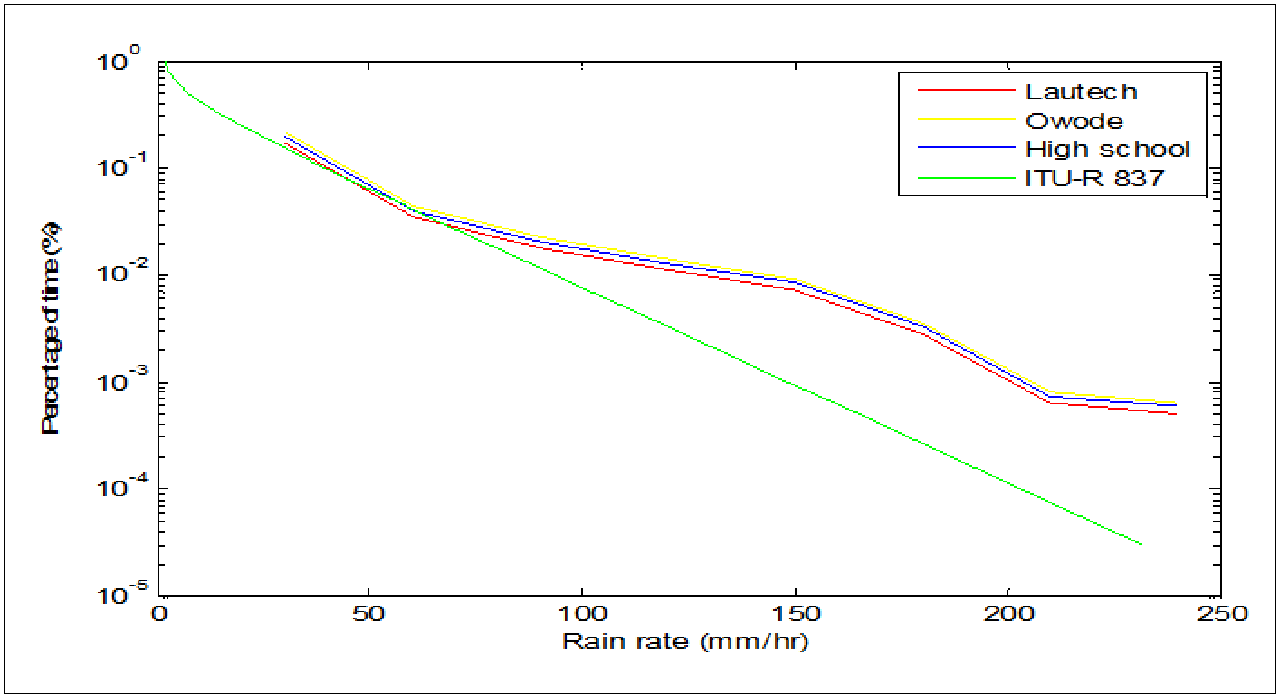

Figure 4: The graph of rain rate against percentage of time

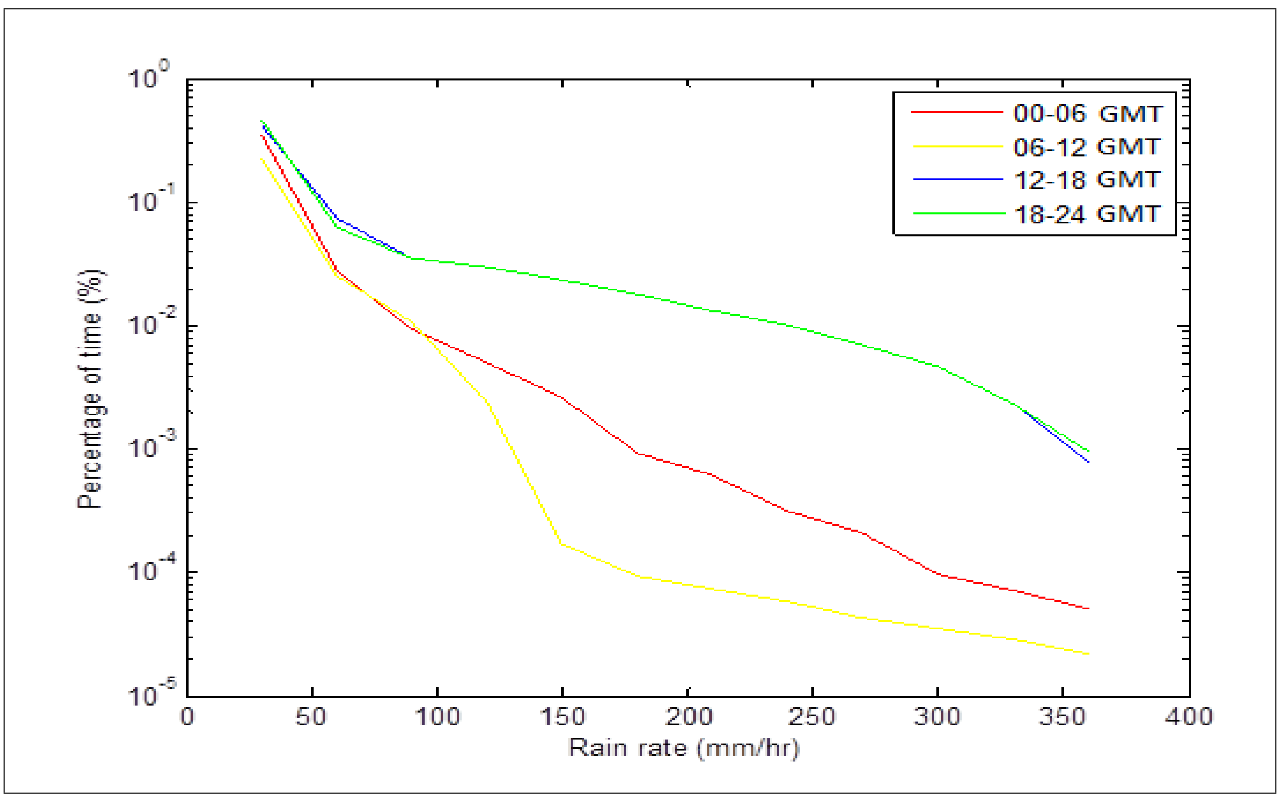

Figure 5: 6-hour cumulative distributions of rain intensities for one year

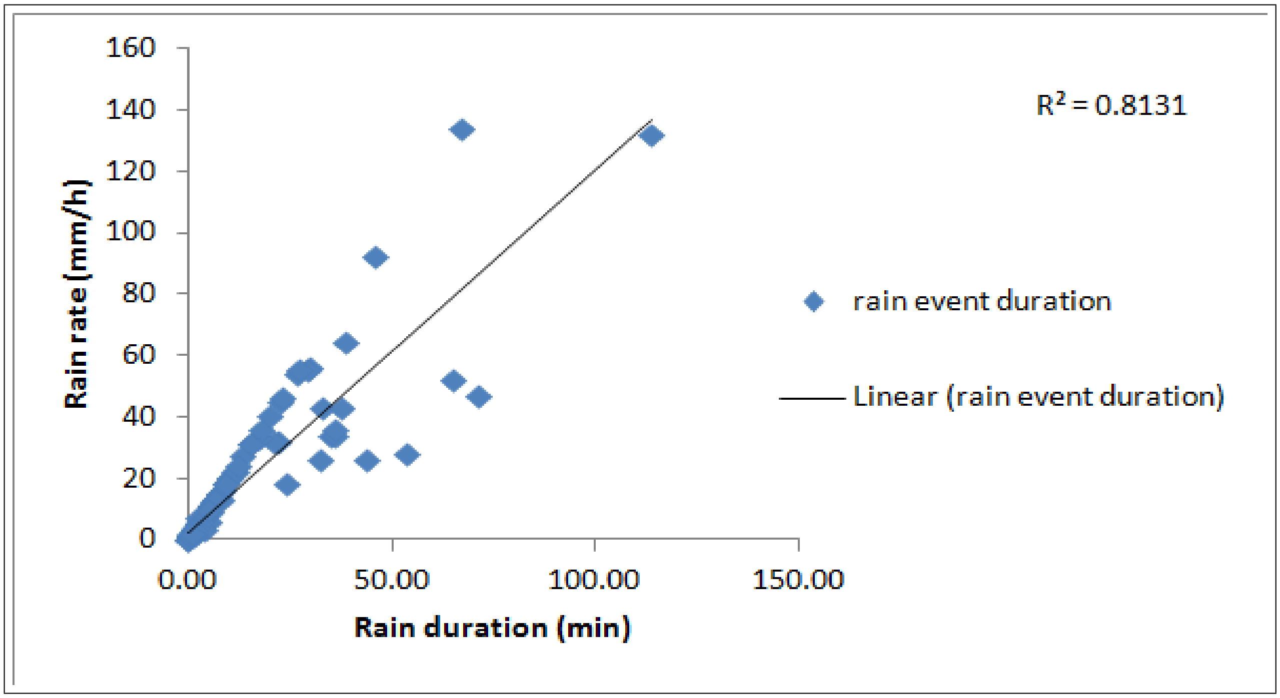

Figure 6: Dependence of average rain event intensity on rain event duration