An-Najah National University

Faculty of Graduate Studies

Integrating microwave links data for analysis of solar radiation in Nablus, Palestine

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Dedication

To my parents (Faisal and Saheer)

To my wife and my soulmate (Danya)

To my beautiful baby girl (Sham)

To my brother and sisters

To my teachers

To all of them

I dedicate this work

Acknowledgment

I would like to thank Dr. Anan Jayyousi and my supervisor Dr. Sameer Shadeed for giving me a great opportunity to participate in a distinguished research project “Integrating Microwave Link Data for Analysis of Precipitation in Complex Terrain (IMAP)” with Karlsruhe Institute of Technology (KIT) in Germany. They have provided me full support in all researches I have done for this thesis. Special thanks to Dr. Christian Chawla from KIT University for his support in IMAP project and my research.

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

Integrating microwave links data for analysis of solar radiation in Nablus, Palestine

أقر بأن ما اشتملت عليه هذه الرسالة هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أي درجة أولقب علمي أو بحثي لدى أي مؤسسة علمية أو بحثية.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name:	**اسم الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

List of Abbreviations

CML	Commercial Microwave Link
DFG	German Research Foundation
IMAP	Integrating MW- Link Data for Analysis of Small Scale Precipitation variability in complex terrain
IMAS	Integrating microwave link data for analysis of solar radiation in Palestine
ITU	International Telecommunication Union
JAWWAL	First Mobile Network Operator in Palestine
KIT	Karlsruhe Institute of Technology
MPM	Millimeter Wave Propagation Model
MW-Link	Microwave Link
PMD	Palestinian Meteorological Data
RADAR	Radio Detection and Ranging
RF	Rainfall
RH	Relative Humidity
RSL	Received Signal Level
SR	Solar Radiation
T	Temperature
WMO	World Meteorological Organization Standards

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Integrating microwave links data for analysis of solar radiation in Nablus, Palestine

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Abstract

The main goal of this research is to develop an indirect method for solar radiation estimation using integrated data from MW-Link. Additionally, it also aims to estimate the rainfall rate and relative humidity from the attenuation caused for MW-Link received signal level. The solar radiation, rainfall rate and relative humidity estimates from the MW-Link signals are compared with on ground measurements at Nablus meteorological station. The historical data of rainfall rate, relative humidity and solar radiation were obtained from the Palestinian Meteorological Department (PMD). Beside to rainfall and relative humidity estimates, solar radiation was estimated from MW-Link measurements using regression analysis.

The MW-Link used as an environmental sensor which can be used to estimate meteorological data precisely at low cost compared with conventional measurement techniques.

The measurements were taken over one geographical region in Palestine which is located in Nablus City. The attenuation measurements from March of 2015 to March of 2016 were taken from commercial MW-Link of JAWWAL.

The rainfall rate measurements from MW-Link were estimated from the received signal level (RSL) during rainy periods. This attenuation occurred on the received signal level has been converted to rainfall rate data using a mathematical model which is explaining the relationship between rainfall rate and electromagnetic attenuation. The same procedure had been used to estimate relative humidity using special model which is explaining the relationship between relative humidity and electromagnetic attenuation and taking into account the RSL measured during time periods with no rain. Finally, regression analysis was applied to solar radiation, rainfall rate and relative humidity data to obtain solar radiation data.

Rainfall rate and relative humidity estimates taken from the MW-Link were very almost similar to the records obtained from PMD with a correlation coefficient R^2 of 0.95 and 0.70 for rainfall rate and relative humidity respectively. The solar radiation measured from the model developed was very almost similar to the measurements provided by the PMD with a correlation coefficient of $R^2 = 0.89$.

Chapter One

Introduction

1.1 General Background

Palestine suffers from lack of traditional energy sources. Because of this suffering, Palestine is looking for renewable sources of energy. The most efficient renewable energy source in Palestine is the solar energy. Since there are about 3,000hours of sunshine per year in Palestine and the strength of solar radiation is about5.4 $kWh/m^2 - day$ (Mahmoud and Ibrik, 2003), solar radiation measurement of renewable solar systems is an important step in the design and implementation of their systems.

Solar radiation measurements using solar radiance meters are not reliable for real time data measurements, beside that these devices are expensive (Awasthi and Mor, 2012). The measurement of solar radiation intensity using MW-Link is a new application and an unconventional method that can overcome some of the shortcomings of traditional measurement techniques using solar cells.

The traditional methods used to measure the rate of rainfall, relative humidity, intensity of solar radiation are expensive and do not meet the needs for difficult terrains and inadequate in most cases (Jenkins, 2007). In this research an alternative method for measuring rainfall rate, relative humidity and the intensity of solar radiation using available commercial MW-Link is to be investigated. These MW-Links can be used as environmental sensors for rainfall measurements (Messer et al., 2012). The amounts of rainfall rate and relative humidity are measured by monitoring the received signal level (RSL) at various environmental conditions (David et al.,2011). In this research, it is also expected to estimate solar radiation intensity from the RSL.

This research work is part of the German project “Integrating MW-Link Data for Analysis of Small Scale Precipitation Variability in Complex Terrain: Theoretical aspects and Hydrological Applications (IMAP)”.It is funded by the German Research Foundation (DFG) with close with Karlsruhe Institute of Technology (KIT).

For the first time data of MW-Link from JAWWAL become available for scientific purposes by cooperation agreement for this thesis as shown in Appendix A-2.

1.2 Importance of this Research

The standard methods for measuring rainfall and relative humidity such as weather stations and radars are either impractical in some situations, expensive or inaccurate in some other cases. A comparison between the different methods used for rainfall and relative humidity measurements is provided in Table 1-1.

Table 1-1 Comparison between Various Methods for Weather Data Collection

Technology / Parameter	Weather Station	Radar	Microwave Link
Measurement technique	Standard (Point)	Traditional (Volume)	Advanced (Line integral)
Measurement method	Direct	Indirect (reflectivity)	Indirect (attenuation)
Location	At ground	Aloft (high elevation)	Everywhere
Areal Coverage	Low	Intermediate	High

Table 1-1illustrate some of the differences between weather station, radar and MW-Link, there is a large uncertainty in observing and estimating the amount of rainfall and relative humidity which are used to estimate solar radiation.

The weather station measurement technique has errors caused by the effect of wind and evaporation (Abtewet al., 2010). Since the density of weather stations are limited in space and may not be possible to be distributed in difficult terrains, the areal coverage of these gauges is limited.

Rainfall rate and relative humidity measurements using radar depends on detection of reflected radio waves, but these measurements suffer from reaching an optimal relationship between reflectivity and rain intensity (Morin et al., 2003). The MW-Link measurements are based on integrating the microwave signal. Another limitation is that radar is installed just on high elevation but MW-Links can be found everywhere (Boudjemaa, 2014).

There are several limitations in the weather stations and radars such as the areal distribution and the large installation cost, following-up, operation and maintenance. The MW-Links are more available with high areal coverage (Messer, 2017).

Until the past few years these MW-Links were only used for communication purposes. According to the international telecommunication union the properties of the electromagnetic waves at microwave frequencies are highly affected by the environmental conditions such as rainfall and humidity (ITU, 2013). As such, it is conventional to utilize MW-Links to obtain a reasonable rainfall rate, relative humidity measurements data with no cost for installation and maintenance (Messer, 2017).

1.3 Objectives

The main objective of this research is to develop and apply a new method/model for solar radiation estimation by utilizing available MW-Links data, from JAWWAL in Palestine. In light of the above, the following objectives will be achieved:

a) Estimating the rate of rainfall and relative humidity in Nablus using commercial MW-Links data. This new estimation technique depends on MW-Link integrated data, which is an efficient method to produce realistic rainfall data and relative humidity data compared with weather station data.

b) Developing a model to estimate solar radiation from historical rainfall and relative humidity data, which can be used indirectly to estimate solar radiation from MW-Link data.

1.4 Research Questions

This research attempts to answer the following two questions:

1. Can the existing cellular companies in Palestine contribute to weather forecast?
2. Is there any relation between the MW-Link data (attenuation of received signal level) and meteorological data?

1.5 Methodology

The methodology of this study is presented in Figure 1-1. The objectives and research questions were determined at the beginning of the research in order to get the objectives of this study. Characterization of the study area contained geography, topography and climate data which are rainfall, ambient temperature, relative humidity and solar radiation. The next step was data collection from two sources which are PMD for climate data and JAWWAL for MW-Links data of the study area.

The analysis and processing data were divided into two steps. The meteorological data were analyzed and processed using regression analysis tool in Excel program. MW-Links data were analyzed and processed using a code called Pycomlink which was built based on Python programming (Chwala et al., 2012). Python code contains the mathematical equations of the relationship between rainfall rate and electromagnetic signal attenuation (Chwala et al., 2012). Another code based on millimeter-wave propagation mathematical model programmed for relative humidity data was processed by a python programming.

Solar radiation data estimated indirectly from MW-Links data. Finally, conclusions and recommendations were illustrated. The methodology of this study is presented in Figure 1-1.

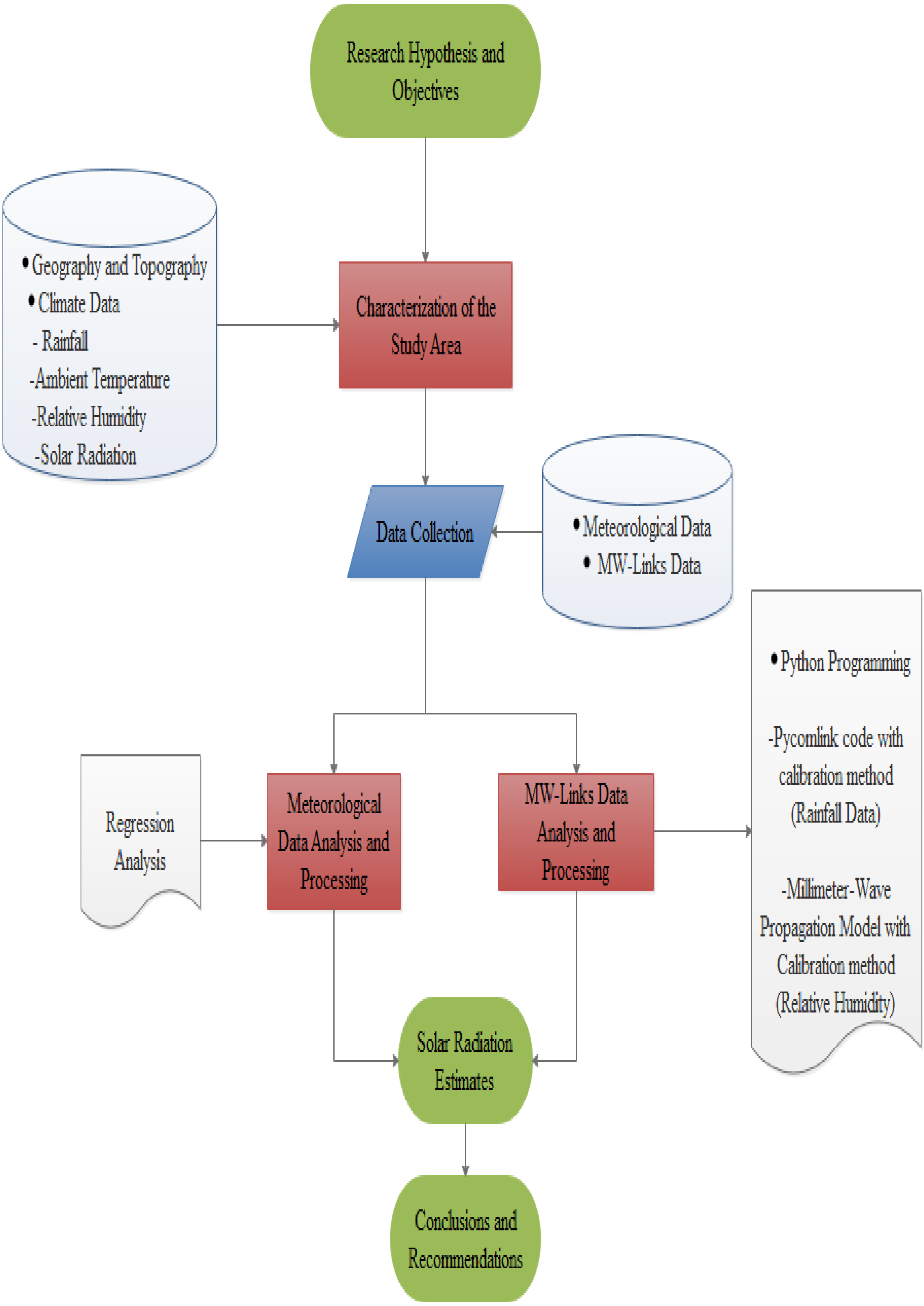

Figure 1-1 A Flow Chart of the Overall Methodology

1.6 Thesis Structure

This thesis consists of five chapters summarized in this section. Chapter one is the introduction which introduces the main idea of the research, the objectives and the importance of solar radiation estimation using MW-Links. Moreover, it presents the methodology as a flowchart. Chapter two is the literature review which introduces the role of meteorological stations and traditional tools in measuring climate elements. Furthermore, it talks about the previous works of rainfall, relative humidity and solar radiation estimation using commercial MW-links in details. Finally, it presents solar radiation measurements using linear regression from previous works. Chapter three is the study area which provides details about the Wadi Faria catchment from the perspective of geography and topography, and presents the climate data of The Wadi Faria and Nablus city as a case study. Chapter four is the model development, result and discussion which summarize all the results of collected data from Nablus weather station and MW-Links. It also explains the calibration process used for correcting measurements taken from MW-Links measurements. It also discusses the final results of rainfall, relative humidity and solar radiation. Chapter five is the conclusions and recommendations which concludes the realized work and the derived results. In addition, it introduces recommendations as outlooks for future researches.

Chapter Two

Literature Review

In this chapter the measurement techniques for rainfall, relative humidity will be reviewed. The several measurement techniques that are used in the literature will be discussed. The most widely used measurement techniques of rainfall data is the ground stations which use rain gauges. Rainfall measurement by radar stations and commercial microwave links will be discussed as well.

CML models with different approaches used to treat the problem of separation between wet and dry events in order to estimate rainfall rates accurately.

The role of meteorological stations and traditional tools in measuring climate elements is presented in section 2.1. Weather radar measurement's in estimating spatial distribution of rainfall is presented in section 2.2. Section 2.3 presents the rainfall measurement by commercial microwave links. Humidity measurements using commercial microwave links are discussed in section 2.4. Finally, section 2.5 presents solar radiation measurements by multiple linear regressions.

2.1 Meteorological Stations

Meteorological stations are used to observe climate elements including rainfall, relative humidity and solar radiation intensity. The position, type and frequency for these measurements should meet the World Meteorological Organization standards (Jarraud, 2006).

2.1.1 Measurement of Rainfall

Precipitation is defined as the product of the condensation of atmospheric water vapor which falls on ground. Rainfall is the liquid of precipitation which is the water drop. It has a diameter of more than 0.5 mm (Glickman, 2009). Rain drops with diameter smaller than $0.5\, mm$ is called drizzle (Glickman, 2009). Where the wavelength of MW-Link is 3 cm which means the raindrop is comparable to the wavelength.

2.1.1.1 Meteorological Station Measurements

The traditional way of rainfall estimation uses rain ground gauges. Rain gauges are instrumentsdedicatedfor measuring the amount of rainfall during rain periods. These instruments were used since 400 BC in India. The use of rainfall gauges for rainfall measurements was the first attempt to record the rainfall by a simple bowl (Strangeways, 2010).The first regular recording for an extended period of fifteen years was in 1677 in the north of England by Richard Towneley (Strangeways, 2010). Towneley used a small gauge installed on the roof of his home and connected it with a lead pipe in order to estimate the amount of rainfall (Strangeways, 2010).

Rain gauges have been evolved over the years. The rain gauges are classifieds into non-recording and recording type’s instruments (Navodayaengg, 2015).

a- Non-Recording Rain Gauges

Non-recording rain gauge is used to show up rainfall amount which is simply used for collecting rainfall without recording the process (Navodayaengg, 2015). There are many types of non-recording gauges such as cylindrical rain gauge which is a simple vessel and ordinary rain gauge which contains a storage bottle inside a shell with receptacle as shown in Figure 2-1(Jarraud, 2006).

The criterion which is used during the process of selecting the appropriate site of the non-recording rain gauges must involve aspecial procedure. The site should be opened and the distance between the nearest object and the instrument should be at least twice the altitude of the object (Punmia and Lal, 2009). It should also be installed on the ground level. In case it is installed on hills, the gauge should be shielded from wind and be in a safe place by using a barrier which is away about twice of the gauge height (Punmia and Lal, 2009).

b- Recording Rain Gauges

This type of rain gauges gives a recorded rainfall data. The main advantage of the recording type rain gauge is the capacity of the gauges which are large. However, the main disadvantage of this type is its high initial cost and is not reliable when a mechanical or an electrical fault occurs (Navodayaengg, 2015). There are many types of recording gauges such as weighing bucket rain gauge which is adopted by the Indian Metrological Department. The chart obtained from this type is a mass curve of rainfall data. The tipping bucket rain gauge which is useful for remote areas is adopted by the US Metrological Department (Navodayaengg, 2015). Figure 2-1 shows the weighing bucket and the tipping bucket rain gauges with the differences in the measuring process and Table 2-1 summarizes the comparison between non-recording and recording types (Punmia and Lal, 2009).

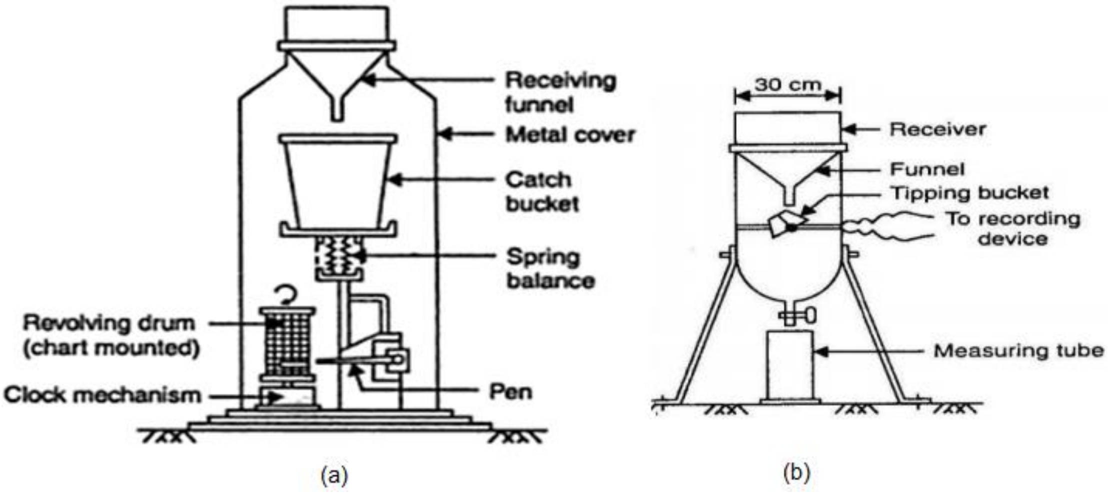

Figure 2- 1 Weighing Bucket and Tipping Bucket (Navodayaengg, 2015)

Table 2-1 Comparison between Non-Recording and Recording Types of Rain Gauges

Technology / Parameter	Non-recording	Recording
Recoding process	Manually	Automatically
Data Recorded Type	Total Rainfall	Rainfall Intensity
Human Error	Exist	Little
Cost	Cheap	Expensive

2.1.2 Measu1rement of Other Climate Elements

There are many types of weather ground stations divided into two basic categories which are manual and wireless automatic stations (Jenkins, 2007).

All these weather stations are used to measure climate elements including rainfall, relative humidity, temperature, solar radiation, etc. Figure 2-3 illustrates the typical wireless automatic weather station equipment which sends all information needs into control room. It also used to measure most of climate elements (Jenkins, 2015).

Figure 2-2 Typical Wireless Automatic Weather Station Equipment (Jenkins, 2015)

Weather stations use the wet and bulb thermometer which is called hygrometer device to measure the difference between wet and dry bulb in order to show up relative humidity values. Most of weather stations use ordinary mercury-in-glass thermometer to measure temperature in Fahrenheit or Celsius unit with a clear scale (Jenkins, 2007).

The direct, diffused and reflected solar radiation is measured by a solar panel sensor as shown in Figure 2-2. These sensorsare used to calculate the daily solar radiation in W/m^2 unit (Jenkins, 2007).

2.2 Radar Measurements

Radar was developed over years until 1946 when the USA has succeeded in receiving echoes from the moon by radar (Wiesbeck, 2009). Radar is divided into several types according to their application. Some of these applications are weather forecast, air craft control, navigation, military applications, etc.

One of the applications of interest for this project is for estimating the spatial distribution of rainfall. The intensity of the reflected signal depends on the raindrop size and distance between raindrops and transmitter (Morin et al., 2003). Radar was used to find an empirical formula that relates reflected signal Z and rainfall rate R to obtain an accurate estimate of rainfall. Many researchers have reached to put a relation between Z and R which is a power law as illustrated by the following equation (Morin et al., 2003):

$$\mathrm{Z} = \mathrm{aR^b} \qquad 2.1$$

Where Z is a reflected signal measured in $\mathrm{mm^6/m^3}$,R is a rainfall measured in $\mathrm{mm/h}$, and a and b are empirical coefficients.

2.3 Commercial Microwave Links Measurements

The term microwave refers to alternate current signals with frequencies between 300 MHz and 300 GHz with a wavelength between (λ) 1 m and 1 mm, respectively, because of that microwave signals are called millimeters waves (Khan, 2009).

A fraction of the incident radiation from MW-Link is absorbed, a portion is scattered and a remaining attenuated. All three fractions depend on the relationship between the incident radiation and the particle parameters. Moreover, Measurement of the scattered power signal or attenuation signal that is caused along path between MW-Links yields information about the scatterer (Chwala, 2015).

Rainfall measurements can be made by observing the attenuation caused to the received signal level during rain hours. The electromagnetic signal attenuation caused by precipitation is a physical phenomenon that can be described using Mie scattering solution equations (Olsen et al, 1978). The rain drop diameter is about 5mm and the wavelength of MW-Link signal is about $\lambda = 3$ cm; means that the size of rain drop is comparable to the wavelength.

The relationship between rainfall rate and electromagnetic signal attenuation can be predicted by the empirical formula as given by (Olsen et al, 1978):

$$A = \alpha R^{\beta} L \qquad 2.2$$

where Ais the received signal level measured in dB, R is the average rainfall rate along the MW-Link measured in$\mathrm{mm/hour}$. L is the path length expressed in km andα and β are constants depending on the MW-Link frequency and drop size distribution(Örs et all.,1999; Chawla et al., 2014; Liberman and Messer,2014).

$$A = 4.343 \times 10^{3} \int_{0}^{\infty} C_{ext}(D) N(D, R) dD \qquad 2.3$$

where $C_{ext}(D)$ is the scattering cross-sectional area in $m^2$of the rain drop, D is the diameter of the rain drop in mm, $N(D, R)$is the drop number concentration per cubic meter and per millimeter of diameter interval which indicate to drop size distribution of rainfall (Chawla et al., 2014).

The received signal level is recorded by the MW-Link every minute, 15 minutes, or one hour depending on the infrastructure of the MW-Links, data logger and modems at commercial cellular grid (Chawla et al., 2014). The estimation of the amount of rainfall when the antenna is dry differs from the estimation of the rainfall when the antenna is wet. This dilemma is known as we wet/dry problem (Chawla et al., 2014). Proper estimation of the amount of rainfall requires prior knowledge of rainy and dry periods.

2.3.1 Swiss Model of CML Measurements

The Swiss model uses the rolling standard deviation method (Schleiss and Berne, 2010). Rainy periods are determined by analyzing the received microwave signal then estimating an attenuation baseline by classifying periods into rainy and dry periods. The first limitation of this method is the difficulty in determining changes during rainy periods (Schleiss and Berne, 2010). The second limitation is the difficulty to determine light rain from noise at 1 dBm power resolution, where the dBm is describes an absolute power and dB relates to power ratios (Rohde and Schwarz, 2015).

In the Swiss model the length, frequency and polarization for each MW-Link are collected. The attenuation is calculated by subtracting the received signal power from the transmitted signal power. The MW-Link provides data as path integrated values while weather radars provide data as averaged values (Schleiss and Berne, 2010).

Also in the Swiss model the total attenuation represents the sum of baseline attenuation and rainfall attenuation. In this model there are two types of variances. The first variance is caused by baseline and the second variance is caused by rainfall. For the dry periods the two variances equal zero. If the variance of the MW-Link is greater than the baseline variance, a rainy period is observed, otherwise a dry period is observed. The MW-Link threshold is determined by comparing rainfall measurements obtained from MW-Link against rainfall measurements obtained from weather radar (Schleiss and Berne, 2010).

2.3.2 German Model of CML Measurements

The German model uses the rolling Fourier-transform method (Chwala et al., 2012). In this method the attenuation data are collected from more than one MW-Link. The attenuation data are analyzed to develop equations that describe the fluctuations between wet and dry periods. This method is based on observing the variations of the square magnitude spectrum and observes fluctuations on the spectrum to decide the dry and wet periods. The threshold can be estimated for each link through prior knowledge of the amount of rainfall obtained from rain gauges. The main limitation in this method is how to determine the changes during rainy periods and detect the types of rain events long or short (Chwala et al., 2012).

2.4 Humidity Measurements by CML's Data

It was noted by previous research work (David et al., 2011), that gases attenuate electromagnetic waves operates in the GHz range. Oxygen for example has a resonance and a significant attention for microwave signals operating near the 60 GHz range (Valdez, 2001). Water vapor molecules will be the dominant attenuating gas for microwave signals operating in the 22-24 GHz range (Vleck, 1947; Gunn, 1954; Bean, 1968).

Although other gases may attenuate the microwave signal at the 20 GHz range (ITU, 2005), their effect is negligible compared with the water vapor at this frequency. Attenuation due to dry air and water vapor can be computed by the following equation (Libie 1989; ITU, 2005; David et al., 2011):

$$\gamma = \mathrm{A_w} + \mathrm{A_0} = 0.1820\,\mathrm{f}\,\mathrm{N}''\ \mathrm{dB/km} \qquad 2.4$$

where $A_w$is the attenuation due to water vapor, A_0 is the attenuation caused by dry air, f is the operating frequency and N'' is the imaginary part of the complex refractive index (ITU, 2005).

The imaginary part of the complex refractive index is a function of the atmospheric pressure, temperature and water vapor density which is expressed mathematically by the following equation (ITU, 2005):

$$\mathrm{N}'' = \sum_i \mathrm{S_i F_i} + \mathrm{N''_D} \qquad 2.5$$

Where $S_i(\mathrm{p}, T)$is the strength of the i^{th} line measured in kHz,$F_i(p, T, \rho, f)$ is the line shape factor measured by $1/GHz$, $N_D''(\mathrm{p}, T, f)$ is the dry continuum due to pressure-induced nitrogen absorption and the Debye spectrum p is the atmospheric pressure, T is the temperature in Celsius andf is the frequency in Hz.

N''_D can be determined from the following empirical formula (ITU, 2005):

$$N''_D = fp\theta^2 \left[\frac{6.14\times10^{-5}}{d\left[1+\left(\frac{f}{d}\right)^2\right]} + \frac{1.4\times10^{-12}p\theta^{1.5}}{1+1.9\times10^{-5}f^{1.5}} \right] \quad 2.6$$

where d is the width parameter for the Debye spectrum which is given by the following empirical formula (ITU, 2005):

$$d = 5.6 \times 10^{-4} p\theta^{0.8} \quad 2.7$$

It was shown that by the International Telecommunication Union (ITU, 2005), under an atmospheric pressure of 1013 hPa; where hPa is a metric measurements of pressure; 15°C temperature and absolute humidity of 7.5 $gram/m^3$, water vapor molecules are attenuated by 0.2 dB/km at 22 GHz (ITU, 2005).

The relationship between relative humidity and electromagnetic signal attenuation was predicted by a function called $\mathrm{MPM}(f, P, T, U)$ which is written in Python (Libie, 1989). The MPM (Millimeter Wave Propagation Model) is a function that is used to calculate the attenuation as a function of frequency, atmospheric pressure, ambient temperature and the relative humidity (Libie, 1989).

The arguments of the MPM function use the following equations when predicting the attenuation due to humidity (Libie, 1989):

$$P = pd + e \quad 2.8$$

$$T = TK - 273.15 \quad 2.9$$

$$\theta = 300/TK \quad 2.10$$

$$U = \frac{e}{e_s} \times 100\% \quad 2.11$$

where pd is the partial pressure of dry air in kPa, e is the partial water vapor pressure in kPa, Tis the temperature in Celsius degrees, TK is the temperature in Kelvin degrees, θ is the reciprocal temperature, e_s is the water vapour saturation pressure e is the partial pressure of water vapor and $U$is the relative humidity (%) (Libie, 1989).

2.5 Solar Radiation

2.5.1 Definitions

The solar radiation at the surface of the earth is composed of four spectral radiant fluxes which are short wave radiation, long wave radiation, reflected wave radiation and emitted radiation from the surfaces.

The short wave radiation is a radiant energy that arrives from sun with a wavelength of 0.15 µm and 4 µm, however, some energy reflected from the surface which called reflected radiation. The long wave radiation is a radiant energy that arrives from the atmosphere with wave length less than 4 µm, however, some energy emitted from the surface which called emitted radiation (Ogolo et al., 2009).

2.5.2 Measurements by Regression Analysis

There are many researches dealing with solar radiation estimation from meteorological parameters such as sunshine hours, relative humidity, ambient temperature, and rainfall data. The best method used to estimate solar radiation uses multiple linear regressions which are described mathematically by:

$$Y = a + b\,X_1 + c\,X_2 + d\,X_3 \qquad 2.12$$

where a, b, c and d are coefficients for intercept, relative humidity, ambient temperature and rainfall, respectively (Umoh et al., 2013).. The regression coefficient can be obtained by comparing estimated to measured values. The previous equation calculates the correlation for the three coefficients then put all results in a table to get the solar radiation readings (Umoh et al., 2013).

Another research aims to predict solar radiation using ambient temperature and relative humidity data based on two methods, one is the decision matrix which contains relative humidity and ambient temperature and the second method uses relative humidity, clearness index for atmospheric transmission and relative humidity correlations (Al Riza et al., 2011). The result for the decision matrix method was better with correlation coefficients of about 0.95 (Al Riza et al., 2011).

Chapter Three

Study Area

This chapter is divided into two sections. Section 3.1 talks about the Wadi Faria catchment from the perspective of geography and topography. Section 3.2 presents the climate data of the Wadi Faria catchment. Nablus city is the case study in this research because the only site in the Wadi Faria catchment that contains a weather station that provides all climate data that is needed in this research as illustratedin Table 3-1.

3.1 Geography and Topography

Geographically, the Wadi Faria catchment is located on the northern part of the West Bank with 320 km^2 of total area.Nablus located about 63 km to the north of Jerusalem. The Wadi Faria catchment stretches from Nablus mountains down the eastern slopes to the Jordan River, where Nablus city is located between Mount Ebal and Mount Gerizim (Shadeed, 2008). Figure 3-1 shows the location of the Faria Catchment in Palestine (Shadeed, 2008).

The topography of the Faria catchment begins at an elevation of about 900 meters above mean the sea level in Nablus mountains and descends dramatically to about 350 meters below mean sea level at the proximity of the Jordan River (Shadeed, 2005).

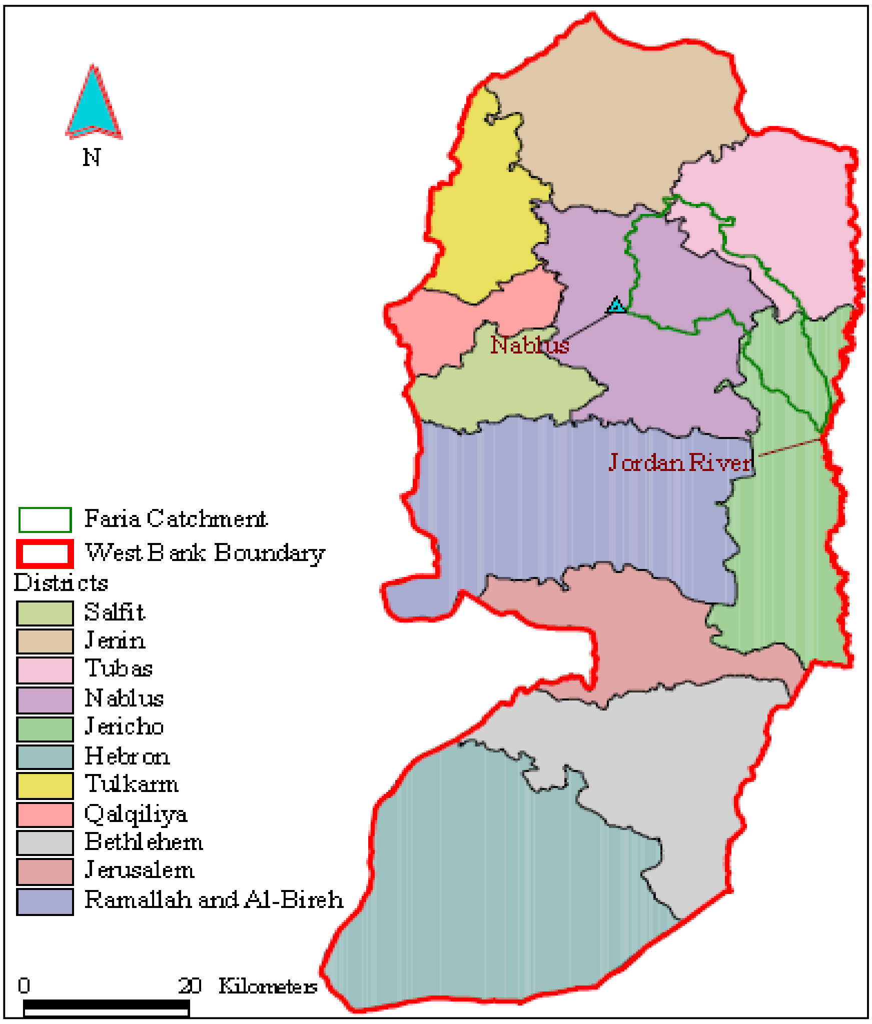

Figure 3-1 Location of the Faria Catchment (Shadeed, 2008)

3.2 Climate Data

The climate of Palestine in general is a Mediterranean climate. There are four seasons in the year with a mild weather (Shadeed, 2008). This section describes the climate elements of the Wadi Faria catchment as shown in the following subsections.

3.2.1 Rainfall

The rainfall in the Wadi Faria catchment falls in autumn and winter (Shadeed, 2005). It extends from October to April. The annual rainfall in the catchment varies from 640 mm at the headwater to 150 mm at the outlet, where the annual rainfall in Nablus varies between 315 mm and 1387 mm (Shadeed, 2005). The accumulative amounts of rainfall for 2015-2016 rainy season in Nablus is about 542 mm, while the average is about 660 mm (PMD, 2016).

3.2.2 Ambient Temperature

The average annual temperature of Wadi Faria catchment varies between 18 C° at the western side in Nablus and 24 Celsius at the eastern side in AL-Jiftlik (Shadeed et al.,2007).

According to the weather station in Nablus, July and August are the hottest months with a mean of 29 C°, however, the lowest temperature in January is 4C° (PMD, 2016).

3.2.3 Relative Humidity

The annual average of relative humidity in Nablus is about 61% (Shadeed et al., 2007). According to PMD in 2016, the relative humidity in winter varies between 57% and 67 %, while in summer it varies between 55% and 64%.

3.2.4 Solar Radiation

The annual sunshine hours in Palestine including the Wadi Faria catchment are about 3000 hours per year (Mahmoud and Ibrik, 2003). The intensity of solar radiation on horizontal surface is about $5.4\ \mathrm{kWh/m^2} -$

day (Mahmoud and Ibrik, 2003). According to PMD from March 2015 to March 2016, the highest solar radiation intensity was about $9\mathrm{kWh/m^2} -$ day in July 2015 while the lowest solar radiation intensity was about 2 $\mathrm{kWh/m^2} -$ day in January 2016.

Table 3-1 General Information of Meteorological Stations in the Wadi Faria Catchment (PMD)

Station	Type	Available Data	Period	Rainfall (mm) Minimum	Rainfall (mm) Average	Rainfall (mm) Maximum
Tubas	Rainfall Gauge	Daily	1972-2016	0	1.1	98
		Hourly	2004-2010	0	0.1	20
Talluza	Rainfall Gauge	Daily	1968-2016	0	1.7	149
		Hourly	2006-2014	0	0.1	27
Beit Dajan	Rainfall Gauge	Daily	1969-2005	0	0.9	133
Tammun	Rainfall Gauge	Daily	1969-2016	0	1.1	84
		Hourly	2005-2016	0	0.1	24

Station	Type	Available Data	Period	Rainfall (mm)			Relative Humidity (%)			Temperature (C°)			Solar Radiation (kWh/m²)		
				Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Nablus	Weather Station	Daily	1975-2016	0	1.8	123									
		Monthly	1972-1997	0	54	154	51	61	67	10	18	24	2.6	5.4	8.4

Chapter Four

Model Development, Results and Discussion

In this chapter, regression analysis for modeling solar radiation will be introduced. Regression was applied to real data measurements in order to predict a suitable model that estimates solar radiation. Also, rainfall and humidity measurements obtained from Mw-Links are presented in this chapter.

4.1 Model Development

4.1.1 Regression Analysis

Solar radiation estimation by regression method was introduced in section 2.6. In this section, we use regression analysis tool developed in MS EXCEL to predict monthly solar radiation from rainfall, relative humidity and temperature measurements. PMD available historical data from 1998 to 2010 has been used to end up with regression method given data of rainfall, relative humidity and solar radiation. For comparison reasons, solar radiation measurements for the same period have been taken from Nablus meteorological station. The regression equation that can be used to predict solar radiation is given by the following equation:

$$\mathrm{SR} = \mathrm{a} + \mathrm{b} \times \mathrm{RF} + \mathrm{c} \times \mathrm{RH} + \mathrm{d} \times \mathrm{T} \qquad 4.1$$

where SR, is the solar radiation, a,b, cand d are the regression coefficients for intercept, rainfall (RF), relative humidity (RH) and temperature (T).

The solar radiation measuring data results for three metrological stations at Tulkarm, Nablus and Jenin are shown in Figure 4-1 (Mahmoud and Ibrik, 2003).The maximum solar radiation readings at June and July while the minimum readings at January and December in unit of $wh/\mathrm{m}^2 - \mathrm{day}$.

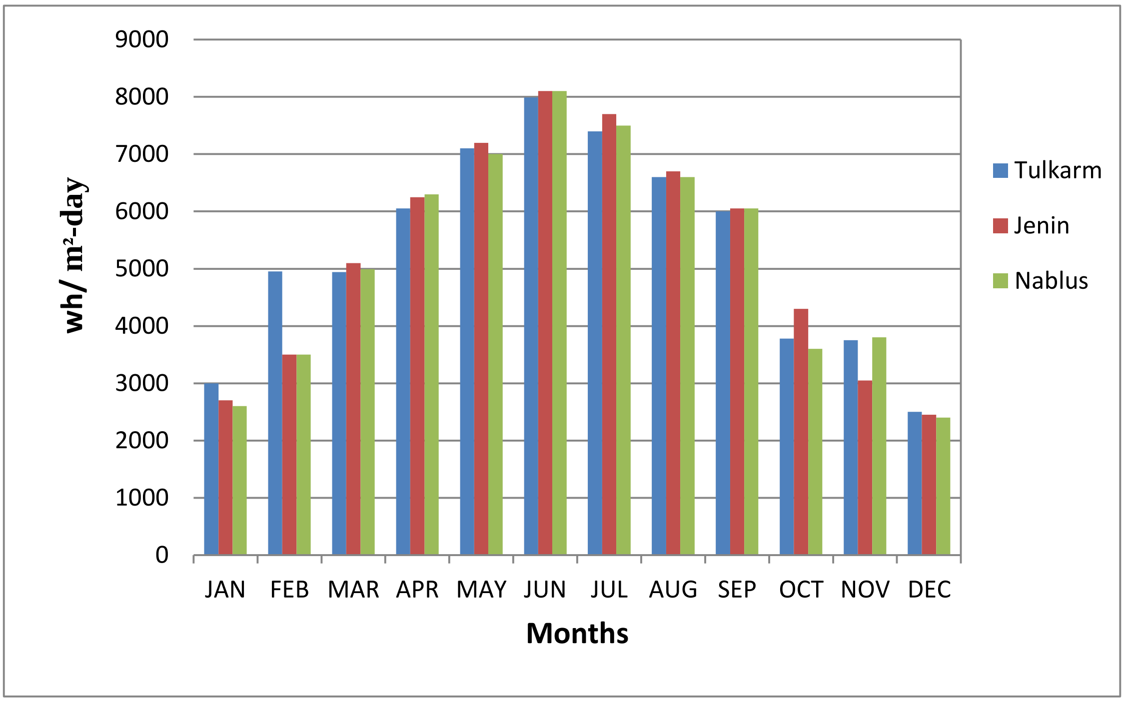

Figure 4-1 Monthly Solar Radiation in Nablus, Tulkarm and Jenin

4.1.2 Verification of data

It can be noticed from Figure 4-1that there is symmetry in solar radiation among the different months of the year. For example, January and December would have the almost same solar radiation intensity. Similar observation is applicable to February and November, March and October, etc.

The verification process was on available PMD historical data from 1998 to 2010 for rainfall, relative humidity, solar radiation and ambient temperature.

By applying the regression method to equation4.1, the numerical values of the regression coefficients were obtained as illustrated by the following equation:

$$Y = -0.606 - 0.00041\,X_1 + 0.02328\,X_2 + 0.20469\ X_3 \qquad 4.1$$

where Y is the predicted solar radiation in $\mathrm{kwh/m^2 - day}$, X_1 is the rainfall in mm, X_2 is the relative humidity in percent and X_3 is the ambient temperature in Celsius.

It has been noticed that the correlation coefficient between estimated solar radiation and actual measurements was 0.95. If the values X_1, X_2 and X_3 have been compensated from the data of March 2005 as an example 37.3 mm, 57.4% and 13.9 C, respectively, solar radiation will be 3.6 $\mathrm{kwh/m^2 -}$ day which is almost similar to the solar radiation in March 2005 which was 3.7 $\mathrm{kwh/m^2 - day}$. The verification technique with actually measured data is shown in Table 1in Appendix A-1.

4.1.3 MW-Links Data Developing and Processing

4.1.3.1 Rainfall

Python code for estimating rainfall data from MW-Links data has been developed by German researchers from Karlsruhe Institute of Technology (KIT). The code converts attenuation of microwave signals into rainfall data (Chwala et al., 2012). A MW-Link in Nablus had been selected to measure the relative humidity indirectly from attenuation caused to MW-Link signal used in this link.

Figure 4-2 shows the available MW-links in the Faria catchment. The attenuation to microwave link data collected from JAWWAL of Nablus–Almasken MW-Link in 2015 and 2016 in rainy seasons were not available due to technical reasons, therefore, Beitforeek–Almasken MW-Link has been selected as a case study during this period to estimate rainfall data.

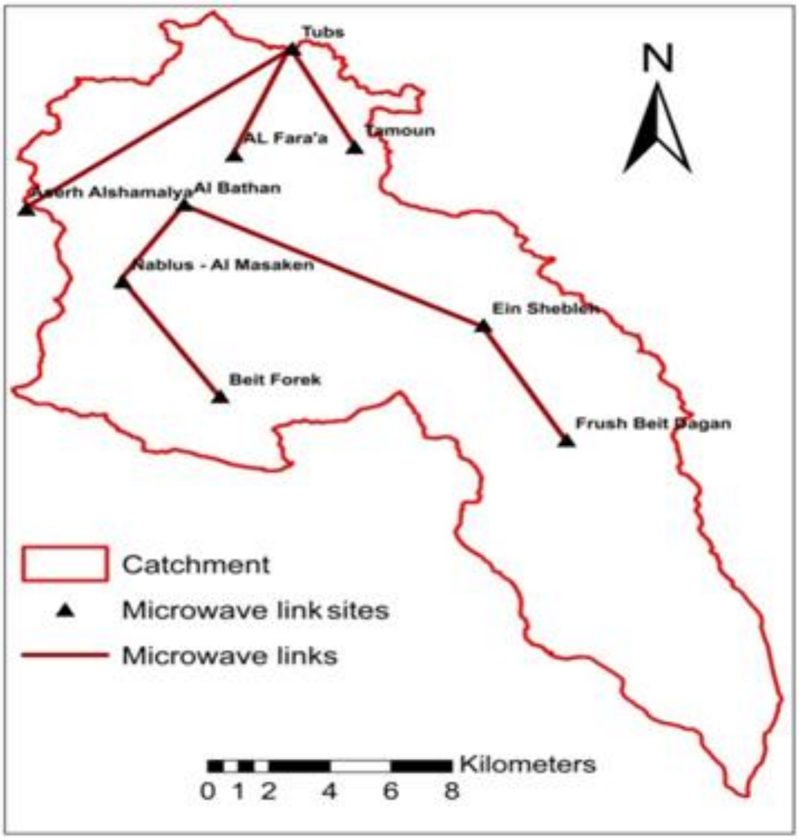

Figure 4-2 MW-Links in the Faria Catchment

Rainfall data for Beitforeek–Almasken area have been modeled and developed using regression analysis performed on observed monthly mean rainfall data collected from six distributed rain gauges within the Faria catchment (Shadeed, 2008).

The rainfall model is given by

$$R = 8285 - 39.41\,X - 2.46\,Y - 0.34\,Z \tag{4.2}$$

where R is the annual average rainfall in mm, X is the x-local coordinate in km, Y is the y-local coordinate in km and Z is the elevation in m. The correlation coefficient for the above prediction formula was equal to 0.99.

In order to use the rainfall equation model on Beitforeek-Al Masaken, four geographical points have been chosen by the Geographic Information System (GIS) to validate this model. These geographical points are in Table 4-1.

Table 4-1 Local Coordinates for the Four Points on Beitforeek-Al Masaken MW-Link

Site	X (km)	Y (km)	Z(m)
Beitforeek	181.92	177.54	480
First point	180.79	179.1	460
Second point	179.55	180.89	475
Al Masaken	178.67	182.15	520

If we substitute the X, Y, and Z coordinates into rainfall model equation, we may obtain the following rainfall rates corresponding to each geographical point.

1. $R = 8285 - 39.41X - 2.46Y - 0.34Z$

   $R = 8285 - 39.41\,(181.92) - 2.46\,(177.54) - 0.34(480)$

$= 516 \text{ mm/year}$

2. $R = 8285 - 39.41X - 2.46Y - 0.34Z$

$R = 8285 - 39.41\,(180.79) - 2.46\,(179.1) - 0.34(460)$

$= 563 \text{ mm/year}$

3. $R = 8285 - 39.41X - 2.46Y - 0.34Z$

$R = 8285 - 39.41\,(179.55) - 2.46\,(180.89) - 0.34(475)$

$= 602 \text{ mm/year}$

4. $R = 8285 - 39.41X - 2.46Y - 0.34Z$

$R = 82\,85 - 39.41\,(178.67) - 2.46\,(182.15) - 0.34(520)$

$= 619 \text{ mm/year}$

The predicted values for the rainfall have been estimated by rainfall model equation deviates slightly from the real measured values. To compensate for this deviation a correction factor has been used. The correction factor is given by:

$$C = \frac{Annualaveragerainfallinmmfor Beitforeek-AlMasakenMW-Link}{AnnualaveragerainfallinmmforNablus} \times RainfalldataofNablus \quad 4.3$$

where C is the correction factor, the average of rainfall for the four points between Beitforeek-Al Masaken equals575mm/year and the long term annual average rainfall in mm for Nablus is equal to 642 mm/year, the correction factor is computed as follows (Shadeed, 2008):

$$C = \frac{575}{642} = 0.90 \times RainfalldataofNablus \qquad 4.4$$

The rainfall rate is also estimated from the attenuation caused to the microwave signal linking Beitforeek-Al Masaken. The amount of rainfall was been predicted by $A = \alpha R^{\beta} L$(Olsen et al., 1978). We use the Python code to plot the attenuation caused to the microwave signal due to rainfall, then estimate the rainfall rate based on the rainfall estimation formula $A = \alpha R^{\beta} L$. The attenuation caused to the microwave signal over December 2015 is shown in Figure 4-3. The rainfall estimation from the MW-Link attenuation measurements will be discussed in section 4.2.1.

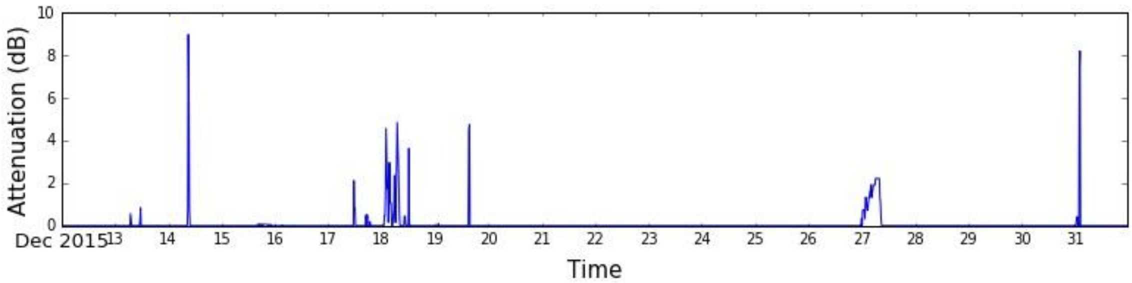

Figure 4-3 Attenuation Signal in December 2015

4.1.3.2 Relative Humidity

In this section, relative humidity measurements from attenuation caused to the MW-Link signal are discussed. Relative Humidity measurements have been predicted using the millimeter wave propagation model (MPM) function written in Python (Libie, 1989).

Three basic parameters are affecting MW-Link signal attenuation and relative humidity measurements. These parameters are frequency of the MW-Link, monthly average ambient temperature and atmospheric pressure(Libie, 1989). The MPM function uses these parameters and signal attenuation to predict the relative and absolute humidity.

It was noticed that attenuation to the microwave signal increases linearly with the absolute humidity as shown in Figure 4-4.

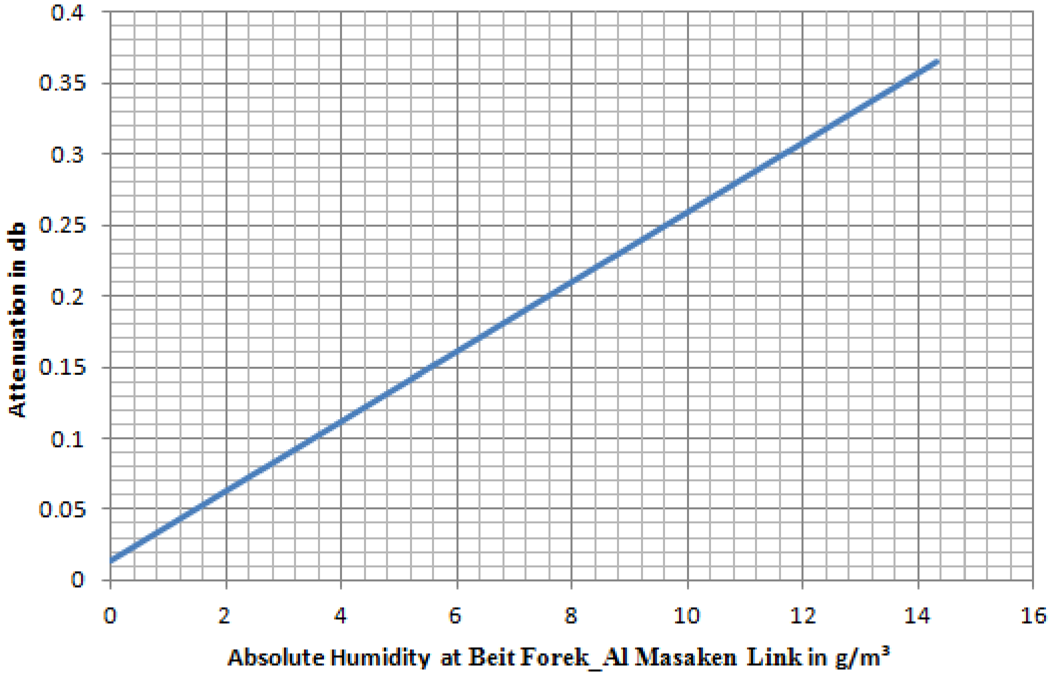

Figure 4-4 Linear Fitting Curve between Attenuation and Absolute Humidity

Humidity measurement from attenuation caused to microwave signal obtained from Beitforeek-Al Masaken MW-Link will be discussed in details.Microwave signal power between transmitter (Tx) and receiver (RX)is expressed in a relation called Tx-Rx, from Figure 4-5 it is noticed that the power signal attenuation as a function of relative humidity fluctuatesfrom 55 dB at little humidity effect on Tx-Rx signal to 80 dB at high effect from humidity on Tx-Rx signal from October 2015 to February 2016.

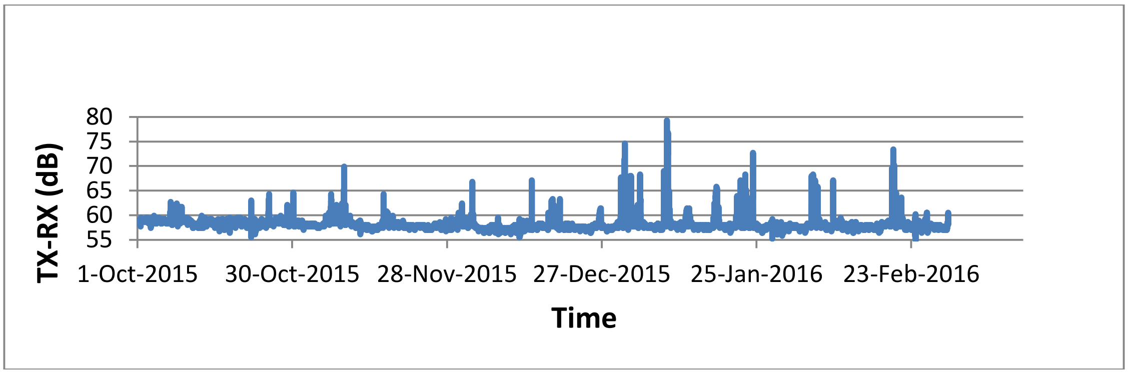

Figure 4.5 Tx-Rx Signal from October 2015 to February 2016

4.2 Results and Discussion

4.2.1 Rainfall

When performing MW-Link signal attenuation measurements, the measurements were subjected to errors due to the MW-Link status, wet or dry (Chawla et al., 2014). To reduce error measurements due to wet/dry status of the antenna, Swiss and German models have been developed by researchers. The Swiss model of MW-Link measurement has been used to separate dry and wet periods then make tuning for threshold which has been used to classify a period as wet or dry (Schleiss and Berne, 2010). After the determination of wet and dry periods by analysis the attenuation data, a dry window of rainy storm can be used for calibration purposes by using rolling standard deviation method with a length numbered from 0 to 200. As final results the threshold ranges from 0.2 to 0.7 as a constant value, while the dry window value was 169 as a constant value. The Python code of rainfall data measurements for all months starting from March 2015 to March 2016 are illustrated in Appendix B.

The real rainfall data in Nablus have been multiplied by the correction coefficient (C) in order to get the estimated rainfall data on Beitforeek-Al Masaken. Figure 4-6 shows the difference between transmitted and received signal power in dB and the rainfall in mm after determining the threshold for December 2015by tuning according to the data from PMD threshold.

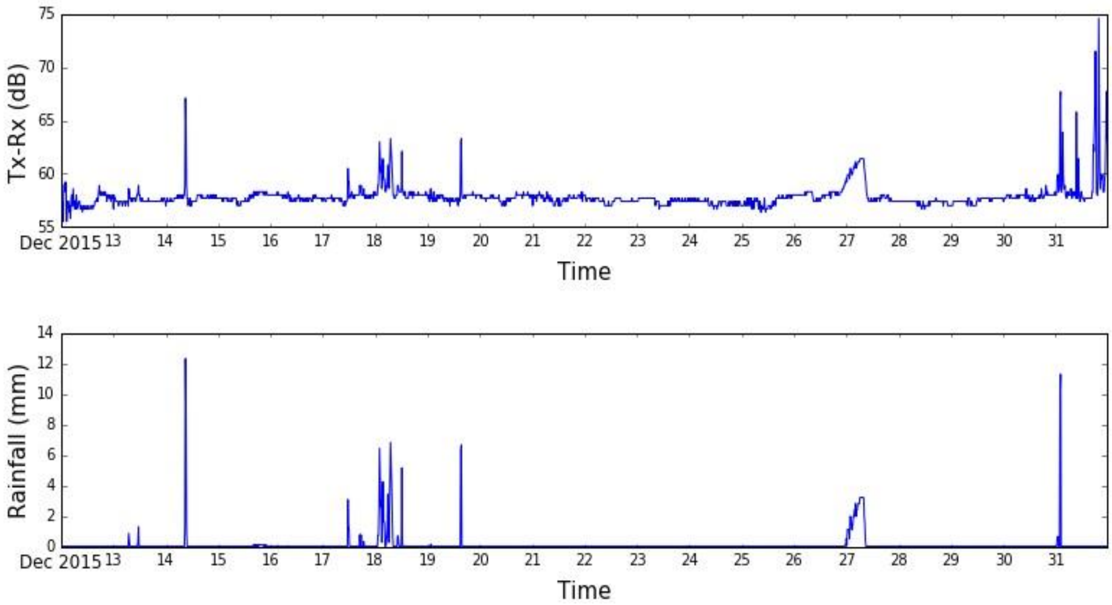

Figure 4-6 Tx-Rx and Rainfall Signals in December 2015

Figure 4-7 shows the cumulative rainfall data from December 2015 which was 55 mm while the real data from PMD was 84 mm and estimated rainfall after multiplying by correction coefficient (C) was 75mm.

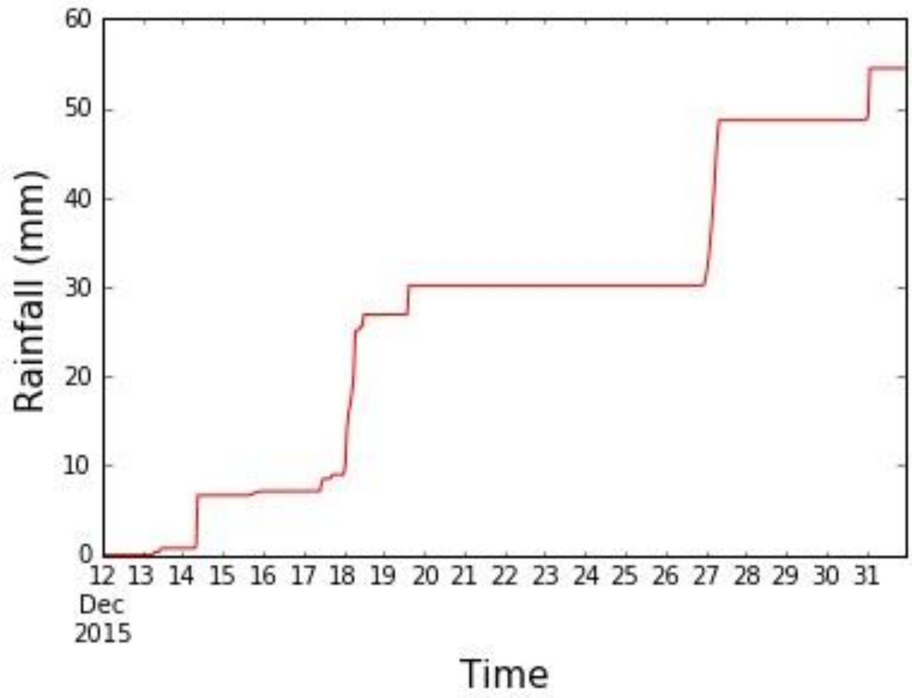

Figure 4-7 The Cumulative Rainfall in December 2015

Real rainfall data for Nablus from PMD, rainfall estimated from MW-Link and processed rainfall data for all months are illustrated in Table 4-2, $R^2 = 0.95$ between PMD and MW measurements.

Table 4-2 Real Rainfall for Nablus from PMD, Estimated from MW-Link and Processed Data for Rainfall from March 2015 to March 2016

Year	Month	Rainfall Data from PMD (Nablus) (mm/month)	Rainfall estimated from MW-Link (mm/month)	Processed Rainfall data (mm/month)
2015	MAR	27.5	30.0	24.8
2015	APR	56.3	62.0	51.0
2015	MAY	0.0	0.0	0.0
2015	JUN	0.0	0.0	0.0
2015	JUL	0.0	0.0	0.0
2015	AUG	0.0	0.0	0.0
2015	SEP	0.0	0.0	0.0
2015	OCT	32.1	31.0	29.0
2015	NOV	41.9	42.0	38.0
2015	DEC	83.8	55.0	75.0
2016	JAN	196.5	222.0	177.0
2016	FEB	111.7	116.0	101.0
2016	MAR	44.7	68.0	40.0

A comparison between rainfall measurements using the MW-Link and data from PMD is shown in Figure 4.8. The measured rainfall was 595 mm during the whole period while the actual measured rainfall during the same period is 536 mm. Based on these results we can see that we have a 10% error in measurements. The error in measurements can be computed from:

$$\text{Percentage Error}=\frac{|\text{EstimatedRainfallData}-\text{RealRainfallData}|}{|\text{RealRainfallData}|}\times 100\% \qquad 4.5$$

$$\text{Percentage Error}=\frac{|\,536-\ 595|}{|536|}\times 100\% = 10\%$$

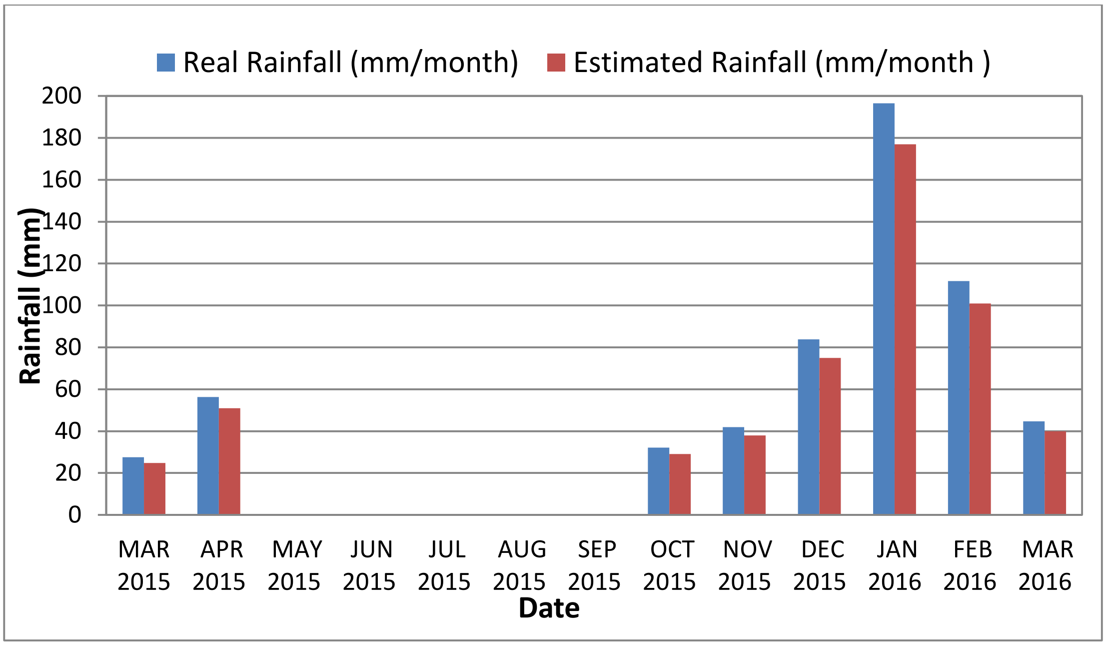

Figure 4.8 Real and Estimated Rainfall

4.2.2 Relative Humidity

Similar to rainfall measurements, the humidity measurements are also affected by the antenna conditions, whether the antenna is dry or wet (David et al., 2011). Therefore, we use the Swiss model to minimize the measurement error due to wet/dry conditions of the antenna. The Swiss model for wet and dry classifications has been used with threshold range between 0.2 and 0.4 as a constant value and window length range between 130 and 170 as constant value for final results.

The most important issue is to estimate the attenuation signal without rainfall events by separating the wet events from attenuation as shown in Figure 4-9 where the attenuation varies from 56 dB to 60 dB from March 2015 to March 2016and then daily resampling has been used to find the values of the absolute humidity from MW-Link data.

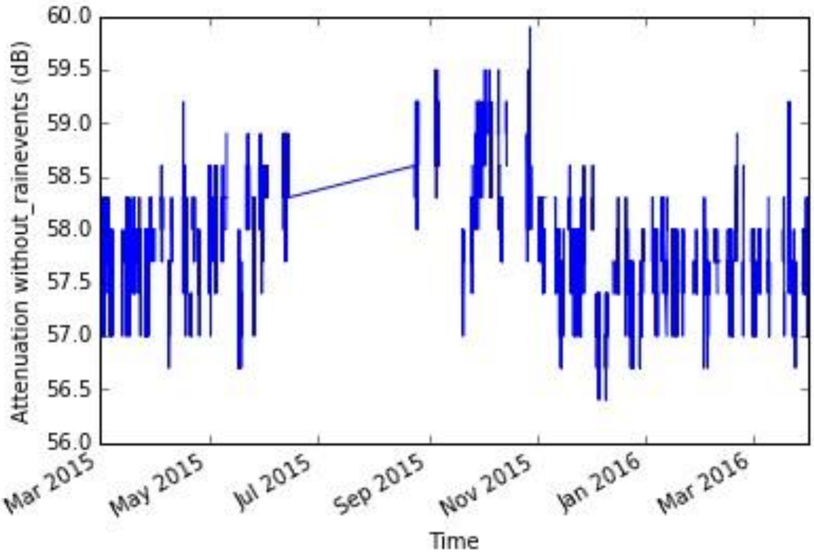

Figure 4-9 Attenuation Without Rainfall Events Signal from March 2015 to March 2016

Finally, relative humidity is obtained from absolute humidity for every month separately. The relative humidity as a function of absolute humidity and average temperature is given by the following equation:

Relative Humidity=absolute humidity *100./ saturated water vapor pressure (T)/(M/R/TK)4.6

Where absolute humidity is measured by g/m^3, saturated water vapor pressure is measured by $mbar$, T is temperature in degree C^o, M is molar weight in $g/$mol which is 18 for rainfall and TK is temperature in Kelvin. Relative humidity at an average temperature of 19 $C^o$is shown in Figure 4-10 and it noticed the relative humidity varies among months from March 2015 to March 2016. The Python code of the relative humidity for the months starting from March 2015 to March 2016 is illustrated in Appendix B.

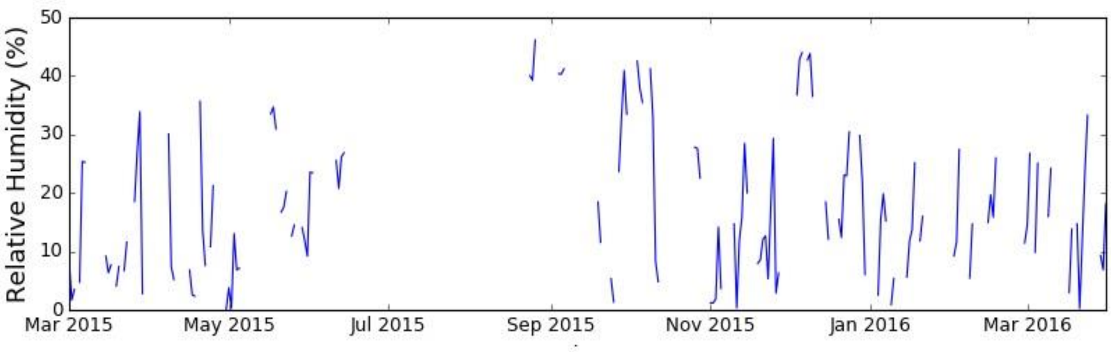

Figure 4-10 Relative Humidity at 19 **C**^{o}

A comparison between relative humidity measurements using MW-Link and real relative humidity measurements using the PMD techniques is shown in Table4-3where the correlation coefficient between real and measured relative humidity is $R^2 = 0.70$.

Table 4.3 Real and MW-Link Estimated Data for Relative Humidity from March 2015 to March 2016

Year	Month	Relative Humidity Estimated from MW-Link (%)	Relative Humidity from PMD (%)
2015	MAR	73	73
2015	APR	64	70
2015	MAY	64	65
2015	JUN	67	77
2015	JUL	73	71
2015	AUG	67	74
2015	SEP	77	71
2015	OCT	98	83
2015	NOV	67	76
2015	DEC	73	77
2016	JAN	84	86
2016	FEB	88	77
2016	MAR	74	71

The monthly average of real and estimated relative humidity from March 2015 to March 2016 was roughly 75%. The percentage of error was less than 1% which means that there is a good level of accuracy between real and estimated readings as it is illustrated by the following formula.

$$\text{Percentage Error} = \frac{|\text{Estimated Relative Humidity Data} - \text{Real Relative Humidity Data}|}{|\text{Real Relative Humidity Data}|} \times 100\% \quad 4.7$$

$$\text{Percentage Error} = \frac{|\,74.5 - 74.7|}{|74.7|} \times 100\% = 0.3\%$$

The results of relative humidity measurements using MW-Links and PMD techniques are illustrated graphically in Figure 4-11. From Figure 4-11, we can observe a good agreement between the two measurement techniques, where the annual average relative humidity from PMD is about 75 % while estimated from MW-Link is about 74%

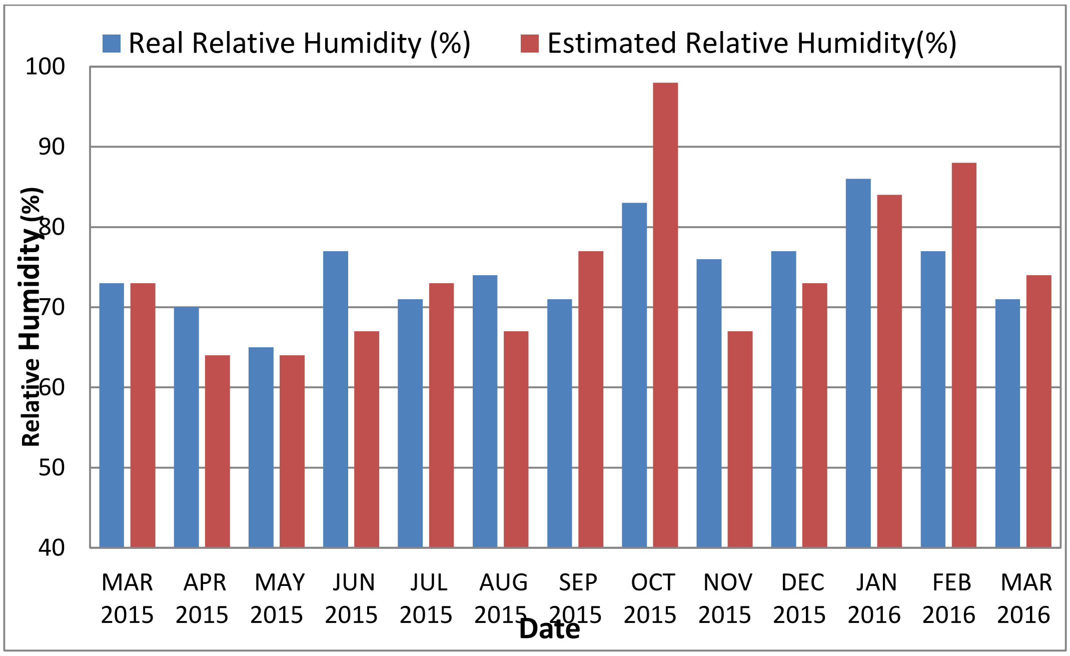

Figure 4-11 Real and Estimated Relative Humidity

4.2.3 Solar radiation estimation

In this section, solar radiation is predicted based on the values of rainfall, relative humidity and temperature. The solar radiation was being predicted using regression analysis. The solar radiation prediction for the various months of the year is provided in Table 4-4.Figure 4-12 shows a comparison between solar radiation measurements obtained from PMD and solar radiation predicted using the regression technique. A closer looks to Figure 4-12 show a good agreement between solar radiation measurements using both techniques.

The average real and estimated solar radiation from March 2015 to March 2016 are equal5.55 and 5.58 $\mathrm{kwh/m^2 - day}$, respectively, as illustrated in Table 4-4.

Table 4-4 Real and Estimated Data for Solar Radiation from March 2015 to March 2016

Year	Month	Estimated Solar Radiation from MW-Link $(\mathrm{kWh/m^2-day})$	Real Solar Radiation from PMD $(\mathrm{kWh/m^2-day})$
2015	MAR	4.2	6.0
2015	APR	5.9	7.5
2015	MAY	8.4	8.6
2015	JUN	8.5	9.0
2015	JUL	9.3	9.6
2015	AUG	9.1	8.0
2015	SEP	7.8	6.3
2015	OCT	6.8	5.7
2015	NOV	2.8	2.0
2015	DEC	1.7	1.7
2016	JAN	1.4	1.56
2016	FEB	2.5	2.59
2016	MAR	4.2	3.6

The percentage of error between estimated solar radiation and real solar radiation data was 0.54%. There is an excellent level of accuracy between real and estimated readings as illustrated in the following formula:

$$\text{Percentage Error}=\frac{|\text{Estimated Solar Radiation Data}-\text{Real Solar Radiation Data}|}{|\text{Real Solar Radiation Data}|}\times 100\% \tag{4.8}$$

$$\text{Percentage Error}=\frac{|5.58-5.55|}{|5.55|}\times 100\% = 0.54\ \%$$

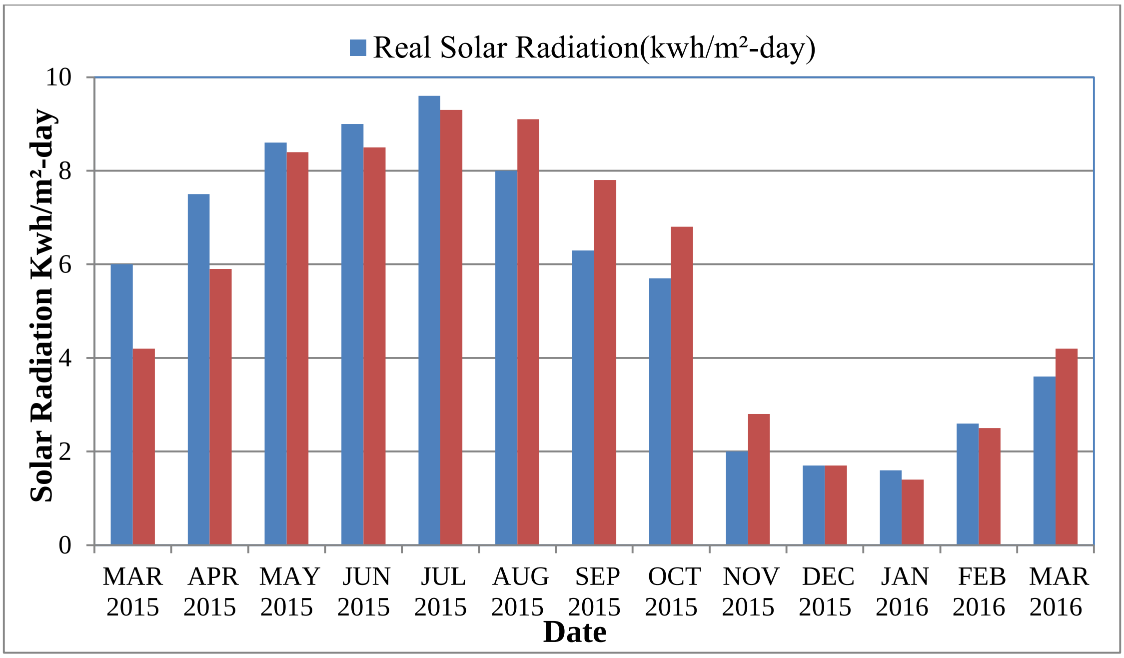

Figure 4-12 Real and Estimated Solar Radiation

The estimated solar radiation from MW-Link in Figure 4-12 ranges between 1.4 $\mathrm{kwh/m^2-day}$ in December 2015 and 9.3 $\mathrm{kwh/m^2-day}$ in July 2015. Thevaries readings in solar radiation are almost similar to the data taken from PMD.

Regression analysis has been implemented on rainfall, relative humidity and solar radiation from March 2015 to March 2016 according to equation 4-1 which links rainfall, relative humidity and ambient temperature to obtain the solar radiation.

According to solar radiation data from PMD, it has been noticed that there is symmetry among months such as January and December, June and July, etc. This symmetry caused by sunshine hours for these months are almost similar. Therefore, regression analysis has been used to reach the highest correlation coefficient by producing six regression equations each one for two months as illustrated in Table 4-5 from March 2015 to March 2016 with high correlation coefficient of $R^2 = 0.89$ between real and estimated data.

Table 4-5Regression Equations of Solar Radiation from March 2015 to March 2016

Month	Regression Equation
March and October	$SR = -0.606 - 0.00041 \times RF + 0.02328 \times RH + 0.20469 \times T$
April and September	$SR = 3.06715 - 0.00605 \times RF + 0.00206 \times RH + 0.17504 \times T$
May and August	$SR = 3.48192 + 0.00219 \times RF + 0.03961 \times RH + 0.10883 \times T$
June and July	$SR = 2.47289 + 0.03914 \times RH + 0.15681 \times T$
February and November	$SR = 1.44596 - 0.00153 \times RF + 0.00244 \times RH + 0.07309 \times T$
January and December	$SR = -0.247 + 0.0002 \times RF + 0.0009 \times RH + 0.16558 \times T$

Chapter Five

Conclusions and Recommendations

5.1 Conclusion

Based on this study, the following conclusions are drawn:

1− This research demonstrates the feasibility of using MW-Links from a cellular communication infrastructure as environmental sensor networks for rainfall, relative humidity and solar radiation monitoring.

2− Solar radiation is an important factor in photovoltaic systems design which are useful for electrical power production as a clean energy application in Palestine.

3− The results of estimated rainfall on Beitforeek-Al Masakenwere 626 mm which is almost similar to PMD rainfall measurements which were595 mm from March 2015 to March 2016.

4− The average estimated relative humidityon Beitforeek-Al Masaken was 74%which is almost similar to PMD data which was 75 % from March 2015 to March 2016.

5− Solar radiation was estimated as a function of rainfall, relative humidity and ambient temperature using regression analysis. The estimated average solar radiation was 5.58$\mathrm{kwh/m^2 - day}$ which is almost similar to real solar radiation measurements taken from PMD which was 5.55 $\mathrm{kwh/m^2 - day}$ from March 2015 to March 2016.

6− The microwave links can be used to estimate rainfall, relative humidity and solar radiation with reasonable accuracy with very low cost compared with other measurement techniques.

5.2 Recommendations

1- Improving and developing effective communication among universities, PMD, JAWWAL and different scientific research centers.
2- Increasing number of rain gauges and relative humidity sensors in the Wadi Faria catchment to make readings of rainfall and relative humidity more accurate, reliable and reasonable.
3- Working on long historical time series from PMD to obtain more reliable results.
4- Increasing number of microwave links in Nablus and other cities in Palestine to collect as much data as possible in order to reduce errors
5- Developing the Python code of rainfall and relative humidity and building new codes by other compilers to reach the most reliable code.
6- Most researches have been focusing on studying the potential of MW-Links for rainfall and relative humidity observations. However, there is still much future work recommended to fully explore the potential of MW-Links.

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Appendices

Appendix A-1: PMD and Estimated Data

Table 1: Verification technique of regression analysis for real data from 1998 to 2008 with example and correlation coefficient

Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	MAR	3.4	244.5	67.2	11.3	1998	OCT	5.3	16.3	53.6	21.6
1999	MAR	3.4	40.1	60.8	13.7	1999	OCT	5	14.5	65.6	20.9
2000	MAR	3.4	79.1	69.9	11.5	2000	OCT	4.3	63.7	59.6	20.6
2001	MAR	4.2	9.3	53.6	17.1	2001	OCT	4.9	20.8	68.3	20.7
2002	MAR	3.4	115.9	58.2	15.8	2002	OCT	5	20.8	62	20.8
2003	MAR	3.2	236	64.3	11.6	2003	OCT	5.1	2.6	60.9	21.7
2004	MAR	4	24.2	54.2	15.3	2004	OCT	5	0.4	59.3	22.1
2005	MAR	3.7	37.3	57.4	13.9	2005	OCT	5	10.5	57.1	20.1
2006	MAR	3.5	20.6	59.3	13.8	2006	OCT	4.9	62.6	63.4	20.1
2007	MAR	3.5	116.6	67.9	12.5	2007	OCT	5.6	0.1	64.3	21.9
2008	MAR	3.5	6	52.2	16.4	2008	OCT	5.1	23.3	68.7	20.1
regression analysis from 1998 to 2008 for regression verification technique											
2009	MAR	4	82.9	68.6	12.1	2009	OCT	5.1	30	52.9	23
2010	MAR	4	12.8	63.2	15.8	2010	OCT	6.9	5.3	55.6	23.4
SR=-0.606-0.00041 × 5+0.02328×56+0.20469× 23=6 kwh/m2-day											
Coefficients	Intercept	-0.6	X1	-0.0004	X 2	0.023	X3	0.205	**R Square**	0.95	

Table 2: Real and estimated Data for Rainfall, Relative Humidity and Solar Radiation from March 2015 to March 2016.

Year	Month	RF_Real Data (Nablus) (mm/month)	RF- MW (mm/month)	RF_Estimated (Beitforek-Almasaken)(mm/month)	RH- MW (%)	RH Real Data (%)	T (C°)	SR_Real (kwh/m^2-day)	SR_Estimated (kwh/m^2-day)
2015	MAR	27.5	30.0	24.8	73.0	73.0	15.0	6.0	4.2
2015	APR	56.3	62.0	51.0	64.0	70.0	17.0	7.5	5.9
2015	MAY	0.0	0.0	0.0	64.0	65.0	22.0	8.6	8.4
2015	JUN	0.0	0.0	0.0	67.0	77.0	22.0	9.0	8.5
2015	JUL	0.0	0.0	0.0	73.0	71.0	25.0	9.6	9.3
2015	AUG	0.0	0.0	0.0	67.0	74.0	27.0	8.0	9.1
2015	SEP	0.0	0.0	0.0	77.0	71.0	26.0	6.3	7.8
2015	OCT	32.1	31.0	29.0	98.0	83.0	22.0	5.7	6.8
2015	NOV	41.9	42.0	38.0	67.0	76.0	17.0	2.0	2.8
2015	DEC	83.8	55.0	75.0	73.0	77.0	11.0	1.7	1.7
2016	JAN	196.5	222.0	177.0	84.0	86.0	9.0	1.6	1.4
2016	FEB	111.7	116.0	101.0	88.0	77.0	13.0	2.6	2.5
2016	MAR	44.7	68.0	40.0	74.0	71.0	15.0	3.6	4.2

Tables 3, 4, 5,6 and 6 illustrate the regression analysis with equation, correlation coefficient and example for each month to get the solar radiation estimation from real data.

Table 3: The regression analysis of December and January with examples and correlation coefficient

Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	DEC	1.16	54.5	59.0	8.0	1998	JAN	1.36	148.2	75.7	9.0
1999	DEC	1.44	39.4	57.0	10.0	1999	JAN	1.71	154.2	67.1	11.3
2000	DEC	1.29	123.9	74.0	9.0	2000	JAN	1.36	150	74.1	9.0
2001	DEC	1.1	161.6	69.6	7.6	2001	JAN	1.61	85.1	67	10.6
2002	DEC	1.15	220.0	77.8	7.9	2002	JAN	1.37	257.2	72.5	9.0
2003	DEC	1.26	130.4	70.3	8.6	2003	JAN	1.41	73.7	62.9	9.3
2004	DEC	1.3	82.6	62.6	9.0	2004	JAN	1.35	230	74.3	8.9
2005	DEC	1.19	83.6	60.4	8.2	2005	JAN	1.38	237.5	66.6	9.1
2006	DEC	1.38	105.0	53.0	9.5	2006	JAN	1.32	152.3	72	8.7
2007	DEC	1.46	78.4	70.0	10. 1	2007	JAN	1.59	105.6	66	10.5
2008	DEC	1.36	153.3	62.1	9.3	2008	JAN	1.59	158	63.7	10.5
2009	DEC	1.37	102.4	73.3	9.5	2009	JAN	1.68	51.2	58	11.1
2010	DEC	1.5	151.1	56.4	10.3	2010	JAN	1.61	89.6	69	10.6
		Intercept	-0.247	X_1	0.00017	X_2	0.0009	X_3	0.16558	R^2	0.98

Table 4: The Regression Analysis of March and October with examples and correlation coefficient

Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	MAR	3.4	244.5	67.2	11.3	1998	OCT	5.3	16.3	53.6	21.6
1999	MAR	3.4	40.1	60.8	13.7	1999	OCT	5.0	14.5	65.6	20.9
2000	MAR	3.4	79.1	69.9	11.5	2000	OCT	4.3	63.7	59.6	20.6
2001	MAR	4.2	9.3	53.6	17.1	2001	OCT	4.9	20.8	68.3	20.7
2002	MAR	3.4	115.9	58.2	15.8	2002	OCT	5.0	20.8	62.0	20.8
2003	MAR	3.2	236.0	64.3	11.6	2003	OCT	5.1	2.6	60.9	21.7
2004	MAR	4.0	24.2	54.2	15.3	2004	OCT	5.0	0.4	59.3	22.1
2005	MAR	3.7	37.3	57.4	13.9	2005	OCT	5.0	10.5	57.1	20.1
2006	MAR	3.5	20.6	59.3	13.8	2006	OCT	4.9	62.6	63.4	20.1
2007	MAR	3.5	116.6	67.9	12.5	2007	OCT	5.6	0.1	64.3	21.9
2008	MAR	3.5	6.0	52.2	16.4	2008	OCT	5.1	23.3	68.7	20.1
2009	MAR	4.0	82.9	68.6	12.1	2009	OCT	5.1	30.0	52.9	23.0
2010	MAR	4.0	12.8	63.2	15.8	2010	OCT	6.9	5.3	55.6	23.4
	Intercept	-0.6	X_1	-0.0004	X_2	0.023	X_3	0.205	R^2		0.81

Table 5: The Regression Analysis of April and September with Examples and Correlation Coefficient

Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	APR	6.3	5.0	55.1	17.8	1998	SEP	7.2	1.6	59.6	24.3
1999	APR	6.3	20.6	56.0	16.5	1999	SEP	7.0	17.6	64.4	24.0
2000	APR	6.1	0.4	55.3	18.1	2000	SEP	7.0	1.6	67.1	23.2
2001	APR	6.0	0.0	55.0	18.2	2001	SEP	7.0	0.0	63.0	24.6
2002	APR	5.6	34.1	64.5	14.3	2002	SEP	7.2	0.0	47.5	23.2
2003	APR	5.7	27.1	51.8	17.3	2003	SEP	7.2	0.0	60.0	23.3
2004	APR	6.1	11.1	49.8	17.7	2004	SEP	7.3	0.0	62.7	23.4
2005	APR	6.1	9.4	50.1	17.4	2005	SEP	7.2	0.0	61.3	23.6
2006	APR	5.3	128.0	60.7	16.5	2006	SEP	7.2	0.0	69.9	23.2
2007	APR	5.8	8.2	62.0	15.9	2007	SEP	7.6	0.0	69.4	23.4
2008	APR	6.6	0.1	49.4	19.0	2008	SEP	7.3	11.0	66.9	23.8
2009	APR	6.6	14.1	59.9	17.0	2009	SEP	7.4	2.2	67.6	23.2
2010	APR	6.4	0.1	60.4	17.8	2010	SEP	8.7	0.0	56.9	24.8
	Intercept	3.07	X_1	-0.006	X_2	-0.002	X_3	0.175	R^2		0.81

Table 6: The Regression Analysis of May and August with Examples and Correlation Coefficient

Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m²-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	MAY	8.0	7.8	53.0	20.6	1998	AUG	9.0	0.0	65.6	25.9
1999	MAY	7.9	0.0	48.4	21.8	1999	AUG	9.0	0.0	64.2	25.5
2000	MAY	7.9	0.0	49.8	20.2	2000	AUG	8.7	0.0	69.3	24.7
2001	MAY	7.7	30.6	53.3	20.6	2001	AUG	8.9	0.0	62.3	26.1
2002	MAY	8.3	19.2	51.2	21.0	2002	AUG	8.5	0.0	60.0	24.4
2003	MAY	7.6	0.0	38.2	25.3	2003	AUG	8.8	0.0	66.9	25.9
2004	MAY	7.3	1.2	51.5	20.0	2004	AUG	8.8	0.0	65.5	24.2
2005	MAY	7.8	2.3	54.7	19.7	2005	AUG	8.8	0.0	64.9	25.2
2006	MAY	7.9	0.0	54.7	20.0	2006	AUG	8.8	0.0	60.9	25.6
2007	MAY	7.3	4.9	53.6	21.9	2007	AUG	8.8	0.0	62.0	25.2
2008	MAY	8.0	0.0	58.1	19.6	2008	AUG	8.7	0.0	65.1	25.5
2009	MAY	8.0	0.0	58.3	20.3	2009	AUG	8.8	0.0	67.5	25.1
2010	MAY	8.0	0.0	52.9	21.3	2010	AUG	8.8	0.0	58.0	27.2
	Intercept	3.48	X_1	0.002	X_2	0.039	X_3	0.109	R^2		0.83

Table 7: The Regression Analysis of November and February with Examples and Correlation Coefficient

Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	NOV	2.8	3.3	60.9	18.4	1998	FEB	2.3	91.9	69.6	10.6
1999	NOV	2.8	16.3	54.6	17.0	1999	FEB	2.3	66.8	64.7	11.4
2000	NOV	2.8	3.5	48.5	17.0	2000	FEB	2.2	84.7	70.8	9.7
2001	NOV	2.5	75.1	66.7	15.4	2001	FEB	2.3	122.5	70.9	10.8
2002	NOV	2.6	85.1	47.9	18.8	2002	FEB	2.4	57.9	53.9	12.7
2003	NOV	2.6	32.1	60.3	17.1	2003	FEB	1.7	350.0	73.0	9.3
2004	NOV	2.3	152.8	61.2	16.2	2004	FEB	2.2	136.2	70.7	10.8
2005	NOV	2.6	56.4	59.9	15.2	2005	FEB	2.0	267.6	71.0	9.7
2006	NOV	2.6	28.5	49.8	16.2	2006	FEB	1.9	154.9	65.1	11.5
2007	NOV	2.8	85.3	60.9	16.3	2007	FEB	2.0	174.9	73.9	10.8
2008	NOV	3.0	4.2	57.5	17.0	2008	FEB	2.4	104.7	65.4	9.9
2009	NOV	2.9	83.7	68.8	15.3	2009	FEB	2.2	210.4	67.8	11.3
2010	NOV	3.2	85.4	46.6	20.4	2010	FEB	2.3	249.7	65.3	13.0
	Intercept	1.44	X_1	-0.0015	X_2	0.002	X_3	0.07	R^2		0.8

Table 8: The regression analysis of June and July with examples and correlation coefficient

Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)	Year	Month	SR (kwh/m^2-day)	RF (mm/month)	RH (%)	Temp (C°)
1998	JUN	8.4	0.0	60.1	22.6	1998	JUL	8.4	0.0	52.1	25.2
1999	JUN	8.4	0.0	63.8	22.8	1999	JUL	8.9	0.0	63.5	24.6
2000	JUN	8.4	0.0	57.6	23.6	2000	JUL	8.9	0.0	59.2	26.4
2001	JUN	8.3	0.0	50.5	24.7	2001	JUL	8.7	0.0	61.0	25.2
2002	JUN	8.4	0.0	46.9	26.3	2002	JUL	8.2	0.0	52.0	22.7
2003	JUN	8.4	0.0	53.4	24.7	2003	JUL	8.7	0.0	55.7	25.8
2004	JUN	8.4	0.0	60.0	22.6	2004	JUL	8.8	0.0	56.4	25.4
2005	JUN	8.3	0.0	59.6	22.5	2005	JUL	8.8	0.0	59.4	25.2
2006	JUN	8.3	0.0	55.4	23.3	2006	JUL	8.6	0.0	57.8	24.3
2007	JUN	8.3	0.0	56.0	23.9	2007	JUL	8.7	0.0	57.0	25.5
2008	JUN	8.2	0.0	51.3	24.4	2008	JUL	8.8	0.0	61.8	25.1
2009	JUN	8.4	0.0	53.1	24.5	2009	JUL	8.9	0.0	60.5	25.7
2010	JUN	8.4	0.0	52.5	24.2	2010	JUL	8.8	0.0	58.7	24.9
	Intercept	2.47	X_1	0	X_2	0.039	X_3	0.157	R^2		0.9

Appendix A-2:Cooperation agreement with JAWWAL

شـركة الاتـصالات الخـلوية
الفلسطينية م.خ.م - جوال
ص.ب: 3999 - البيرة - فلسطين
هاتـف: 8000 296 2 970 +
فاكس: 8636 296 2 970 +

جوال

التاريخ : 18/11/2015

الاشارة:END/28/399

السيد /الدكتور عماد بريك المحترم ،،،

منسق المراكز العلمية

<u>الموضوع: التعاون في تنفيذ مشروع بحث علمي</u>

تتقدم اسرة جوال ببالغ تحياتها وتقديرها لحضرتكم على جهودكم المميزة والمتواصلة في خدمة المسيرة التعليمية وعلى تعاونكم الدائم مع شـــركة جوال ، ولما تبذلونه من جهود عظيمة للارتقاء بطلابنا ومجتمعنا ليواكب مجتمعات العالم المتحضرة . بناءا على العلاقات المتميزة والمستمرة بين جامعة النجاح الوطنية وشركة جوال في كافة المجالات ومنها التعاون في المجال الأكاديمي فانه يســـعدنا ابلاغكم عن اســـتعداد جوال التعاون معكم في مشـروع البحث العلمي الذي تم مخاطبتنا بخصـوصـه بكتابكم المؤرخ بتاريخ **2015/11/01** بخصـوص مساعدة الطالب محمد حنايشـة في مشـروع رسـالة الماجسـتير بعنوان " دمج بيانات وصـلات الميكرويف لتحليل بيانات الاشـعاع الشـمسـي في فلسـطين " وتقديم كل ما يلزم من معلومات لغايات المشـروع المذكور بما يتلائم مع ما هو متفق معكم به بخصـوص التعاون في مشـاريع الطلبه الخريجين ويضـمن سـياسـات جوال من حيث خصـوصـية وسـرية المعلومات , بحيث يعتبر هذا الكتاب موافقتنا على التعاون معكم بهذا المشـروع. وتترك التفاصـيل الفنية للفريقين التقنيين من قبل الطرفين , ويمثل جوال المهندس عنتر سيلم

وتفضلوا بقبول فائق الاحترام ،،،

<u>مدير إدارة عمليات الشبكة</u>

<u>م. ماهر بروق</u>

18/11

Appendix B: Rainfall and Relative Humidity Python Codes

Rainfall Code

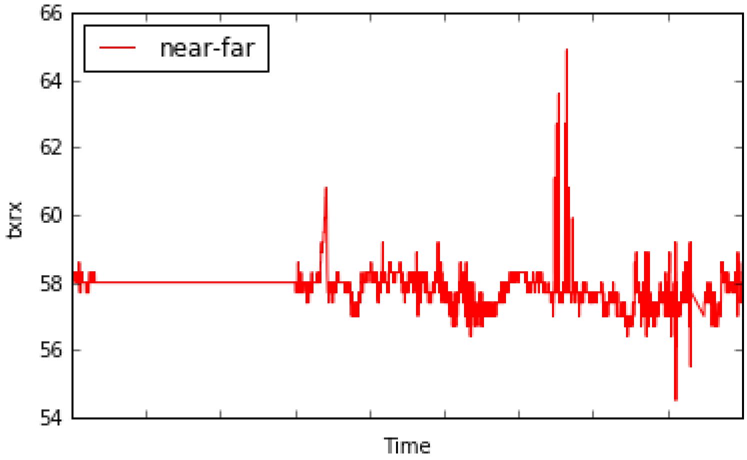
```
%pylab inline

import pandas as pd

import pycomlink as pycml

from IPython.html.widgets import interact

# Read in data for MW link in Wadi Faria (Beit Forek(WBR069),Nablus -
Al Masaken (NABL04)), 69N4,, 19-02-2015 to 26-02-2015

df = pd.read_csv('Beit Forek_Al Masaken.csv' ,

parse_dates=True,

index_col=0)

df.columns = ['rx']
```

```
tx_rx_pairs=  {'nf': {'name': 'near-far',
                'tx': 'tx',
                'rx': 'rx',
                'tx_site': 'site_A',
                'rx_site': 'site_B',
                'f_GHz': 23.551,
                'pol': 'V',
                'linecolor': 'r'}}

# This is additional metadata, in particular on the sites

metadata = {'site_A': {'lat': 32.233,
                'lon': 35.302,
                'id': 'NABL04'},
```

```
        'site_B': {'lat': 32.191,
                   'lon': 35.336,
                   'id': 'WBR069'},
        'link_id': 'N469',
        'length_km': 6.64}

cml = pycml.comlink.Comlink(data=df.copy(),
                            metadata=metadata,
tx_rx_pairs=tx_rx_pairs,
const_TX_power=('tx',11))
```

```
from copy import deepcopy
cml_short = deepcopy(cml)
cml_short.data = cml.data['2015-04-01':'2015-04-30'].copy()
```

cml_short.plot()



defdo_wet_dry_and_plot(window_length, threshold):

cml_short.do_wet_dry_classification(method='std_dev',

window_length=window_length,

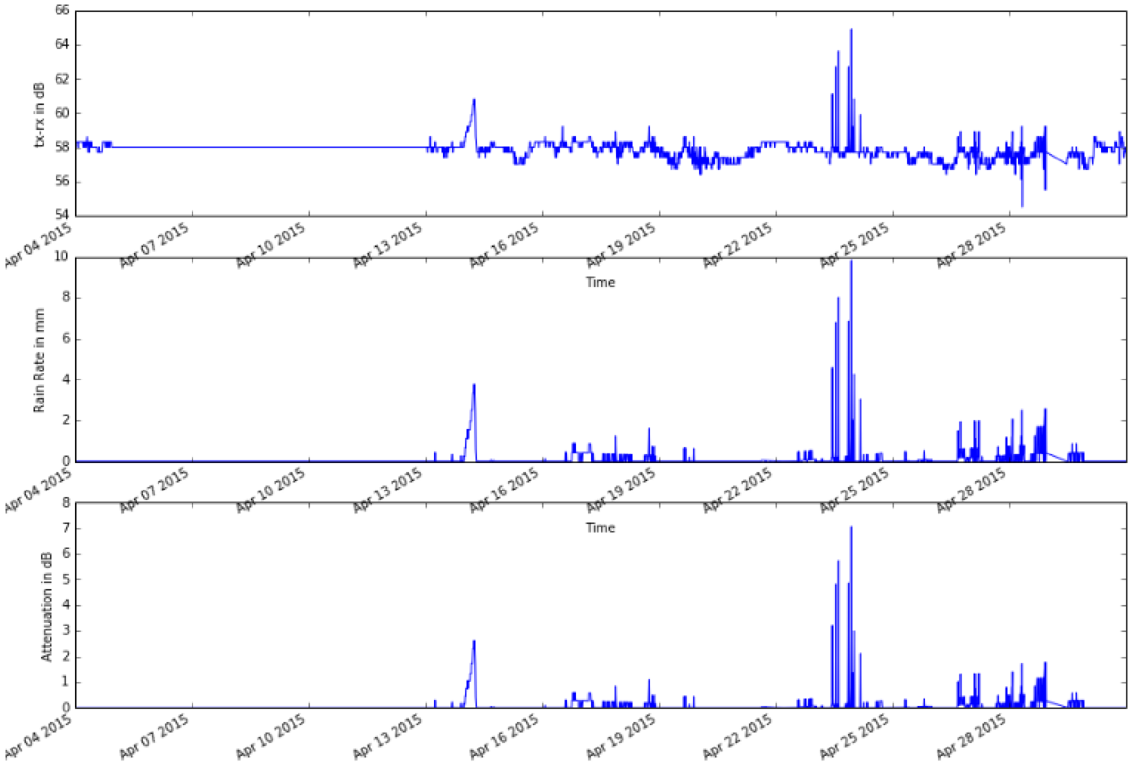
threshold=threshold)

cml_short.do_baseline_determination(method='linear')

cml_short.calc_A()

cml_short.calc_R_from_A()

```
fif, ax = subplots(3,1, figsize=(15,11))

cml_short.data.txrx_nf.plot(ax=ax[0]);

ax[0].set_ylabel('tx-rx in dB');

cml_short.data.R_nf.plot(ax=ax[1])

ax[1].set_ylabel('Rain Rate in mm');

cml_short.data.A_nf.plot(ax=ax[2]);

ax[2].set_ylabel('Attenuation in dB');

    #std_dev

interact(do_wet_dry_and_plot, window_length=(1,200,1),
threshold=(0.0,1,0.01));
```

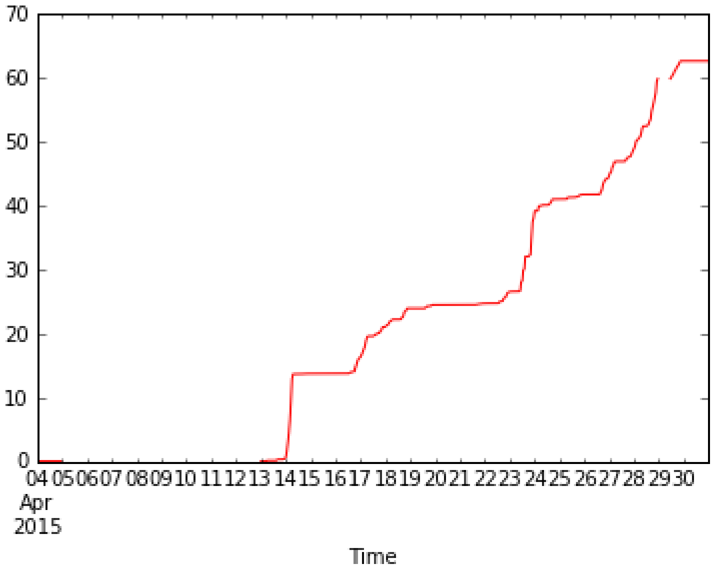


cml_short.data.R_nf.resample('H')

#cml.calc_R_from_A()

PLOT

cml_short.data.R_nf.resample('H').cumsum().plot(color='r');



Relative Humidity Code

```
%pylab inline
```

```
from pyMPM import MPM

import pandas as pd

import pycomlink as pycml

from IPython.html.widgets import interact
```

```
f = 23          #  frequency in GHz

T = 17          # Air temperature in degree Celcius
```

```
P = 1013              # Air pressiure in mbar

RH_vec = arange(100)
```

```
A_dict = {}

A = [MPM(f, P, T, RH, 0, 0, 0, 'att') for RH in RH_vec]

A_dict[str(f) + 'GHz'] = A
```

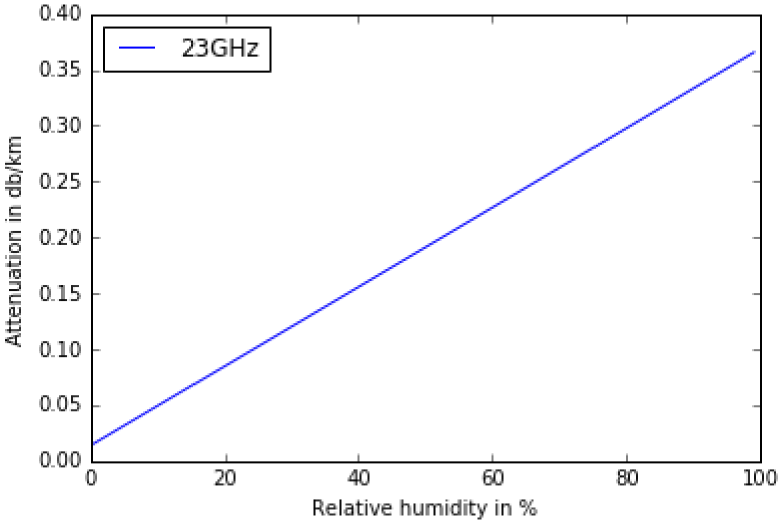
```
defsat_water_vap_pres(T):

    '''

sat_water_vap_pres(T)

    T     = Temperature in ∞C

e_sat = Saturated water vapor pressure in HPa (=mbar)

    Calculates the saturated water vapor pressure with
```

```
    the approximation by Bolton (1980)

    '''

    import numpy as np

    return 6.112 * np.exp(17.67 * T / (T + 243.5))



defabs_hum(RH,T):

    '''

    Calculate absolute humidity from temperature and relative humidity

abs_hum(rh,t)

abs_hum = absolute humidity on g/m^3

    RH      = relative humidity in percent

    T       = temperature in degree C
```

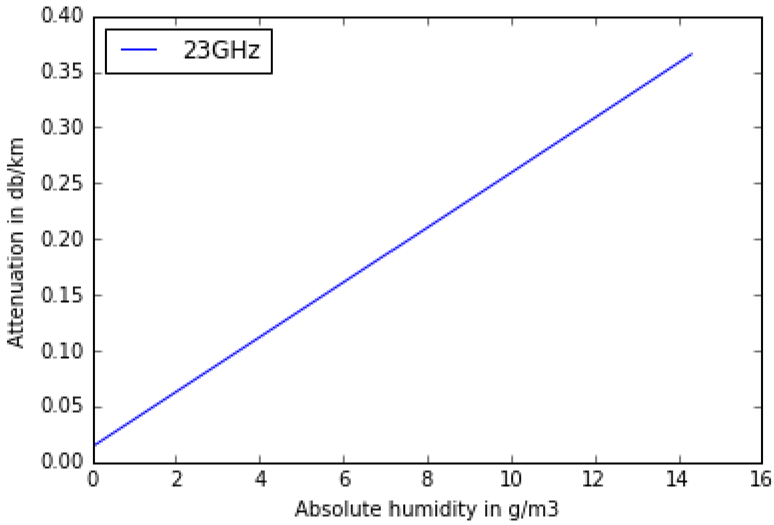
```
    '''
    R = 8.3144621e-2 # gas constant in hPa*m^2/(mol*K)
    M = 18.02       # molar weight in g/mol
    TK = T + 273.15

abs_h = RH / 100.0 * sat_water_vap_pres(T) * M / R / TK
    return abs_h

abs_hum_vec = abs_hum(RH_vec,T)
defrh_from_abs_hum(abs_hum,T):
    R = 8.3144621e-2 # gas constant in hPa*m^2/(mol*K)
    M = 18.02       # molar weight in g/mol
```

```
    TK = T + 273.15

rh = abs_hum *100. /sat_water_vap_pres(T)  / (M/R/TK)

    return rh
```

```
key = str(f) + 'GHz'

plot(RH_vec, A_dict[key], label=key)

legend(loc=2)

xlabel('Relative humidity in %')

ylabel('Attenuation in db/km');
```



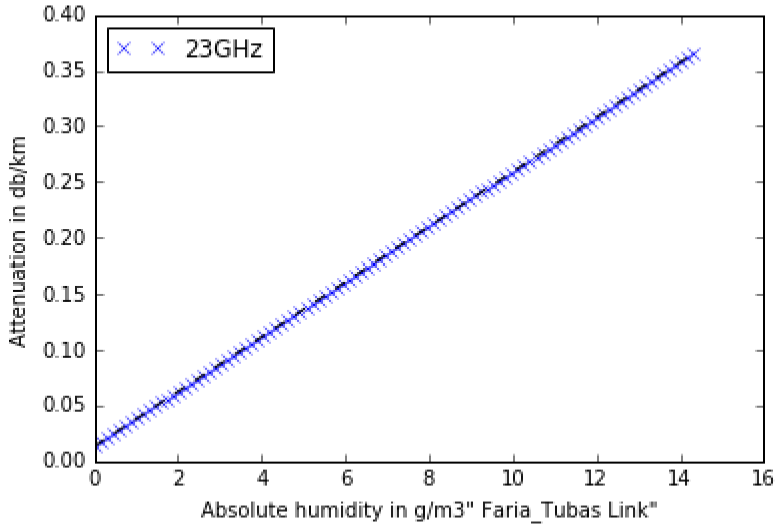
```
key = str(f) + 'GHz'

plot(abs_hum_vec, A_dict[key], label=key)

legend(loc=2)

xlabel('Absolute humidity in g/m3')

ylabel('Attenuation in dB/km');
```




```
deffit_linear(xd,yd):

    # determine best fit line

    par = np.polyfit(xd, yd, 1, full=True)
```

```
    slope=par[0][0]

    intercept=par[0][1]

    return slope[0], intercept[0]
```

```
f=23

key = str(f) + 'GHz'

plot(abs_hum_vec, A_dict[key], 'x', label=key)

slope, intercept = fit_linear(abs_hum_vec, A_dict[key])

plot(abs_hum_vec, intercept + slope*abs_hum_vec, 'k--')

legend(loc=2)

xlabel('Absolute humidity in g/m3" Faria_Tubas Link"')

ylabel('Attenuation in db/km');
```




```
defA_to_abs_hum(A):

    return (A-intercept)/slope
```

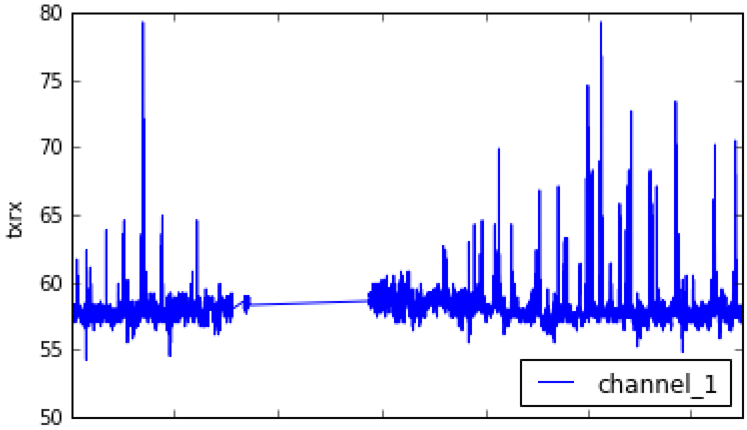
```
import pycomlink as pycml
```

```
cml_list = pycml.io.read_from_cmlh5('Beit Forek_Al
Masaken_03_2015_03_2016.h5')
```

```
for cml in cml_list:

    print cml.metadata
```

```
cml.data=cml.data.tz_convert("UTC")#('Asia/Jerusalem')
```

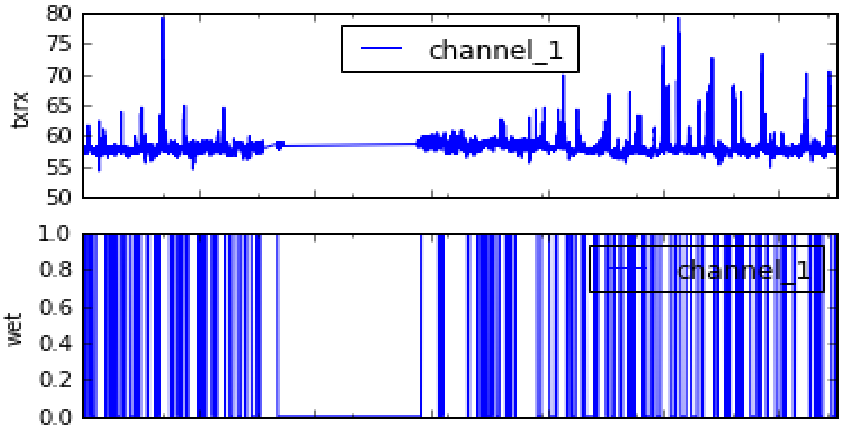
cml.plot('txrx')



cml.do_wet_dry_classification(method='std_dev',

threshold=0.30,window_length=130)

cml.plot(['txrx', 'wet'])



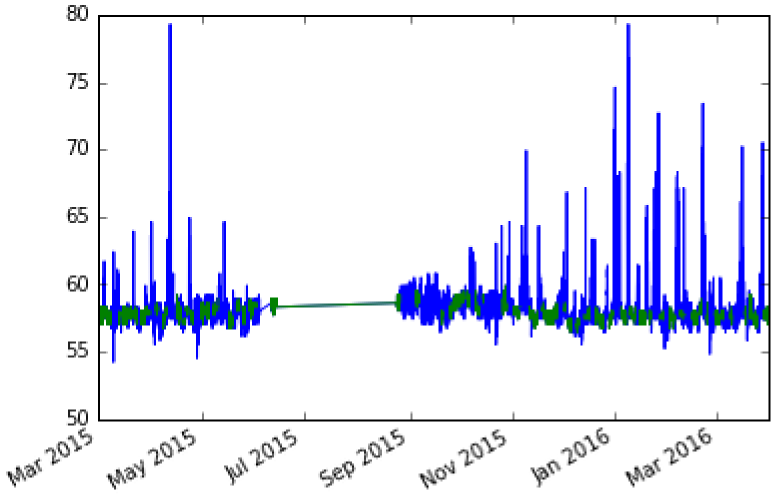
A_raw = cml.data.txrx_channel_1.copy()

A_raw_without_rainevents = A_raw.copy()

A_raw_without_rainevents[cml.data.wet_channel_1==True] = nan

A_raw.plot()

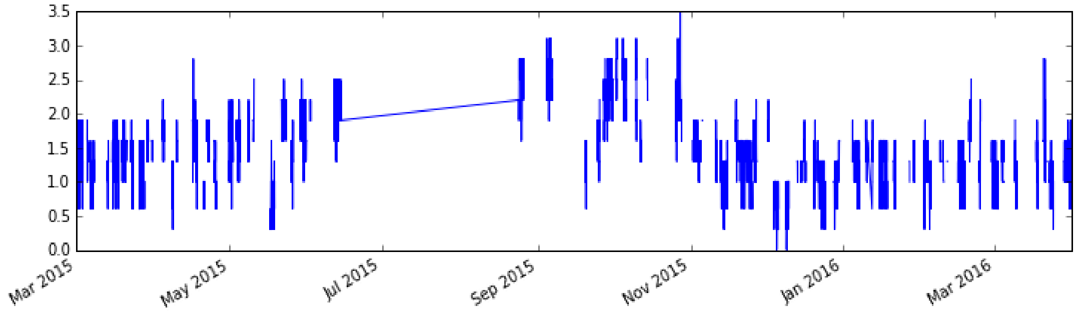
A_raw_without_rainevents.plot()



A_zeroed = A_raw_without_rainevents - A_raw_without_rainevents.min()

fig, ax = plt.subplots(figsize=(12,3))

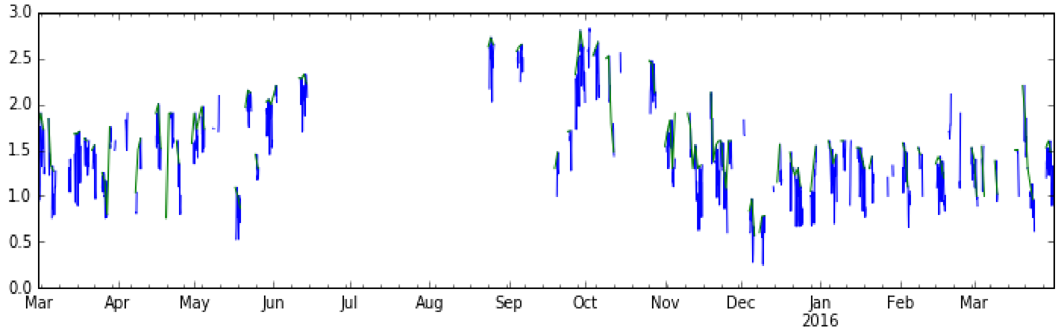
A_zeroed.plot()



fig, ax = plt.subplots(figsize=(12,3))

A_zeroed.resample('3H', 'mean').plot()

A_zeroed.resample('3H', 'mean').resample('D', 'max').plot()

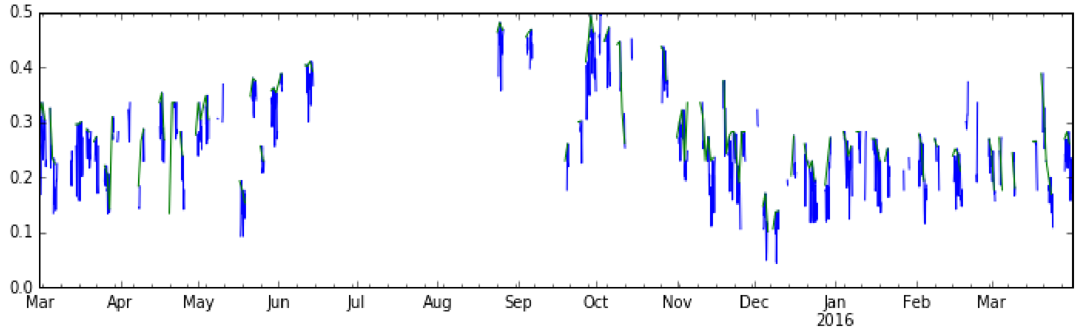


A_zeroed_db_km = A_zeroed/cml.metadata['length_km']

fig, ax = plt.subplots(figsize=(12,3))

A_zeroed_db_km.resample('3H', 'mean').plot()

A_zeroed_db_km.resample('3H', 'mean').resample('D', 'max').plot()



A_smoothed_daily_max = A_zeroed_db_km.resample('3H', 'mean').resample('D', 'mean')

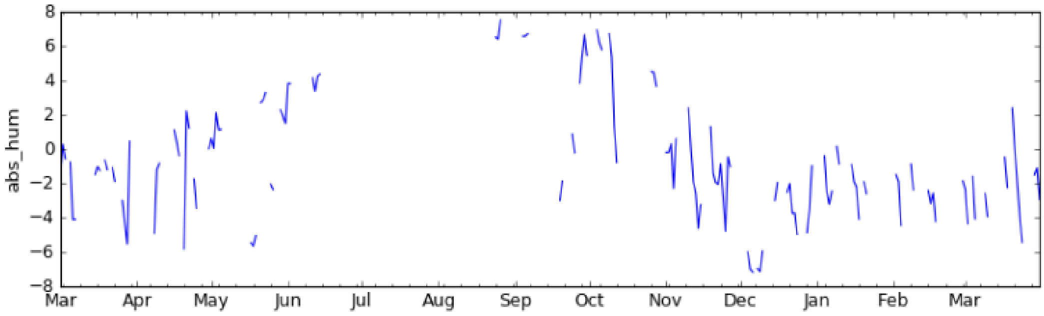
abs_hum_derived_from_cml = A_to_abs_hum(A_smoothed_daily_max-A_smoothed_daily_max.mean())

%matplotlib notebook

fig, ax = plt.subplots(figsize=(12,3))

abs_hum_derived_from_cml.plot(figsize=(12,3))

ylabel('abs_hum')



rh=rh_from_abs_hum(abs_hum_derived_from_cml,17)*5

mean(abs(rh['2015-04-01':'2015-04-30']))

64.9693972834544441

جامعة النجاح الوطنية
كلية الدراسات العليا

دمج بيانات وصلات المايكروويف لتحليل بيانات الإشعاع الشمسي في نابلس، فلسطين

إعداد
محمد فيصل خلف حنايشه

إشراف
د. سمير شديد
د. فلاح حسن

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة واستراتيجية الترشيد بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2018

دمج بيانات وصلات المايكروويف لتحليل بيانات الإشعاع الشمسي

في نابلس، فلسطين

إعداد

محمد فيصل خلف حنايشه

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الملخص

الهدف الرئيسي من هذا البحث هو تطوير طريقة غير مباشرة لتقدير الإشعاع الشمسي عبر إستخدام بيانات متكاملة من وصلات الأمواج الدقيقة، بالإضافة إلى ذلك فإنه يهدف أيضا إلى تقدير معدل سقوط الأمطار والرطوبة النسبية من التهوين الناجم عن الإشارة المستلمة من وصلات الأمواج الدقيقة، حيث يتم مقارنة تقديرات معدل سقوط الأمطار والرطوبة النسبية والإشعاع الشمسي من إشارة وصلات الأمواج الدقيقة مع القياسات الأرضية في محطة نابلس للأرصاد الجوية، حيث تم الحصول على البيانات من دائرة الأرصاد الجوية الفلسطينية، إلى جانب تقديرات سقوط الأمطار والرطوبة النسبية تم تقدير الإشعاع الشمسي من قياسات وصلة الأمواج الدقيقة بإستخدام تحليل الإنحدار.

تم إستخدام وصلات المايكروويف كمجسات بيئية والتي يمكن إستخدامها لتقدير بيانات الأرصاد الجوية بأقل تكلفة مقارنة مع تقنيات القياس التقليدية، حيث ان هذا النهج المنخفض التكلفة يعطي البحث أهمية إقتصادية.

يتم أخذ القياسات على منطقة جغرافية واحدة في فلسطين داخل مستجمعات الفارعة الواقعة في مدينة نابلس، وتؤخذ قياسات التهوين من شهر اذار للعام 2015 حتى شهر اذار للعام 2016 من وصلات الأمواج الدقيقة التجارية التابعة لجوال.

إن قياسات سقوط الأمطار المأخوذة من وصلات الأمواج الدقيقة تم تقديرها من مستوى الإشارة المستقبلة خلال الفترات الماطرة، ويحول هذا التهوين إلى بيانات معدل سقوط الأمطار بإستخدام

نموذج متكامل، تم إستخدام إجراء مشابه لتقدير الرطوبة النسبية بإستخدام نموذج خاص و خوارزميات مع الأخذ بعين الإعتبار أن مستوى الإشارة المستقبلة تم قياسها خلال فترات غير ماطرة، وأخيرا طبق تحليل الإنحدار على بيانات سقوط الأمطار والرطوبة النسبية والإشعاع الشمسي للتنبؤ بنموذج الإشعاع الشمسي.

إن تقديرات كمية الأمطار والرطوبة النسبية المأخوذة من وصلات الأمواج الدقيقة كانت قريبة جدا من التسجيلات المأخوذة من الأرصاد الجوية الفلسطينية بمعامل تحديد يساوي (R^2) 0.95 و 0.70 لسقوط الأمطار والرطوبة النسبية،وكان الإشعاع الشمسي المقاس من النموذج الذي تم تطويره في هذا البحث قريبا جدا من القياسات التي قامت الأرصاد الجوية الفلسطينية بتوفيرها بمعامل تحديد قيمته 0.89.