RADIO FREQUENCY INTERFERENCE (RFI) MAPPING FOR RADIO ASTRONOMY IN PENINSULAR MALAYSIA

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FACULTY OF SCIENCE
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KUALA LUMPUR

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ABSTRACT

Radio Frequency Interference (RFI) Mapping for Radio Astronomy In Peninsular Malaysia

Radio astronomy observations are increasingly contaminated by human-made Radio Frequency Interferences (RFI). If these interferences are continuously present, they will be a major problem for radio astronomers in their observations. The purpose of this study is to create a radio interference intensity distribution map of Peninsular Malaysia using the RFI mapping technique. The Geographical Information System (GIS) was employed as a tool to carry out the mapping technique. A systematic procedure of decision analyses has been proposed by Drobne and Lisec, namely Multi Criteria Decision Analysis (MCDA), in order to process complex and various amounts of data obtained from different sources, and it offers many benefits, such as cost-effective, and efficient and rapid management. The proper decision-making process for selection of local RFI sites requires collection of information of various parameters. The factors that affect the selection process were decided and taken into account. In this study, the parameters involved are: the population density, the presence of telecommunication transmitters (e.g: mobile phone, radio and television), road networks, the rain effect and contour shielding. In this study, we found that the most suitable value for population density was below 150ppl km^{-1}, for the contour effect, we found that type-V contours show the minimum effect of RFI and for road networks we found that 520 m is the minimum distance of RFI effects from vehicles. However, we did not see that the rain effect played an important role in low-frequency windows. This study will benefit radio astronomy research in Malaysia, especially in RFI profiling.

ABSTRAK

Kajian Pemetaan Interferen Radio Frekuensi (RFI) Untuk Radio Astronomi di Semenanjung Malaysia

Pemerhatian radio astronomi semakin terbatas disebabkan oleh ganguan frekuensi radio (RFI) buatan manusia. Jika ganguan ini berterusan, ia bakal memberikan masalah besar kepada ahli astronomi radio dalam penyelidikan mereka. Tujuan kajian ini adalah untuk menyediakan sebuah peta taburan keamatan gangguan frekuensi radio bagi Semenanjung Malaysia dengan menggunakan teknik pemetaan RFI. Sistem Maklumat Geografi (GIS) digunakan sebagai alat dalam teknik pemetaan tersebut. Satu prosedur yang sistematik untuk menganalisis keputusan telah dicadangkan oleh Drobne dan Lisec, iaitu Analisis Keputusan Multi-kriteria (MCDA) untuk menyelesaikan masalah yang kompleks dengan pelbagai data yang diperolehi daripada sumber-sumber yang berbeza dan sangat bermanfaat serta menawarkan kos yang efektif, cekap dan pengurusan yang pantas. Proses membuat keputusan untuk pemilihan ini memerlukan pengumpulan maklumat daripada pelbagai parameter. Faktor-faktor yang mempengaruhi proses pemilihan ini juga diambil kira. Dalam kajian ini, pelbagai faktor atau parameter yang terlibat antaranya adalah kepadatan penduduk, kewujudan pemancar telekomunikasi (seperti telefon bimbit, radio, dan televisyen), rangkaian jalan, jumlah hujan, dan kontur. Hasil kajian mendapati tahap ambang untuk kepadatan penduduk adalah dibawah 150ppl km^{-1}, untuk kesan kontor pula hasil kajian menunjukan jenis-V memberikan kesan RFI yang minimum dan untuk factor rangkaian jalan pula, 520m adalah jarak minimum dari kesan RFI yang disebabkan oleh kenderaan. Walaubagaimanapun untuk kesan hujan tiada sebarang nilai yang boleh memberi kesan kepada gelombang radio pada frekuensi rendah. Kajian ini akan memberi manfaat kepada penyelidikan radio astronomi terutamanya dalam menghasilkan profil RFI di Semenanjung Malaysia.

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In the name of Allah, the most gracious and the most merciful. I would like to thank all people around me for their support. First and foremost, I owe a great deal to my supervisor, Dr. Zamri Zainal Abidin, for his outstanding guidance and thoughtful ideas. Also to my co-supervisor Prof. Dr. Zainol Abidin Ibrahim for his help and advice. His enthusiasm in research and his relentless curiosity, have motivated and inspired me during those years that I had the opportunity to be his student. I would like to appreciate my true love, Dr. Nor Hazmin Sabri, the most understanding, patient and tolerant person for being by my side along this journey and always there to lend me her shoulder to rely on. I am thankful for having such wonderful kids, Muqri Wafa, Irdina Wafa, Rayhana Wafa and also the unforgotten deceased daughter, Syafiqatul Wafa for cheering up my life. Not to forget my helpful and caring parents, Umar and Eshah, for his/her unconditional love, patience and inspiration. An appreciation also goes to my mother-in-law, Naimah for her neverending du'a. I would also like to thank my whole family for their endless support. During the completion of this work, I had the privilege of working with many inspiring colleagues, in particular with Norsiah, Dr. Zety and Ferwani for their helpful discussions and endless assistance, Shaiful, Wan Zul, Khalaf and Zul for always being there for me, Aqma, Suzian, Jazeel and Nabila for their support; their contributions to this work is gratefully acknowledged. I had a very colorful life with them and have always enjoyed the friendly atmosphere of the group (Radio Cosmology Research Lab), and it was a privilege for me to work with such an outstanding group of people. The warmest gratitude goes to several parties; Universiti Sultan Zainal Abidin, Ministry of Higher Education, and University Malaya for their financial support (IPPP-PV025-2011A) and great help. Beyond these specific acknowledgments, I would like to thank all the people involved in this work whether directly or indirectly who gave their support until this work was successfully completed.

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CHAPTER 1

INTRODUCTION

During the last seven decades (since world war II), radio astronomical observations at radio wavelengths have created a new branch of astronomy called radio astronomy. Before that the field of astronomy was mainly performed in the visible wavelengths and was known as optical astronomy. The wavelength window involved in radio and optical astronomy dictated by the earth's atmosphere and ionosphere. These transparent windows are commonly referred to as the radio and optical windows. Radio astronomy can be defined as a subfield of astronomy that studies celestial objects at radio frequencies. It covers a frequency range from a few MHz ($100m$) up to $300GHz$ (or about 1 mm in wavelength). The radio window is often divided into bands by frequency and wavelength: HF (below $30MHz$), VHF ($30-300MHz$), UHF ($300-1000MHz$), microwave ($1000-30000MHz$), millimetre-wave and sub-millimetre-wave (Burke & Graham-Smith, 2010). This is shown in Table 1.1.

Table 1.1: The allocated radio spectrum with frequency range and designation

Frequency Range	Designation	Abbreviation)
3 – 30 kHz	Very Low Frequency	VLF
30 – 300 kHz	Low Frequency	LF
300 – 3000 kHz	Medium Frequency	MF
3 – 30 MHz	High Frequency	HF
30 – 300 MHz	Very High Frequency	VHF
300 – 3000 MHz	Ultra High Frequency	UHF
3 – 30 GHz	Super High Frequency	SHF
30 – 300 GHz	Extremely High Frequency	EHF

Another group of allocations for radio frequency windows can be seen in Table 1.2. Radio astronomy is carried out with a radio antenna and a receiver, called a radio telescope. Radio telescopes in use are either individual (single dishes) or in an array using the techniques of radio interferometry and aperture synthesis. In radio astronomy, atmospheric conditions and the geographical location may affect measurements. As the low frequency, for example, it is determined by the opacity of the atmosphere (the iono-

Table 1.2: The letter band designations as defined by the IEEE

Designation	Frequency Range
L-band	1-2 GHz
S-band	2-4 GHz
C-band	4-8 GHz
X-band	8-12 GHz
Ku-band	12-18 GHz
K-band	18-27 GHz
Ka-band	27-40 GHz
V-band	40-75 GHz
W-band	75-110 GHz

sphere). However, the strong absorption bands of oxygen and water in the lower atmosphere may limit the high-frequency windows (Karttunen, 2006). Early detections of radio waves from an astronomical object were made early in the 20th century. James Clerk Maxwell's equations showed that electromagnetic radiation is related to electricity and magnetism, and may exist at some wavelengths.

Radio astronomy is one of the astronomy research fields which studies various ranges of wavelengths. It is a complementary to optical astronomy for observing terrestrial to celestial objects. In the nineteenth century, several attempts were made to detect radio emission from the Sun have been done by Sir Oliver Lodge (1890), Wilsing & Scheiner (1896) and Charles Nordman (1900) (Debarbat, Lequeux, & Orchiston, 2007). However, the trials could not detect any output due to technical limitations of the instruments used and the system sensitivity was very low (receiver and antenna). The first observations of cosmic radio emission were done by Karl G. Jansky in 1931, when he observed using the wave frequency $20.5MHz$ $(14.6m)$. Karl Jansky discovered a radio source belonging to the object of the Milky Way galaxy (Kraus, 1966). Before Jansky observed the Universe in the 1930s, physicists thought that radio waves could not be observed from astronomical sources. Karl Jansky made the first discovery of astronomical radio emission seriously in the early 1930s. He was an engineer with Bell Telephone Laboratories, where he studied thunderstorm electricity static. By using a large directional antenna of about 100 feet long and 12 feet high, he found a pen and paper recording system kept on recording an analog signal repeating from an unknown origin (Sullivan III, 2009). Starting from this point, research in the field of radio astronomy began to grow for the discovery of celestial radio sources. In the last few decades, radio astronomy has finally revealed which sources are from quasars, masers and pulsars. It has also revealed the structure of the Milky Way and the Galactic Centre, molecular clouds, the creation of stars, and the Cosmic Microwave Background (CMB), which is produced from the oldest photons in the Universe (Wilson, Rohlfs, & Hèuttemeister, 2009).

Since only two groups of electromagnetic waves that can be observed from the surface of the Earth, there are only two possible types of astronomical studies, which are radio astronomy and optical astronomy. Light pollution may limit optical astronomical observations while radio spectrum interference may hinder the study of radio waves. It has been shown that radio and optical observations performed in remote areas can overcome this problem. Optical telescopes, for example, are built on mountains like Mount Mauna Kea in Hawaii. Radio telescopes are also placed in desert regions of Australia and South Africa to reduce the interference that could impair the signals detected by the radio telescopes.

Basic requirements of a radio telescope share some features as those of optical ones. These requirements are high sensitivity, high angular resolution, high dynamic range, and broad spectrum coverage. By high sensitivity, it means it requires a large effective collecting area, which is a common feature of most radio telescopes used in the research forefront. The signals are collected at the Earth's surface of a celestial object at the radio frequency band are very weak. If the received signal is indicated as a force per unit area orthogonal to the direction of the signal, the power flux density (i.e. the flux density in the radio band for the strongest radio source, the Sun) is only about 10^{-20} $\mathrm{Wm^{-2}Hz^{-1}}$. This is considered "quiet" (quiet Sun). In radio astronomy, the flux density uses another smaller unit, the Jansky (Jy); one Jansky equals to 10^{-26} $\mathrm{Wm^{-2}Hz^{-1}}$ (Cheng, 2009).

1.1 RFI Profile in Malaysia

RFI mapping using the Geographical Information System (GIS) is a useful technique to identify the best location of low RFI profile. This technique helps to locate and monitor the spectrum occupation to identify and recognize the most intense sources of interference, especially from terrestrial transmitters. This chapter will show the potential of GIS and Multi-Criteria Decision Analysis (MCDA) in choosing a suitable location for a radio astronomy observatory in Peninsular Malaysia. There are a number of factors such as population density, contoured cover, road networks and raindrop and all of these factors have been determined and grouped into two categories: anthropogenic and geographic criteria. Mapping technique is a tool in recognizing and identifying the most intense sources of interference. Required parameters were generated using data in GIS mode. By using threshold value obtained from the previous chapter, the threshold level is inserted into the GIS database. By using the technique of AHP and MCDA integrated with GIS to generated RFI map. RFI map will be used by astronomer to identify the best location to build radio telescope and radio astronomy observatory. As we mentioned in the previous chapter, there were types of threshold value, predicted and obtained from observation. In this chapter, we will focus more detail on data taken from observation to produce RFI map. We also compared the RFI map using predicted value of the observed data.

1.1.1 The study area : The peninsular of Malaysia

Malaysia has been identified among the best location for radio astronomy studies since there are still many remote areas which are far away from the radio interference sources. Malaysia can be divided into three main regions: Peninsular of Malaysia, Sabah and Sarawak. Sabah and Sarawak also called Borneo. Approximate locations of these three regions are given below. Peninsular: $06°45'$ and $01°02'$ N latitude and $99°40'$ and $104°20'$E longitudes, Sabah : $04°00'$ and $07°00'$ N latitude and $115°20'$ and $119°20'$E longitudes and Sarawak : $00°50'$ and $05°00'$ N latitude and $109°35'$ and $115°40'$E longitudes. In this study, we were focusing on the areas around peninsular Malaysia.

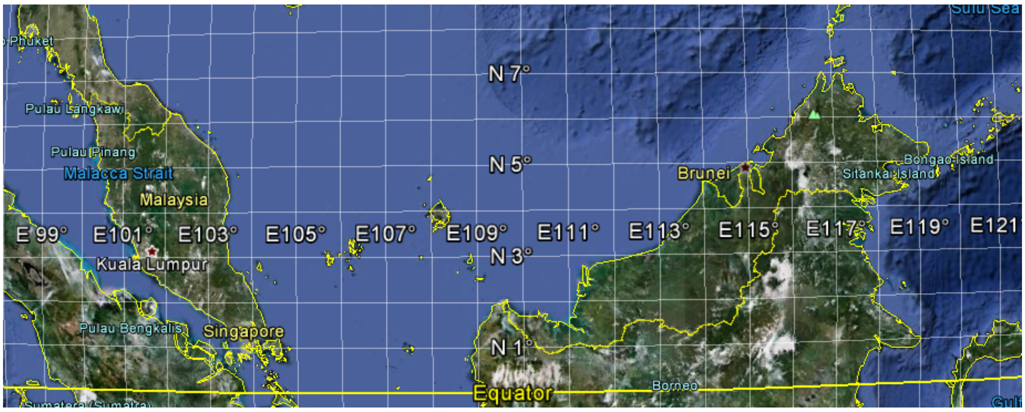


Figure 1.1: Location of study area

The nearby countries of Malaysia are Thailand and Brunei on the north and Singapore and Indonesia on the south (Figure 1.1). The centre of Malaysia is Kuala Lumpur and the population stands at over about 35 million. Peninsular Malaysia borders by Thailand, Indonesia and Singapore however Borneo border through Brunei and Indonesia. In this study, we only focus to the Peninsular of Malaysia. Malaysia is located near the equator and experiences a tropical climate. This country is also free from earthquake and volcano, thus it gives an advantage of location of observatory. The country is generally warm throughout the year with temperatures ranging from 21° to $32^\circ C$ in the lowlands. This can however be as low as $16^\circ C$ in the highlands.

Annual rainfall is from about $164cm - 241cm$ but sometime heavy at $250cm$. On the rainy day, thunder and lightning often accompany the heavy downpour which normally lasts for about an hour or two. The high humidity level which is at 80% throughout the year favors light and sweat absorbent material like cotton for drying season. In general, Malaysia has two distinct seasons. The dry season occurs during the southwest monsoon from May until September. The Northeast monsoon brings the rainy season to the country during mid-November until March. The Peninsular Malaysia is divided into the east coast by the Main Range; known as Banjaran Titiwangsa which runs from the Malaysia- Thailand border in the north to the southern state of Negeri Sembilan. Geographically, East Malaysia is rugged, with a series of mountain range encompassing the interior regions of both states.

1.2 Research Background

Normally, in the area of radio astronomy, astronomers use a very sensitive radio receiver to detect and study the faint radio emissions from space. From the emission detected, almost the entire radio frequency spectrum contains valuable information about the physical nature of the Universe. In ground-based astronomical radio frequency measurement, the spectrum is severely limited by the attenuation that occurs by the Earth's atmosphere as well as man-made radio frequency interference(RFI). The Earth's atmosphere is transparent to electromagnetic radiation from $30MHz$ to $300GHz$. Within that window the biggest spectral limiting factor in radio astronomy is man-made RFI. This radio interference is often greater than the weak celestial radio signals, and as such it can cause serious distortion of the data collected (Gilloire & Sizun, 2009; Fridman & Baan, 2001).

There are many factors that can contribute to the contamination of the spectrum. Among these are human associated with telephones, electronic equipment, transportation systems (such as cars, trains and airplanes), and the use of satellites, telecommunications and other gadgets. Malaysia is not spared from all of the interference mentioned above. There are factors effect the RFI and some of them are population density, rivers, altitude, rainfall, telecommunications transmitters (2G and 3G), radio and television (AM and FM), land use, and road networks as well.

The Asia-Pacific region primarily comprises countries in ITU-R Region 3 from South and East Asia, Oceania and the Pacific islands, while excluding Malaysia. Organizations in the Asia-Pacific region face special challenges in coping with the very diverse cultures and languages of the different nations. Telecommunications in each country are usually administered by a single National Communications Administration, for example the Malaysian Communications And Multimedia Commission (MCMC) which is under the Malaysian Government which manages all spectrum allocations (J. Cohen, Spoelstra, Ambrosini, & van Driel, 2005; Communications & Commision, 2011).

Radio frequency interference study was initiated in the University of Malaya in 2005. The project was known as Radio Frequency Interference Study. This research is needed to examine the pollution spectrum in Malaysia. This study requires a scrutiny 24 hours a day to see the overall interference in certain frequency ranges. During the observations, this interference was monitored and compared with the MCMC book as the main reference. As in optical systems, the spectral pollution not only limits the visibility of radio waves, but it may extinguish the radio source signals. Thus, prevention and legislation are very important in order for observations of the cosmos to be performed (Abidin, Ibrahim, Hamdan, & Asarani, 2006).

At the beginning of the RFI monitoring events, the researcher chose a site at the University of Malaya. After that the study was continued in other areas such as Pulau Langkawi in Kedah and Jelebu in Negeri Sembilan (Abidin, Ibrahim, Ramadzan, & Anuar, 2009; Abidin et al., 2009). The following monitoring events, were performed in many places in Peninsular Malaysia. Radio astronomy is allocated several frequency windows below 2 GHz for observations from ground level (Abidin et al., 2013). These frequencies are listed by the ITU in Article 5 of the Radio Regulations (Refer Appendix D). Recommendation ITU-R RA.769 (A. R. Thompson, 2004) outlines the protection criteria that are necessary to enable radio astronomical observations without interference. Most of the allocated windows are also listed for radio astronomy for our national spectrum manager, monitored by the MCMC (Communications & Commision, 2011). We compare the allocations to our neighbouring country's spectrum manager, namely the Thailand National Broadcasting and Telecommunication Commission (Broadcasting & of Thailand, 2011).

As we know, the frequency allocation reserved for radio astronomy in the L-band is fall between $1400 MHz$ and $1427 MHz$. We found that the nearby frequencies are still very important for radio astronomers on the ground by investigating radio objects (HI sources) around $1300 - 1500 MHz$. In proving the interference from nearby window, we first classified the L-band into groups of four windows, namely:

- Window A ($1400 - 1427 MHz$)
- Window B ($1380 - 1400 MHz$)
- Window C ($1350 - 1380 MHz$)
- Window D ($1300 - 1350 MHz$)

These windows are selected according to their redshifts from a rest frequency for Hydrogen spectral Line at $1420.4057 MHz$ (Kraus, 1966). Radio objects up to ≈ 0.1 or frequency down to 1300 MHz are examined. Since window B has important radio objects within the four windows, this window should also be given to radio astronomy. They are galaxies, spiral galaxies and galaxy clusters. This underlines the significance of window B for radio astronomers on the ground. By investigating the severity of RFI within these windows, we have determined that window B still has significant, consistent RFI. The main RFI sources in the four windows have also been identified. We also found that the department of Civil Aviation of Malaysia is assigned in the frequency range of $1215 - 1427 MHz$, which is transmitted within the four windows and inside the protected frequency for radio astronomy. We also investigated the RFI in the four windows on proposed sites of future radio astronomy observatories in Malaysia and Thailand and

Table 1.3: MCMC and ITU Allocation between 1300-1427 MHz

Windows	Red shift/ Frequency	MCMC/ITU Allocation
A	0-0.01457/ 1400-1427 MHz	Earth Exploration-Satellite (passive), Radio astronomy, Space research (passive), Assigned to Department of Civil Aviation Malaysia (1215-1427MHz)
B	0.01457-0.02927/ 1380-1400 MHz	Radiolocation service, (limited to the military), Fixed services (1381.05 MHz-GPS paging system) and, Mobile services (1391-1400 MHz-wireless medical telemetry services), All three on a primary basis.
C	0.02927-0.05215/ 1350-1380 MHz	Radiolocation
D	0.05215-0.09261/ 1300-1350 MHz	Aeronautical radio navigation, Radiolocation, Radio navigation-Satellite (E-to-S)

found the two best sites as UPSI and Ubon Ratchathani, respectively. It has also been determined that RFI in window B increases with population density(see Table C). The astrophysical importance of these radio objects was also studied, especially in windows A and B. ((Worrall, Biemesderfer, & Barnes, 1992);(Egret, Wenger, & Dubois, 1991)).

By referring to these windows, the average RFI values and peaks were also measured within them as well as in the overall L-band range. These values were then compared to the ITU threshold level. The investigation was also done to determine whether window B has any significant number and types of radio sources coupled with high level of RFI when compared to window A. Additionally, the population density effect on all the four sites was also studied, plus 7 more sites in Malaysia, within the selected windows in order to find out how much RFI is affecting the windows especially in windows A and B.

In Malaysia, we have recently started converting an existing telecommunication antenna into a radio astronomy telescope at L-band, ultimately to be used for Very Long Baseline Interferometer (VLBI) purposes (Abidin et al., 2012). The initial aim is to observe galaxy clusters for the purpose of learning about their dark matter mass (Battye, Davies, & Weller, 2004). We have also started a collaboration with the International Centre for Radio Astronomy Research (ICRAR) based in Perth, Australia, in order to be part of the first ever Asia-Oceania interferometer network involving China, Japan, South Korea, Malaysia and Australia (N. Hashim et al., 2011). The network will initially start with L-band observations of bright radio sources such as Active Galactic Nuclei (AGN).

In this thesis, not only do we monitor, but we also determine the parameters or factors that can affect the RFI, and the trespassing radio frequency from nearby L-Band windows. Two major factors that we emphasized were the terrain or geographical factors, and human activities known as anthropogenic factors. The threshold value of each parameter studied was compared to the threshold that has been specified by the ITU. Details of each factor will be discussed in detail in the results section.

1.3 Problem Statement

Radio astronomy research is complementary to optical astronomy. Radio astronomy has traditionally focussed on the high-frequency spectrum. The low-frequency window is usually used for industrial or commercial activities, and also in military systems. Generally, the antennas used in radio astronomy are passive consumers that can only receive and detect signals, while the industry sectors have active users, which they can also transmit signals as well as receive them. The difference between the two users are active users will radiate a strong radio wave signal while passive users only detect weak radio signals from space. Radio frequency interference studies are still in their infancy in Malaysia, especially in the study of astronomical applications. Early studies of radio interference are very important to create a good atmosphere in the organization of radio observations in the area.

There are many factors that could limit the radio observations. The fastest-growing electronics technology demands the increase of the use of electronics equipment, circuits, telecommunication systems and other electronic reasons. This will lead to high-use of the radio spectrum for commercial uses. Another example is mobile phone usage, which may pose a significant threat to the future of radio astronomy. This problem is exacerbated by the fact that radio telescope receivers are very sensitive, because they are designed and built to detect signals that originate in the far reaches of our Universe.

The study of radio astronomy is limited by the existence of interference produced by human activities. In the meantime, growth in technology has fuelled the development of human pleasure. This leads to the existence of various gadgets to facilitate two-way communication between human beings. These communications involve the use of the spectrum and it may expand, thus further limiting the view of radio astronomy. This technology is good for human life, but not a good thing for radio astronomical observations because it limits our vision of the Universe.

The spectrum of the world's pollution is getting worse as the launch of satellites is almost one hundred per year. The spectral contamination rate in each country is different and for cities and outlying areas. Similarly, in Malaysia, there are many areas which are less or more in the interference spectrum.

Therefore, we need to identify the lowest possible interference or if there is no contamination of the spectrum. A study of radio interference has been conducted, and the reflection spectrum pollution that exists in Peninsular Malaysia has been observed. This study aims to identify the radio spectrum pollution in this region and it can also be seen as one of the early indicators of the locations suitable for radio observatories in Malaysia. However, there is no place in this world free of the spectrum; therefore studies are necessary to find the least interference detected areas. We also managed to understand how the nearby bands usage interferes the radio astronomy frequencies. The study outcome can also be used to determine whether there is any trespassing activity on the radio frequencies of interest. As a result, the allocated band of radio astronomy frequencies shares their window with other applications. One of the examples can be seen in the tool that calculates the distance and navigation used by aircraft using a frequency of $960 - 1400MHz$ which is called Distance Measuring Equipment (DME). This overlaps with the use of radio frequencies in the range of $1400 - 1427MHz$ to detect neutral hydrogen (HI). The radio astronomical window is allocated by the International Astronomical Union (IAU) and is said to be protected from others application, but the neighbourhood frequencies could be red-shifted and enter the radio astronomy windows. This will also interrupt the radio astronomical observations.

1.4 Objectives of the Study

The objectives of this study are:

1. To identify the geographical and anthropogenic factors affect the radio astronomy observations.

2. To measure the level of radio frequency interference (RFIs) and determine the threshold value for each factor.

3. To provide an RFI profile map using GIS and MCDM technique for radio astronomy in Peninsular Malaysia.

1.5 Research Significance

There are several motivations in our research. Firstly, we are interested in investigating $21cm$ emission due to its significant impact on our understanding of the Universe. We know that at present the highest detection of $21cm$ emission is $z = 0.18$. We can speculate that we will be able to detect the onset of the epoch of reionization by using $21cm$ emission which is $z = 17$ (Battye et al., 2004).

The study conducted is significant for the development of radio astronomy in general. It also supports the development of radio astronomy research in Malaysia. Research in this area is important to prepare for the detection and observation of radio signals from outer space. The RFI profile constructed for this study is very important if we are to make a decision about the most suitable potential radio observatory site in Malaysia. We believe the profile can be used to help astronomers plan their observations, around Peninsular Malaysia. In the meantime, we can expand the use of GIS applications in new areas, especially in the field of astronomy, and we can identify factors associated with RFI for radio astronomical observations.

At the end of this study, we will produce an RFI map to profile the interference distribution in peninsular Malaysia. We managed to determine the possible factors affecting the radio signals observed from the Universe and then the threshold values were decided. Based on these values, researchers can verify how the factors affect the observation.

In general, among other significant research we wish to expand radio astronomical research in Malaysia. The RFI research project was not only conducted within Malaysia but also was done in neighbouring countries such as Thailand and Indonesia, so it will have a good impact on research and at the same time we can establish valuable research internationally as long there is collaboration among researchers from different countries. This will help boost the research finding and outcomes. It will bring Malaysia to the same level of achievement in radio astronomy research development which is good for future needs.

We also observed the interference pattern in Peninsular Malaysia to study the potential for radio astronomical research in Malaysia. On the other hand, from this research, we can identify illegal spectrum usage which disturbs radio astronomy windows.

In Malaysia, the space programmes is popular nowadays,which are organized by the Space Agency of Malaysia. Public awareness of the Astronomy field is growing rapidly in conjunction with the astronaut programme, and the launch of several satellites. This will improve the education of space science among children and assist in the development of scientific knowledge in surrounding communities.

1.6 Thesis Organization

The remainder of this thesis is organized as follows:

1. Chapter 2 - Literature Review

   Review on the past reseaches of interference problem in the 0-2800MHz frequency band in general. A brief overview of the L-Band to present the current RFI problem in the band. This chapter describes the types of interference and how they can interfere radio astronomy frequency allocations.

2. Chapter 3 - Radio Astronomy and Radio Frequency Interferences (RFI)

   A brief history of radio astronomy is described along with the radio astronomy role in astronomy and astrophysics field of study. This chapter describes the types of interference and how it can interfere with radio astronomy frequencies. The interference problem like 0-2800MHz frequency band is explained in general. Technical specification of RFI observation and GIS system is presented. We also discuss a brief overview of the current RFI issues.

3. Chapter 4 - Methodology

   This chapter describes the overall process and the method used in this study, how the measurement was done and the protocol used in this study. Specifications of the equipment used in each observation and the technical specifications of the GIS system are also discussed in detail. For RFI events, data were taken over a 24 hour period in both Thailand and Malaysia. This chapter explains the step-by-step procedure and methods used in this study, including the details of instrument setup, instrument testing and RFI mapping.

4. Chapter 5 - Result and Discussion

   This chapter discusses the results from the observations conducted. It describes how each anthropogenic and geographic parameter can affect the RFI in the area of radio astronomy observations. In this chapter the threshold level for each selected parameter is determined. By using the RFI mapping technique, we combined all layers together, both predicted and observation values, to derive the final results and the map is produced.

5. Chapter 6 - Summary and Outlook

   The conclusion, summarizes of the research's contributions and suggests possible future research.

6. Appendixes

CHAPTER 2

LITERATURE REVIEW

Past related studies have been selected and referred to in order to understand this research problem in depth. The reviews are explained in the following subsections.

2.1 L-Band Related Studies

One of the most widely observed spectral lines occur at a wavelength of $21cm$, which has a rest frequency of $1420.4057 MHz$ relating to the neutral atomic Hydrogen Line (HI). Among the important of HI researches include the study of evolution of galaxy and galaxy clusters. Examples of galaxy clusters within the L-band are the Virgo Cluster (at rest frequency 1415 MHz) and the Coma cluster (around 1388 MHz). The galaxy clusters that this study has identified as suitable candidates for our L-band observations are A262 and A569.

Observations of galaxy and galaxy clusters in L-band can lead to research in cosmology as the effect of dark matter and dark energy in our universe can be seen through the observational effect of galaxy rotation curves in individual spiral galaxies (Rubin & Ford Jr, 1970), velocity dispersion distribution by applying the viral theorem (Zwicky, 1937), and gravitational lensing due to foreground objects of galaxy cluster (Einstein, 1933). These techniques can also be used for galaxy cluster (both in low and high redshift). In the large scale of the galaxy cluster, the distribution of the galaxy cluster is varied by the richness of the cluster. For the intermediate clusters, HI is distributed evenly throughout the field of the clusters (since when the galaxies tend to move towards the cluster centre) the phenomenon of HI deficient is more noticeable. This is due to the ram pressure stripping occurred within the galaxies because the hot intra-cluster in the cluster centre sweeping out the HI gas from the galaxies ((Giovanelli & Haynes, 1985);(Bravo-Alfaro, Szomoru, Cayatte, Balkowski, & Sancisi, 1997) and (Chung, Gorkom, Kenney, Crowl, & Vollmer, 2009)). The HI surveys, especially in clusters provide better and concrete understanding about the composition of matter, formation and evolution of the clusters. Another main science that can be studied in the nearby L-band frequencies is to study rotation curves of galaxies such as the spiral and dwarf galaxies.

The evolution of the galaxy can also be studied in the nearby L-band frequencies by comparing Hydrogen Line(HI) and Carbon Monoxide(CO) data. The Atacama Large Millimeter/submillimeter Array (ALMA) telescopes observe the emissions of both CO(1–0) and CO(3–2) in order to see the rotational transitions of the prototypical Seyfert 2 galaxy NGC 1068 (Tsai, Hwang, Matsushita, Baker, & Espada, 2012). AGN plays an important role in the different behaviours of these two CO transition lines.

Applying this study, there is a possibility to investigate the structure of AGNs using the same technique in (Robert C. Kennicutt, 1998) by replacing CO with HI. In an effort to build a radio astronomy observatory operating at L-band, there is a need to do an RFI survey on a few selected sites in Malaysia. There are many factors affecting the chosen of the site for the construction of a radio telescope. We considered some methods for this operation. In China, for example, the RFI study has been performed by Bo Peng research group in the project called Kilometer-square Area Radio Synthesis Telescope (KARST) to identify the interference of frequencies starting from $70MHz$ to $22GHz$. This radio telescope spherical reflector looks like the telescope constructed in Arecibo, USA (Peng et al., 2004). Portuguese researchers, Fonseca and his team have also performed an RFI measurement for several sites in Portugal to identify potential galactic emission mapping experiment (GEM) research. RFI survey was performed in the range $5GHz$ to $10GHz$ band. There are two sites selected in their RFI measurement: California and Castanheira da Serra (Fonseca et al., 2006).

Another RFI measurement study focusing on self-generated RFI around radio telescope was done due to demand of having installation sites with a very quiet radio frequency environment (Ambrosini et al., 2010). Our own previous study of RFI measurement with our own standard practice and procedure detail can be seen in (Abidin et al., 2012).

Compared to the Square Kilometer Array (SKA) RFI protocol, we only focus on a general study of RFI and within the L-band. For the SKA project, they performed a broadband study covering frequencies from $150MHz$ to $22GHz$. The SKA protocol is divided into two broad classes which is Mode 1 (strong RFI) and Mode 2 measurement (weak RFI). They used both types of antennas, which are horizontally and vertically linear polarized (Ambrosini et al., 2003). For our study, it is deemed sufficient to observe a more general level of RFI, which can be seen as a mixed-mode of the SKA-protocol.

2.2 Literature on Population Density

The radio astronomy spectrum is increasingly polluted by intentional and unintentional human-generated RFI. This RFI is mainly produced by humans in dense residential and commercial areas. This RFI is essential if humans are to enjoy such benefits as internet wireless access, satellites (GPS, GLONASS and IRIDIUM), television sets, mobile phones and other basic personal electrical equipment such as laptops, radios, electric heaters and vacuum cleaners. There are also RFI-related basic infrastructures for human life such as transportation vehicles, electricity power line and power stations. It is important to quantify the effects of these RFIs on the radio astronomy spectrum. For example, a mobile phone signal is 10^{12} Jansky (Jy), where 1 Jy is $10^{-32}Wm^{-2}Hz^{-2}$. A typical spectral power flux density for a radio astronomy source is at a level mJy (Ponsonby, 1991). In order to limit RFI, radio telescope sites are usually chosen as far as possible from population centres (Ambrosini et al., 2010). Abidin showed that on average the RFI level of high population density sites increased compared to those in lower dense areas (Abidin et al., 2013).

In rural areas, one need to take into account the absorption, reflection, and scattering of radio energy around objects such as trees and other plants, and their impact in the various directions near the receiving antenna of telecommunication link. The study was done by Trevor in 1940 through miniaturization 500 feet thick patch of forest at 500 and 250 MHz in the summer and in winter. He observed a strong standing wave pattern, with the loss of about $3-4dB$ with vertical than with horizontal Polarization (Longley, 1978). This sudy found that, normally compact, practical and rather extensive forest is opaque to radio signals in the UHF and High Frequency. The study found that radio frequency can be attenuate by plants or trees and this radio signal will be attenuate severe in the dense forest. This factor may contribute to the reduced RFI in radio astronomy observation. It may not good for telecommunication, FM and AM radio, or TV service but it benefit the radio astronomy research activitiies. The dense of the forest is related to low range of the population density, hence, the radio signals from the intentional RFI is lower so the radio astonomical observation is worthy.

In Italy a measurement was done on city streets at both frequencies 146 and 475 MHz. This frequency belongs to mobile transmitters. The study showed that the additional loss in an urban environment depends on the density of the heights of the buildings and on the vertical angle of arrival of the signals. This result is similar to the measurements made by Okumura in Japan, where the attenuation increased about 30 dB when elevation angle was reduced from 4 degrees to zero.

An RFI measurement done by a SKA group in New Zealand at several locations showed that a rural site in Awarua and Kauri Flat ($2.8 ppl/km^2$) has low RFI levels when compared to Auckland City ($2900 ppl/km^2$) and Mt. Wellington (Gulyaev & Banks, 2012). Yet another example is the ALMA, which is located in a remote area of the Atacama Desert with not only a small population density ($18 ppl/km^2$), but also has low absorption by water vapour. Some other radio telescope sites located around the world can be seen in Table 2.1 which includes the population density of those sites (Umar et al., 2012). These radio telescopes observe in protected spectral windows maintained by the ITU and their respective countries' spectrum management arragements (R. J. Cohen, 2003).

There are many radio telescopes in Europe that have $1km$ to $3km$ RQZ radius for their deeper zone, $20km$ to $30km$ for their larger zone and $100km$ for their largest zone (Küçük et al., 2012). To further protect the radio telescopes from interference, for example the Green Bank radio telescopes have restricted rules on the electrical gadgets in their RQZ area. They have an RFI monitoring van in the RQZ. There is an exclusion zone in which the only vehicles allowed are diesels (with no spark plugs) and bicycles. Inhabitants are only allowed to use electronic equipment that produces very high RFI at least $16km$ from the observatory site (A. R. Thompson, 2004). For the future, RQZ is important to be well established since it will protect the radio signal emitted by astronomical sources, from inside Earth radio frequency interference (Umar, Abidin, & Ibrahim, 2013). We identified population density as a major factor in this selection and we set just to quantify the threshold of the population density for our site selection criteria.

Table 2.1: Population density for several main telescopes in the world (Umar et al. 2012).

Location of Radio telescope/names	Diameter (m)	Pop.density(ppl/km^2)
Australia, ASKAP	12	0.94
Australia, Mount Pleasant	26	124.8
Australia, Parkes	64	9.12
China, Delingha	13.7	7.48
Finland, Metsahovi	13.7	103
Ukrain, Crimea	22	77
Ukrain, Grakovo	12	80
Italy, Medina	32	100
Italy, Sardina	64	31
Japan, Nobeyama	45	158.14
New Zealand, Warkworth	12	29.6
South Africa, Indlebe	5	110
South Africa, MeerKAT	13.5	3.1
Russia, Ratan-600	600	18
Russia, RT-7.5	7.5	155
United State, GBT	100	17
United State, VLBA	25	1
United States, VLA	25	1

2.3 Past Studies of the Contour Effect

According to Longley study on telecommunication service, in both urban and suburban areas, increasing the height of the transmitting antenna may have more prominent effect. The field may be associated with increased elevation angle. The total attenuation should depend on the angle of approach of the receiving antenna, and should be greater for the low approach angle because of the long path through the obstacles that interfere longer. One more thing that can be done to increase the impact of the transmitting antenna is that it can be raised above the nearest obstacles, for example, high-rise buildings, which can often shield an entire area (Longley, 1978). This finding shows that the blockage and obstacles may shield the radio transmission from transmitter, thus, the contour factor should play a role in reducing the RFI effect on radio signals from outer space.

Radio telescopes encountering RFI have become a serious problem nowadays (A. R. Thompson, Gergely, & Bout, 1991). There are many factors affecting the site selection for a radio telescope, and the ambient RFI environment is one that is particularly critical (Peng et al., 2004). Radio spectrum pollution is the straying of waves in the electromagnetic spectrum outside their allocations that can cause problems for some activities. This RFI is an increasing problem for radio astronomers due to the spread of electronic devices (mobile phone, smart phone etc.), microwave ovens, digital radio and television transmission, and the like. It corresponds to the same problem that light pollution causes optical astronomy. Radio telescopes also differ widely in how vulnerable they are to RFI. ALMA, for example, observes at such high frequencies, so most forms of RFI do not affect it. The fact of having multiple radio telescopes also allows some RFI to be rejected because unlike astronomical signals it affects the signals differently. Radio telescopes that observe at $1420 MHz$, the (non-red-shifted) HI line, are in a legally-protected region of the spectrum, and so are somewhat protected. The Low Frequency Array (LOFAR), for example, uses a low frequency and is located in Netherlands, so would ordinarily be horribly vulnerable, but the antennas are so low to the ground that they are shielded and protected from much RFI.

An RFI study at two sites in Thailand with different altitudes found different RFI level (Umar, Abidin, Ibrahim, Gasiprong, et al., 2013). One of the ways to prevent RFI wave from propagate to a radio astronomy station is geographic selection of the site's altitude (meaning above an atmospheric inversion layer), temperature, temperature stability, topography, turbulence, air pollution, light pollution, spectrum pollution (for radio astronomy case) and seismic activity (Ardeberg, 1983). Another solution to avoid this interference is to build a radio telescope on a rural site and also consider establishing a Radio Quiet Zone (RQZ). This technique applies to most of the radio observatories in the world (for example ALMA, SKA, ASKAP and others, as shown in Table 2.2). An RQZ is largely determined by transmission losses of interfering signals, which can be divided by the free space loss and diffraction loss. According to Peng, the size of RQZ is determined mainly by the transmission losses rather than effective radiated power (Peng & Han, 2009).

The strength of the RFI can be calculated using this formula:

$$\frac{P_r}{P_t} = \frac{\lambda}{4\pi D^2}. \tag{2.1}$$

where the P_r is the receiver power, P_t the transmitter power, λ the wavelength and D is the distance between the transmitters and the radio telescope. Nakajima shows that there is $-10 dB$ RFI signal absorption from transmitting from hilly areas. This shows that radio telescope surrounded by a complex geological environment has an advantage of less RFI

Table 2.2: Several main features most of telescopes in the world.* Under Construction

Radio telescope	Location	Protected by RQZ	Features
Jorell Bank	Cheshire, England	Yes	-
SRT	Cagliari, Italy	No	Surrounded by moutains
MRO	Murchison, Autralia	Yes	Low population density
Parkes	Parkes, Australia	No (RNZ)	Low population density
ALMA	Chajnantor Plateau, Chile	Yes	High land, driest place
MeerKAT*	Northern Cape, SA	Yes	Low population density
NRAO (Green Bank)	West Virginia, United State	Yes	Surrounded by moutains
Arecibo	Arecibo, Puerto Rico	Yes	Natural valley (bowl-shaped)
GMRT	Pune, India	Yes	-
OVRO	California, US	No	Surrounded by mountains
KARST*	Guizhou, China	-	Bowl-shaped

(Nakajima et al., 2001). Obstacles, such as building and terrain features (mountains, hills and trees), usually will attenuate the signal. A lot of measurements have been made of the effects of geological environment as well as forests, and individual trees on radio propagation. Some of RFI can be combated by distance, topographical shielding and regulatory coordination and protection (Millenaar & Boonstra, 2011).

There are a lot of models that explain how to calculate attenuation: for example the Okumura Hatta and Longley-Rice model (Emerson & Lewis, 2004). When investigating the propagation conditions of radio waves between a relay station (satellite system) at a high altitude and the surface of Earth, the following most important propagation mechanisms should be taken into account: the free space loss and the attenuation by the atmosphere, such as gaseous absorption, cloud and rain attenuation (Pawlowski, 2000). Absorption turns out to be maximum in correspondence with the resonance frequencies of the gas molecules. At high altitude (atmosphere pressure is low) the energy loss is limited to a narrow range in the vicinity of the resonant frequencies. Resonance peaks are not too sharp, and their width, due to Doppler phenomena induced by molecular motion, is small. On the contrary, at low altitudes (where the pressure is higher) the attenuation grows because of the higher gas density and the resonance band spreads over a wider range, due to frequent collisions among the molecules. (Giannetti, Luise, & Reggiannini, 1999).

However, in this study, we provide the threshold value for contour effect (elevation position) and compared to ITU threshold level. Six sites with different contour types, around Cameron Highland in the state of Pahang have been selected for observation. Later in chapter 5, We will discussed in detail, on how the contour type, as well as altitude, will affect the RFI profiles.

2.4 Road Network Related Studies

The advancement of automobiles' system nowadays provides more electronic equipment and devices which will results more electromagnetic interference. The problem caused by the electromagnetic interference (EMI) of electrical systems is therefore becoming increasingly serious. EMI may cause failure or malfunction of the other electrical devices and affect both the safety and reliability of automobiles, which has aroused great concern among automotive manufacturers and designers (Burgett, Massoll, & Uum, 1974; C. Chen, 1999). Thus, international and local institutions have standardized the electromagnetic compatibility (EMC) in order to minimize the effect of interference. For example, the International Special Committee on Radio Interference (CISPR) indicated EMI standards with specifications on the threshold of the automotive electromagnetic radiation for conducting EMI (from $150kHz$ to $30MHz$) and radiated EMI (from $30MHz$ to $1GHz$) (Wang, Zheng, Yu, & Jia, 2012). The same consequense goes to this field of research, where EMI may interrupt the radio signals observed in radio astronomical windows, thus, effecting the radio observation conducted.

Mohammadi (2009), has developed a system for vehicle to assist the driver to control the vehicle to facilitate convenience functionalities entertainment and communication system. This system performs measurement for a wide range of possible frequency for about $500KHz$ to $100MHz$ (Mohammadi et al., 2009). Radar detector using frequency in the $2.5 - 10MHz$, which is in the microwave range (Barker, 1970). Mercury arc rectifier, welders, power lines, radio-frequency helter, fluorescent lights and electric motor, all types are examples of industrial equipment can be detected at range few miles (Myers, 1963). All of these sources of RFI contribute to the attenuation of the signals of interest from astronomical objects. Hence, the radio telescope should be placed away from the vehicular traffic area, especially the road network to reduce the interference effect.

By referring to the project done by Hashim et al. (2013), they managed to analyze and implement the wireless communication; the radio frequency (RF) transmission in the traffic light control system for emergency vehicles. The prototype of this project is using the frequency of $434MHz$ and function with the sequence mode of traffic light when emergency vehicles passing by an intersection and changing the sequence back to the normal sequence before the emergency mode was triggered (N. M. Z. Hashim et al., 2013). Radio interference data have been measured throughout the frequency range of $30Hz$ to $1GHz$ on a power transmission line, automotive traffic, and Radio frequency (RF) stabilized arc welders by many investigators. RF stabilized used frequency below $25MHz$, it can detect within $100feet$ from the source. Above $40MHz$, automotive traffic and lower voltage transmission line are major radio noise source and it can be detected within $50feet$ from the source (Skomal, 1967).

Measurement of motorcar-ignition system peak field strength were made on frequency $40, 60, 100, 180, 240$, and $450MHz$. Propagation was over Long Island ground and the receiving antenna was $35feet$ and $100feet$ from the road (George, 1940).

From all of these studies findings, we can conclude that the road network is one of the factor affecting the radio astronomical observation, where the source of interference originates from the electronic and ignition system of the vehicle running on the road. However, the resultant interference may be avoided by conducting observation far from the road network.

2.5 Past Studies on the Rain Effect

The study of millimetre-wave propagation effect was done in 1956((Stevens & Bony, 2013)), in $35GHz$ band. Radiowave attenuation due to rain was anticipated to be increasingly severe for frequencies higher than about $10GHz$ (Okamura & Oguchi, 2010). From the literature, the effect of raindrop especially below $3GHz$ especially in L-Band not thoroughly investigated since it is well known that rain fall effect on radio wave only at high frequency at above $5GHz$ (Meng, Lee, & Ng, 2009). Attenuation due to rainfall is one of the most important constraints in the performance of line of sight (LOS) microwave links above a certain threshold frequency (Baldotra & Hudiara, 2004; da Silva Mello, Costa, & de Souza, 2002). This frequency threshold, in temperate climates, is about $10GHz$. In tropical and equatorial climate, due to higher rainfall and larger raindrops than in temperate climates, the incidence of rainfall on radio links becomes important for frequencies as low as about $7GHz$ (Mandeep, 2009; Moupfouma, 1984; Moupfouma & Tiffon, 1982).

A comparison one minute rain attenuate statistics at $32.6GHz$ have made using several rain attenuation models such as ITU-R P.530-12, Synthetic storm Technique (SST), Moupfouma, Crane Global and Silva Mello et al (Mandeep, 2009). At $20GHz$ for example the attenuation down to uniform rain rate at $100mm/hour$ is about $10dB/km$. The radio is path defines as the volume of the Fresnel zone and the rain attenuation is assuring proportional to the number of raindrops in this path volume (Buthroff, 1970). At frequency below $60GHz$ the attenuation caused by frozen particles such as snow or ice or ice crystal is very small and may be neglected (Crane, 1980). Thus, the knowledge of raindrop effect on the frequency of operation is necessary, especially to choose or design a reliable telescope system at a particular location. VLBI.

2.6 Research Conducted on Mapping Techniques

In the process of selecting the best site to locate a radio astronomy observatory, it is essential for decision makers to determine the factors influence the radio astronomical observation, and then analyze them. However, the site determination is not as simple as we could imagine, where it involve a complex and detail analysis as various criteria and factors need to be considered. To produce a reference map, which describes the RFI profile in peninsular Malaysia, one need to perform two major steps: site determination using decision analysis, and site testing by doing observation to obtain the RFI level for the particular site determined. A decision analysis involved a systematic procedure to solve the complex problems of MCDA had been proposed (Drobne & Lisec, 2009).

MCDA integrated with GIS technique is a powerful tool with the ability to explain the complex and diverse data obtained from sources which offer many advantages such as cost- effective, an efficient site determination method, and saving time. GIS is a process of gathering, processing and storage (Qian, 2013) as shown in Figure 2.1.

GIS is the best solution to facilitate the decision-making. In 1991 for example, the integration of multi-criteria evaluation technique with GIS in finding suitable sites for the disposal of radioactive waste in the UK (Carver, 1991) has been reported. Spatial multi-criteria decision problems will typically involve a set of clear geographical alternative (events) that the choice of one or more alternatives made with respect to a set of evaluation criteria. There are two important considerations for spatial multicriteria decision analysis:

1. GIS components (for example data acquisition, storage, retrieval, manipulation, and analysis capabilities)

2. the MCDM analysis components (such as, aggregation options spatial data and decision makers' into discrete decision)

These elements are involved in spatial multicriteria analysis as shown in Figure 2.1 (Malczewski, 1999). Figure 2.1 presents an order of three levels, namely intelligence, design and choice to represent the decision-making process. In the intelligence phase, the data acquired, processed, and exploratory data analysis is done the design phase usually involves a formal interaction modelling GIS in order to develop a set of alternative solutions to spatial decision.

Integration systems and functional results of GIS analysis is critical to support the design phase. The selection phase involves choosing a particular alternative from those avail- able. In this phase, the specific decision rules that are used to evaluate and rank the alternatives. The several stages of the decision-making do not necessarily follow a linear path from intelligence, to design and others (Malczewski, 1999).

Various studies which involve site selection for different purposes have been carried out using MCDA, integrated with GIS. As an example, in geology field, GIS is used to predict the possible location for destructive widespread tsunami wave from the epicenter of earthquake, so the tsunami alert system should be activated (Berriman & Groom, 2011). This technique also implemented in other studies, such as, determining the placement of optical astronomy observatory (Koc-San, San, Bakis, Helvaci, & Eker, 2013), improving the efficiency of monitoring system for hazardous and harmful species (H. Chen, Weng, Chi, Qiu, & Zhao, 2013), and flood risk assessment, a case study on China's Huaihe River Basin (Liu, Li, Liu, & yin Cao, 2008). Moreover, the placement of a sanitary landfill in Northern Cyprus (Kara & Doratli, 2012), identifying the location for ecotourism on the island of Qeshm, Iran (Dashti, Monavari, Hosseini, Riazi, & Momeni, 2013), environmental quality monitoring system in Europe (Christophoridis, Bizani, & Fytianos, 2011), and the location determination of an earthquake related to construction activity for residence (Lou, Ding, & Li, 2010).

Another technique relatively important is the Analytical Hierarchy Process (AHP) method. It is used to determine the hierarchy of the criteria, base on their importance or level of influence to the interference. AHP was developed by Saaty in 1980, it is a method of making decisions using pairwise comparisons to smooth parameter weight (Saaty, 1980). Almost similar but different field such as site selection, a combination of GIS and AHP was first used by Rao (Koc-San et al., 2013). This technique is very attractive and suitable for studies, such as the determination of radio astronomy sites. This technique is described in detail in the methodology chapter.

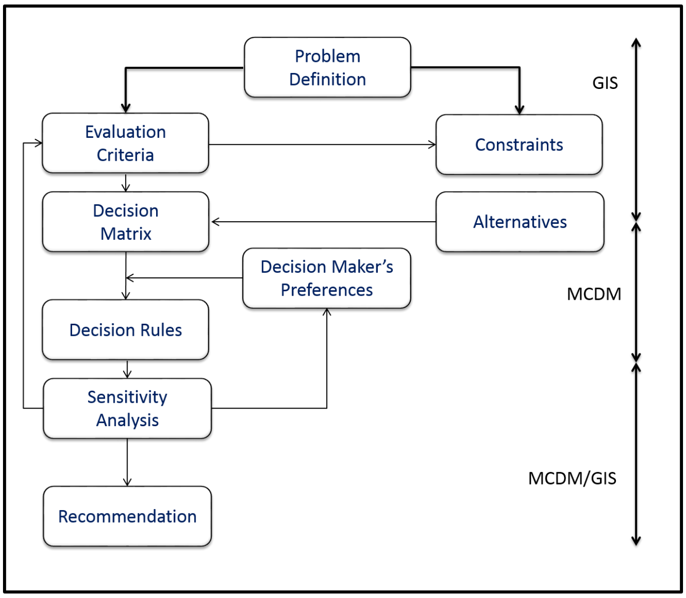


Figure 2.1: MCDA and GIS technique (Malczewski, 1999)

2.7 Summary

The reviews on related studies in RFI parameters presented here are essential to understand the current related problem in radio astronomy field. The information gathered are used to enhance the research and to establish future works.

CHAPTER 3

RADIO ASTRONOMY AND RADIO FREQUENCY INTERFERENCES (RFI)

Astronomy refers to the study of the universe outside the earth, which may involve celestial objects such as stars and interstellar medium. The astronomy field has begun from the ancient time and maintains its importance to expand the knowledge concerning the phenomena from outer space and the birth of the universe.

Radiowaves is a type of electromagnetic radiation which corresponding wave lengths ranging from 1 millimetre to 100 kilometres. The low-energy waves have long wavelengths, and high-energy light waves have short wavelengths. They travel at the speed of light, $c = 2.99 \times 10^8 ms^{-1}$.

Radio astronomy field is very well established, which become popular among researchers around the world. The scope of research involves the study of radio waves from the depth of space. As we know, many objects in the universe, including stars, planets, nebulae, galaxies as well as a wide variety of peculiar, fascinating, and often mysterious objects emit radio waves through naturally occurring processes (Verschuur, 2007).

In astronomy observation, an optical telescope used to detect wavelengths of objects which fall in visible light range, while a radio telescope operates in the radio emission spectrum. Radio telescopes consist of parabolic antennas or normally called the "dish". The observation can be made using a single dish or in a combination of several dishes depends on the purpose of study. An example of a radio telescope is as illustrated in Fig. 3.1. This telescope is located in Warkworth Radio Astronomical Observatory and operated by the Institute of Radio Astronomy and Space Research, Auckland University of Technology, New Zealand.

Radio waves from the celestial objects contain useful information such as the chemical composition of the objects (stars, planets, etc.), the position and the distance of the observed objects, the death of stars and many more. The radio signals are weak because of the distance of the source and attenuation of the intervening medium. Man-made radio waves in the atmosphere are much stronger and they interfere the radio signals from the

Figure 3.1: A 30m Radio Telescope in Warkworth Radio Astronomical Observatory, New Zealand : Picture taken by Mohd Shaiful Rizal Hassan

radio source. Several example of man-made radio waves are telecommunication activities such as mobile phones, walkie-talkie, cordless, and many more. Furthermore, the electrical apparatus, antennas and signal trans- mission (TV, AM, FM etc.) also affecting the cosmic radio signal. Thus, the we need to find the best location, where the level of man-made radio waves is as low as possible for the sitting of radio telescope.

3.1 A Brief History of Radio Astronomy

Back in 1932, Karl Jansky was studying radio telephone service when accidentally had discovered an unknown source interrupting the radio telephone signal. It has been identified to come from outer space at a frequency of $20MHz$. He then tried to track down the source of the radio signal detected and found that it was coming from the centre of the Milky Way galaxy. This unwanted radio source is called RFI. Beginning of this great event, the episodes of radio astronomy studies have been established.

Subsequent researcher active in this field is Grote Reber, known as the founder of radio astronomy, who was interested in Jansky's work and tried to detect the radio signal from the galaxy. Around 1940, he had successfully constructed a parabolic Radio

Telescope all by himself in the backyard of his home to detect the radio source. He had conducted observations and successfully managed to detect radio waves and reported his research findings in a journal.

However, while he was making an observation, he discovered a disturbance in the radio waves detected of which was recognized as a source of RFI. The source is then identified to come from the ignition system of the vehicle (Kraus, 1988). This is the beginning of RFI studies in order to identify the radio sources that may interrupt the radio signal observed.

The radio frequencies from the outer space are actually exist ever since the galaxies were born after the big bang event. Interference also can be defined as "the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, or loss of information which could be extracted in the absence of such unwanted energy", as the Radio Regulations defined by ITU in their Article 1.166 (van Driel & Spoelstra, 2004).

After World War II, advances in radio astronomy accelerated for several reasons. One of them is large numbers of surplus military radar equipment became cheaply available (Hey, 1973). It is well known that the military sector is the primary user of radio signal and its application. Hence, they had owned advanced radio equipment for military purposes and as well as research.

Several instruments affordable at that time are microwave receivers and reflector-type dish antennas. They were perfect tools for radio astronomy research. Also, according to Hey (1973), the requirements of war put a stop to non-war-related research and, when the war ended, there was a need to catch up.

3.2 The Role of Radio Astronomy

From the very beginning of astronomy studies, optical astronomy plays a major role in knowledge seeking of the universe. Time after time, the knowledge is expanding and the research's technologies are advancing. It is the nature of a great researcher to invent the enhanced technology; improves the methodology and explores the new idea. Thus, as the knowledge advanced, they discovered the new technique of observation - radio telescopes - which is managed to receive the radio signals emitted by an extra-terrestrial source.

According to Wilson et al. (2009) in their book, the new astronomical discipline of radio astronomy has been instrumental in changing our view of astronomy. The results required mechanisms for their explanation that differed considerably from those used previously. While the objects studied in the optical wavelength range usually radiate because they are hot and therefore thermal physics is the rule. Most often, in radio astronomy, the radiation has a non-thermal origin, which sometimes called synchrotron radiation, and different physical mechanisms apply (Wilson et al., 2009). The electromagnetic spectrum illustrated in Fig. 3.2, is showing the spectrum characteristic, including the spectrum name with its range of wavelength, and the relevant temperature of bodies emitting the wavelength (Gilloire & Sizun, 2009).

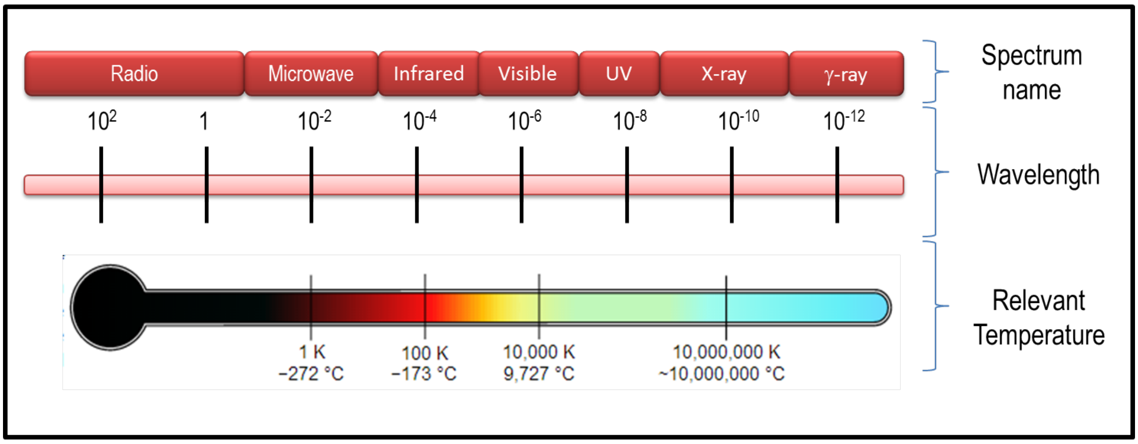


Figure 3.2: The classification of the electromagnetic spectrum (Kraus, 1966)

Different objects emit different wavelengths: some of them can only be detected in certain spectral windows. This is one, among the reasons why we need various observation instruments to meet the suitable spectral windows for every object. Radio astronomy is not developed to replace the optical astronomy, but to complement the existing results. Other than radio windows; ultraviolet, X-Rays and infrared are also available in astronomy observation. Each of the spectral windows requires its own technology.

3.3 Observation Methods in Radio Astronomy

There are several methods used in radio astronomy observation. The observation technique is determined by the purpose of the study. Some of the common purposes are the observation of continuum emission, spectral line determination, solar activity detection, and interferometry. The methods for the first three purposes are using only a single dish antenna, while the latter requires an array of radio telescopes. The detail explanation of these techniques is as follows.

3.3.1 Radio continuum emission

The continuum (nonthermal) observations is the study of long-term variability of the objects of the universe, for example, Quasars, Active Galactic Nuclei (AGN), Pulsar and Supernova remnants. The observation detects emission at all radio wavelengths. Observed emission from radio sources from space is very weak, and thereby they produce little variation in antenna noise temperature (Porko et al., 2011). The antenna temperature contribution come from the cosmic background, the earth's atmosphere and radiation from the earth. In continuum observation, a long integration time and a wide spectral bandwidth are applied to improve the sensitivity of the radio receiver.

The sensitivity of the radio receiver depends on the power level P, the spectral bandwidth Δf_o, and integration time t, which satisfy the equation given by:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_o t}} \tag{3.1}$$

By using Boltzmann's constant k, the power spectral density of the noise can be expressed as

$$\Delta P = k\Delta T \tag{3.2}$$

$$P = kT \tag{3.3}$$

where

$$T = T_A + T_r \tag{3.4}$$

T is the sum of T_A (antenna temperature) and T_r (receiver temperature). Thus, we may also express the sensitivity using the following equation:

$$\Delta T = \frac{T}{\sqrt{f_o t}} \tag{3.5}$$

By referring to the previous explanation, we can see that radio receivers are themselves a strong source of noise and therefore, their effects in the observation need to be identified and try to fix them in order to minimize the disruption.

3.3.2 Spectral line emission

Extremely sensitive radio receivers are used for studying the content of the interstellar medium source in spectral line observation. The first and most studied spectral lines in radio astronomy are the HI-line, it originates from neutral (un-ionised) hydrogen, which can be detected in rest frequency of $1420.4057MHz$. This source is important due to the abundance of molecules and the dynamics of our galaxy (Gilloire & Sizun, 2009). We can measure the velocity of interstellar material from the Doppler shift of the spectral line. A list of important spectral line frequencies in radio astronomy below 3GHz can be found in the appendix.

To name a few related researches in radio astronomy is solar activity study and interferometer. The sun is the greatest sources in the whole frequency spectrum from radio waves to X-rays. In radio astronomy solar observations, including the detection and mapping of all kinds of radio activity in the Sun. The most studied phenomenon such as the radio bursts, gradual bursts, the solar S-component, the 160 min oscillation and coronal mass ejections (Porko et al., 2011). In radio interferometry observations, very high angular resolution radio imaging is accomplished by using various radio telescopes monitoring equal sky objects at the same time. The distances between two or more radio telescopes can be large, for example, in Very Long Baseline Interferometry (VLBI) telescopes can be located on different continents. The data collected in different telescopes and combined as well correlated. By synchronizing data, all geometric delays and errors between the observatory is corrected, with respect to this that will make this technique can reduce the interference. Normally GPS and atomic clock used in synchronizing a data.

3.4 Radio Frequency Interference (RFI)

Light pollution that disturbs optical observation is as an analogy to radio RFI which disturb radio astronomy study. In radio astronomy observation, all signals locating in observatory band does not relate to the radio sources are considered as RFI. The RFI also can be defined as any unwanted signal entering the receiver system (Ekers & Bell, 2000). The RFI is generated by essential human activities such as mobile phones, radio and television broadcasting, radar, satellite and so on. Another unintentional RFI such as microwave oven, power line, electrical equipment, automobile ignition system and many more. The presence of unintentional interference cannot be ignored. We need to monitor and concern since the frequencies transmitted by these electronic gadgets are playing a big role in detrimental the Signal of Interest (SOI). As a result, the growths in human technologies are somewhat harmful to the radio astronomy studies.

Last decade, most of the interference had been occurring and limited number of services, such as microwave, satellite, military and radar systems (Nakajima et al., 2001). To protect this, several frequency bands are allocated and reserved by the International Telecommunication Union (ITU) for radio astronomy used. For example, the band $1400-1427MHz$ is allocated for Hydrogen line (neutral hydrogen) spectral line (21-cm); an allocated band at 1660-1670MHz protects observation for Hydroxyl molecule (OH) maser (18-cm) spectral line and so on. The complete list of radio astronomy windows allocated by ITU below $2.8GHz$ and its purposes have been described in Abidin (Abidin et al., 2013).

Basically, RFI disturbs scientific observation, and it occurs in many ways, for example: (a) spurious, harmonic and inter-modulation products due to nonlinear devices, (b) unwanted signal from out of band and nearby bands (Ambrosini et al., 2010). According to (Keiser, 1979), harmonic and spurious from automobile ignition system transmitted from frequency around 30-1000MHz. Others interference can be seen in appendix F.1. The vehicle ignition system, generated RFI signals at its entertainment radio antenna terminals, have been measured in time and frequency domain. In general, it has been found that the received signals in the time domain are pulsed in nature, and very little correlation has been observed between two or more received pulses. Frequency components of a received pulse have been measured in the range 20 to $1000MHz$ (Ferris & Sengupta, 1980).

Several of the worst sources of radio frequency interference (RFI) for radio astronomy are low earth orbit (LEO) satellites. Unlike ground-based RFI sources, there is no place on earth where we can hide from such satellites. Because of their low orbit, their angular position on the sky can vary faster than 1 degree per second. They broadcast strong signals that sometimes impinge on protected radio astronomical radio bands. For example, a recent study shows that Iridium satellites generate unwanted signals that are $25dB$ above the detrimental level in the 1610.6-1613.8MHz radio astronomy band (Ellingson, Hampson, & Johnson, 2003).

3.5 RFI Sources

Interference can be defined as any unwanted signal that entering the receiver system (Ekers & Bell, 2000). There are several sources of interferences in radio astronomy. They can be whether intentional or unintentional RFI which are listed as the following (Kesteven, 2009).

1. Satellites interference

   Satellites are potentially a serious problem as far as RFI is concerned and some sources always present. However, there are some mitigating factors: their orbits are known so observations could be scheduled to minimize the disruption. In some cases, their frequencies are not critical to an astronomical observation. The signals from satellites such as GPS (1381.05 MHz), GLONASS (1610.6-1613.8 MHz) and IRIDIUM (1612.46 MHz) are alays present and could eliminate the weak radio signal (Nakajima et al., 2001; Gilloire & Sizun, 2009).

2. Aircraft interference

   Transmissions from passing aircraft are a transient problem, and so may not represent a problem when the observations are averaged over an extended period of time. However, their appearance is not readily predicted, which will preclude evasive strategies. The probable increase in mobile and network traffic from aircraft suggest that the problem is likely to get worse.

   A good example of interferences from aircraft which may overlap or nearby the radio astronomy band are shown in Table 3.1. This signal generated by Distance Measuring Equipment (DME) which occupies the frequency between 960 and 1400MHz. This range was used by aircraft for measuring distance and navigation as well.

Meanwhile radio astronomy services study in this range or nearby are in- tergalactic spectral line and neutral hydrogen line emission detected in frequency band from 1370-1427 MHz (Dunn, 2008).

Table 3.1: Typical frequency used by aircraft (Dunn, 2008)

Services	Ground to air (MHz)	Air to ground (MHz)
Radar transponder	1030	1090
DME	962-1024	1025-1150
DME	1151-1213	1025-1150

3. Ground-based interference

   This RFI could be the reflection of ground-based transmissions, for example reflecting windmills. The RFI from ground-based installations tracks the population density, which is why observatories tend to be located in remote sites. This topic will be discussed in the next section.

4. Observatory-based interference

   As far as the radio telescope is concerned, the establishment of its observatory has a down-side: it provides a focus for high-end computing and high-speed electronics, along with an increase of more pedestrian sources of RFI such as faulty appliances and faulty contactors. Ensuring that the observatory itself is radio-quiet is a full-time task.

In general, the observation is based on long-term (within hours) effect. This means that the episodes of transient RFI manageable when taken in view of the average value but will also contain short calibration observations. An unfortunate coincidence of calibration observations with transient outbursts RFI can compromise the calibration and all observations that depend on it. This makes RFI costs can be high. It is a priority to eliminate RFI in astronomy; predicting the occurrence of RFI is a poor second choice, but it is better than complete ignorance. There are two types of radio interference which are intentional and unintentional as shown in Table 3.2.

Table 3.2: RFI environment types

Types of RFI	Intentional	Unintentional
1.	TV and FM	Power line
2.	Police wireless communication	TV boosters
3.	Air traffic control	Industries
4.	Mobile communication	Electronic instruments, computers
5.	Air force control	Networking devices
6.	-	Automobile ignition system

3.5.1 Spectrum management

Spectrum management as a means to cope with the task of competing radio services and systems within a finite radio frequency spectrum, such as to allocate frequency bands or to define the limits of RFI. Almost 100 satellites launched per year and there are always new gadgets are produced applications and electronic equipment is growing exponentially. If we can control or reduce electromagnetic smog, this is some wise enough. However, this mission is impossible because money is a priority to the world today.

What can commit by members of astronomy union is to provide education and awareness on the importance of the astronomy studies to the world. As we know that, only 2% below 50 GHz radio frequencies allocated to radio astronomy research and activity. The rest of the spectrum have been allocated for other purposes such as telecommunication, radio and TV transmission, and many more, which are sometimes interfere the radio astronomical observation. However, we are appreciate to the international union for sparing the hydrogen lines (HI) frequency for radio astronomy study and remains protected for astronomers to further study this spectrum and the Universe.

3.5.2 Radio interference free zones

Nowadays the use of the electromagnetic spectrum for human technology has increased enormously. The protection of radio fequency allocation for radio astronomy purposes is critical due to the commercial demands. Moreover, the site determination of the lowest RFI detected for ground base radio observatory is become complicated. In order to optimize the protection from RFI, several enforcement need to be done which involves the spectrum regulation and government policies. One of the ideas is escaping from radio spectrum pollution; it is the same technique used in optical astronomy field where we can locate the observatories in the hidden and isolated areas which is specialized for radio astronomy purposes. This is what we called Radio Quiet Zones (RQZ).

Radio astronomical observatories, especially those equipped with large radio telescopes, establish a radio frequency protect zone in their neighbourhood. We can see that before the SKA creates a RQZ for it stations. RQZ divided in three parts, its core, central arrays and outer station respectively (Peng, 2010). The general configuration of the RQZ includes two structural components to achieve the required radio quietness at the observation area (array stations), there are exclusion zone (EZ) and coordination zones (CZ). Exclusion zones mean, within which all radiations are forbidden. Meanwhile the coordination zones mean the Power Flux Density (PFD) levels in the core area and the remote locations and the transmission power determine the coordination distances by appropriate propagation studies (ska report). These protection levels are based on ITU-R Recommendation RA.769-2 (J. Cohen, Spoelstra, & Ambrosini, 2005), which describing the protection criteria for radio astronomy observations in the bands allocated to the Radio Astronomy Service. Station radial distance divides three regions, namely central, intermediate and remote region representative by $5km$, between $5-200km$ and above $200km$ (Ambrosini et al., 2003).

As an example, the LOFAR Telescope Array, which is a multi-purpose low frequency sensor array such requires relatively modest RFI environments. Primary application is astronomy Telescope at low frequencies between 10 and $240MHz$. For LOFAR astronomy application, it consists of multiple interferometric dipole antenna stations distributed throughout the Netherlands and some countries of Europe. All these stations have movable parts. This is intended for all-sky coverage effectively of polished components, giving LOFAR-of-field is very large. There are two different types of antennas, Low Band Antenna (LBA), which operates between 10 and $90MHz$ and High Band Antenna (HBA), which operates between 110 and $250MHz$. The tentacles are organized at multiple stations aperture. Therefore, good atmospheric environment (RFI) is required. Here are the site requirements environment for practical reasons have been made and list of requirements for LOFAR stations (Bentum, Boonstra, & Millenaar, 2010):

1. Fairly isolated

2. No power lines within 2 km

3. No highway within 500 meters

4. No urban development within 500 meters

5. No railroad, tramway within 2 km

6. No windmills within 2 km

7. No forest or high trees within 100 meter. At south no trees within 500 meter

8. No other radio interference sources in the neighborhood

9. A location in or at the fringe of a nature reserve is favorable but requires good communication with environmentalists and nature organizations.

However, the RFI will still be present, even if these requirements are fulfilled. Base on the ITU, the radio interference noise level is basically defined as a value of $10dB$ less than the radio telescope noise. Ammendment has been recorded to the ITU Radio Regulation on the protection of the Radio Astronomy Services (RAS) in the bands 150.05 - 153 MHz, 322 - 328.6 MHz, 406.1 - 410 MHz and 608 - 614 MHz from harmful interference according to the threshold levels listed in Recommendation ITU-R RA.769 (J. Cohen, Spoelstra, Ambrosini, & van Driel, 2005). In 1956 the first RQZ zone was set up in the USA, when the state of West Virginia approved the Radio Astronomy Zoning Act, enacting zoning restrictions governing the use of electrical equipment and the emanation of electrical impulses there from within about ten mile radius of any radio astronomy facility in the state of West Virginia. All radio telescopes around the world use this to protect from other sources of interference for example National Radio Astronomical Observatory (NRAO) in Green Bank, and Jodrell Bank Observatory (JBO) in Manchester. The latest project is SKA which also apply RQZ in order to maintain low interferences in that area. Midwest RQZ for example, there are no residents within $30km$ and only a few within $70km$. SKA project demand difference RQZs for its core, centre arrays and outer stations respectively (Peng & Han, 2009).

An RQZ can be set up locally by the state or national law to limit housing and industrial growths in the neighbourhood of an observatory and also to restrict the use of electrical equipment. In order to manage this entire spectrum, The ITU was established to manage this entire spectrum. It has a monitoring protection from licensed radio transmitters or unwanted emissions and so on (J. Cohen, Spoelstra, & Ambrosini, 2005). There are two types of RQZ could be considered: the real RQZ and the reasonable RQZ. Based on the map generated by the GIS, there are no places in Peninsular of Malaysia, which are far away from telecommunication transmitters, for example 200 *km* and above. So that in Malaysia, the reasonable RQZ only can be applied in this situation. The reasonable RQZ radius are 1 to 3 *km* for the central region, intermediate region is about 20 *km* while 30 *km* for the remote region.

3.6 Radio Frequency Allocation in Malaysia

Since radio astronomical observation is so susceptible to man-made RFI, MCMC has arranged several frequency bands reserved for radio astronomy use only. A list of these frequency bands is shown in Appendix C. The protection of these frequency bands is effective around the world to ensure joint observation sessions like VLBI between different countries. ITU is the radio frequency spectrum controlling authority worldwide. The fundamentals of the protection criteria for the radio astronomical measurements can be found in ITU's Recommendation ITU-R RA.769-2. Protection criteria used for radio astronomical measurements.

CHAPTER 4

METHODOLOGY

This chapter discuss the methodology of this study. The overall method used is as shown in Fig. 4.1 and the detail explanation of each step is described in the sections throughout this chapter.

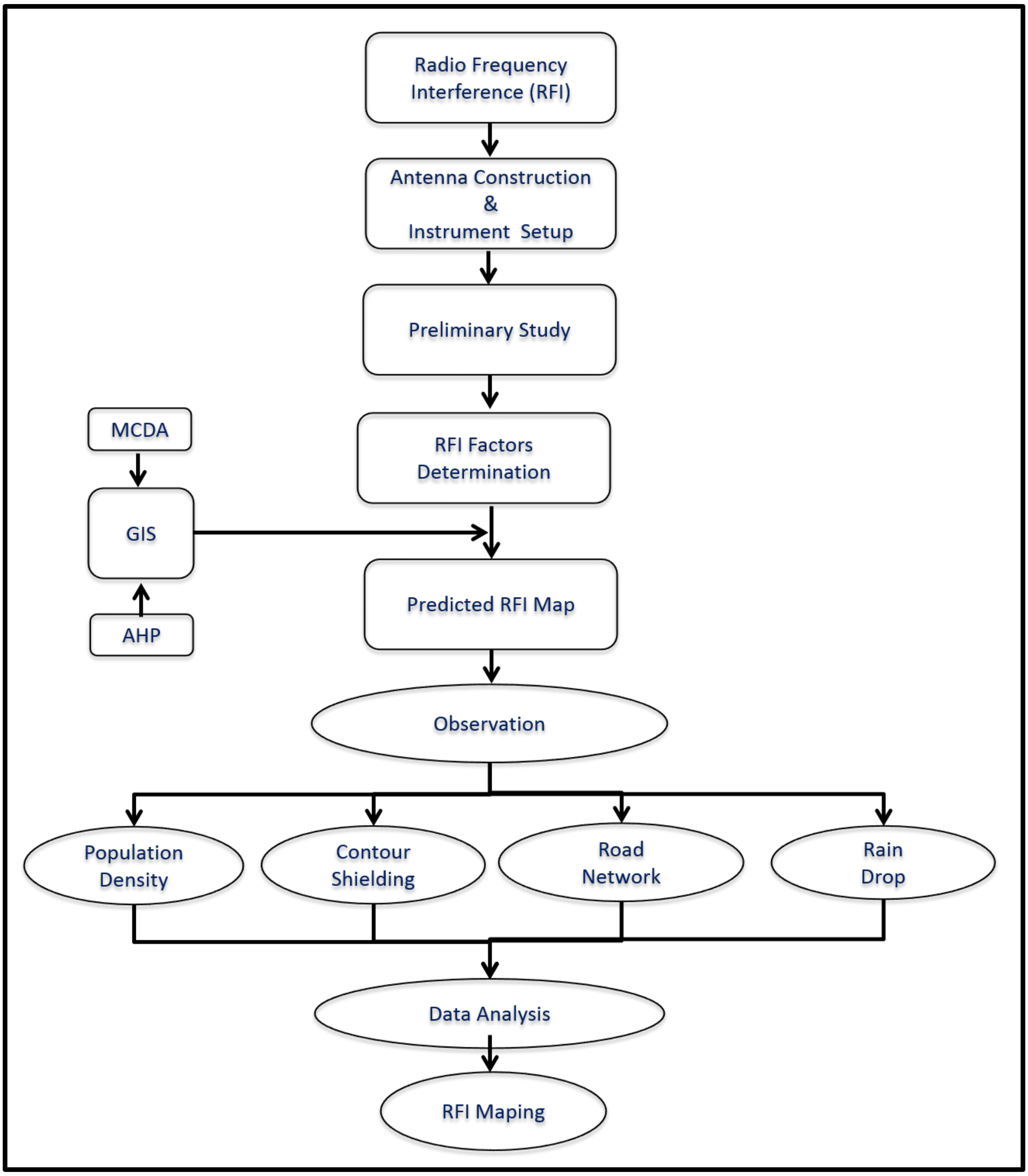


Figure 4.1: The overall research methodology

The flowchart in Fig. 4.1 explained a step by step process of work done in this research. In this study, the antenna construction takes the first step and followed by the instrument setup. The antenna diagram and instrument details will be explained in the following antenna construction and instrument setup section. The L-band study was conducted to determine the range of frequencies where the RFI exists in radio astronomy window and nearby to select and determine the appropriate frequencies of interest to be studied.

Then the parameters involve in RFI measurement were identified and analysed using Multi-Criteria Decision Analysis (MCDA) and Analytical Hierarchy Process (AHP) technique integrated with GIS. This step is essential as the outcome is the predicted RFI map of peninsular Malaysia as a reference to begin the observation stage. We have classified eleven parameters in predicting the map; however, due to the time constraint, we managed to perform the observation of four factors which are population density, contour shielding, road network and rainfall.

The observation begins once the parameters have been defined. The different site is chosen to fulfil the criteria of each parameter. The data analysis takes place when the observation is done completely. We use Microsoft Excel to combine the data and plot the graphs. The RFI mapping stage is then being carried out by GIS once again using the observed data collected to produce the actual map so that the RFI characteristics can be illustrated.

The detailed explanation for each of the steps will be discussed in the next sections.

4.1 Antenna Construction and Instrument Setup

To observe the RFI, Ambrosini et al. (2003) reported that the discone antenna can be used for SKA project to identify the low or high RFI. The discone has a pattern which is uniform in azimuth, with a maximum gain slightly below the horizon and nulls toward the zenith and nadir ((Ellingson, 2002)). These antennas are primarily vertically polarized with uniform azimuthal directivity. The discone antenna was used as a solution in order to identify surrounding RFI near the observation site. Material for discone may be made from solid metal (normally copper is used). Discone antenna very suitable for small indoor Very High Frequency (VHF) antenna such as WIFI.

In this study, we have constructed a copper discone which detect radio frequencies from $0-2800MHz$ (optimize at $1420MHz$). The antenna design and the specified dimensions of the discone is as shown in Fig.4.2.

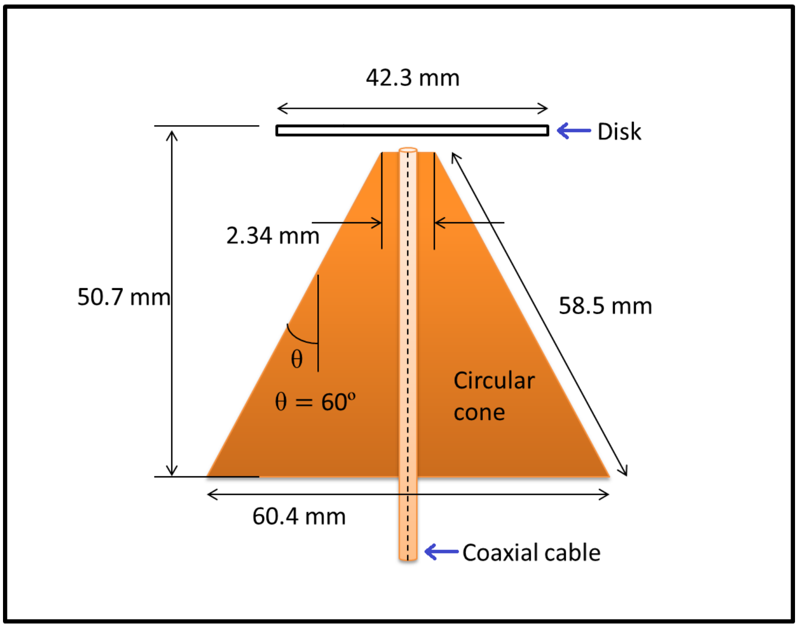


Figure 4.2: The diagram and specification used in making the discone antenna.

The discone constructed for the observations in this study is shown in Fig.4.3(a). A discone antenna has three important components:

1. the disk
2. the cone
3. the insulator

The disk should have an overall diameter of 0.7 times quarter wave length of antenna minimum frequency. The antenna's feed point is at the centre of the disc. A 50-ohm coaxial cable with connector is connected to the cone. The length of the cone should be a quarter wavelength of antenna minimum operating frequency.

The discone is used as an antenna in the observation to detect radio frequency from the environment. The desired radio frequency window to be studied is L-Band window. The complete instrument setup for an observation is shown in Fig.4.4. The discone is attached to the $1.4GHz$ Low Noise Amplifier (LNA) as shown in Fig.4.3(b) with $-28dB$ gain/ $0.34dB$ noise frequency, to amplify the signal so the peaks are easier to read. They are then connected to the spectrum analyser to capture the RFI data at a certain time

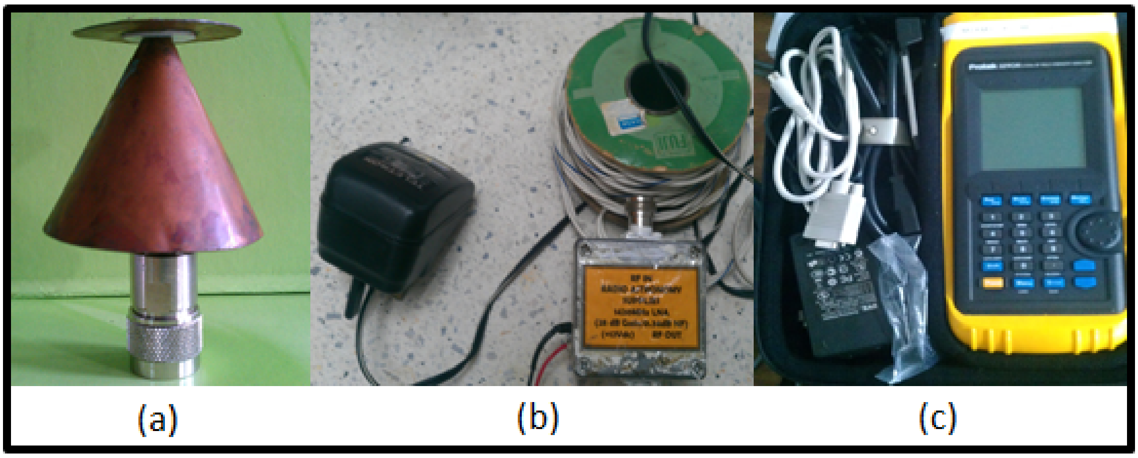


Figure 4.3: (a) The discone antenna (b) The LNA and (c) The spectrum analyser, utilized in this study

before the data is sent to the computer to be displayed and analysed. The spectrum analyser (Fig.4.3(c)) utilized in this study is a high quality handheld style RF Field Strength Analyser with wide band reception with specification as follows:

- Model: Protek 3290N
- Frequency Range: $100KHz$ to $2.9GHz$
- Resolution: $3.1255kHz$
- Modulation: $180kHz$(W-FM), $12.5kHz$(N-FM)
- Measurement Range: $-20dBm$ to -$100dBm$
- Average Noise Level: $-100dBm$
- Weight: $1.4lbs$
- Size: 9.5" H x 4.0" W x 1.8" D

To make sure the antenna could work well in the L-band window, we have done the instrument testing of the discone antenna used in this study. It shows that the discone antenna is sensitive to the below frequency of $3GHz$, which is within the L-band window. For the calibration measurement, the discone antenna constructed with known radiation efficiency have been tested to identify the base line of the noise spectrum. The antenna was connected to the spectrum analyser, and the spectrum reading has been obtained from

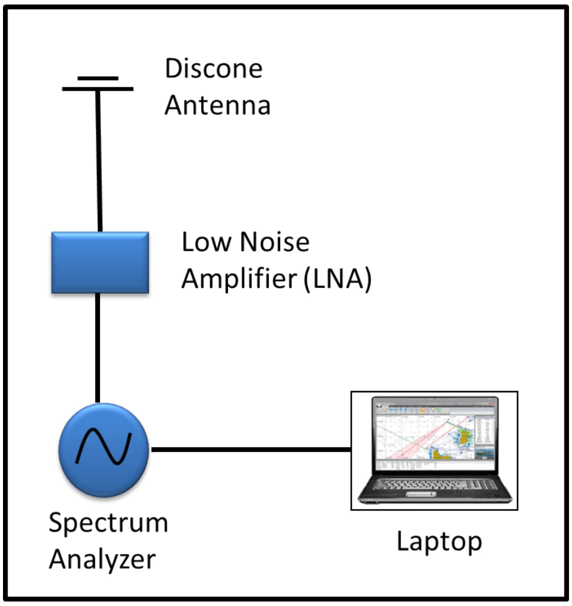


Figure 4.4: The instrument setup for observation work

inside the Faraday Cage room as illustrated in Figure 4.5. This room is located at Radio Cosmology Research Lab, University Malaya. The Faraday Cage room is designed to avoid the radio spectrum emission from the environment. Thus, the spectrum reading is solely come from the antenna noise, which is -99.7dBm.

4.2 Preliminary Study

Before we move to the main objective of this study (the RFI mapping), we first reviewed the frequency allocation reserved for radio astronomy in the range of $1300MHz-1500MHz$ which is located inside the L-band frequency. L-Band in chosen as a window of interest since this window is essential to study the Universe. We are focusing on several spectral lines within the L-Band window which are:

1. Hydrogen Line, HI ($1420.4MHz$)
2. Hydroxyl-1 Line, OH-1 ($1612.2MHz$)
3. Hydroxyl-2 Line, OH-2 ($1720.5MHz$)

We also interested in Deuterium Line, DI ($327.3MHz$), since it is also one of the important spectrum in radio astronomy study.

As a pre-survey study, we identified that there are several signals that originate from human-generated interference affecting L-band and nearby frequencies' observations, for

Figure 4.5: Sensitivity of the antenna in the L-Band

example, closed-circuit TV link (at $1393 MHz$), GPS navigation satellite ($1381 MHz$) and point to point radio link (narrowband signal between $1385 MHz$ and $1389 MHz$) as shown in Cohen (2003). The harmful Interference from GPS to allocate 1381.05MHz to the L3 carrier of the satellite is not of continuous use, but when it is switched on, it is devastating to the radio astronomy service (Ponsonby, 1991). One of the suggestions to mitigate interference from all electronic equipment and computers in use around the observatory is to put them in a shielding room or Faraday cage. There are several techniques recommended to suppress interference, for example, blanking, adaptive cancelling of RFI and estimating and subtracting methods (Gilloire & Sizun, 2009). The use of the interferometer techniques such as in the VLBI networks can also cancel out major RFI peaks since the interferometers are more robust against RFI than single antennas (A. Thompson,

Table 4.1: Population densities of the seven RFI monitoring sites in Malaysia and the two sites in Thailand

* Observation sites in Thailand.

Sites	Latitude/Longitude	Population density (ppl/km2)
DGN	04^o 46’20.90”/103^o 24’ 18.17”	58
TPH	04^o 10’ 44.52”/101^o 11’ 57.45”	70
TI	03^o 59’ 44.50”/101^o 02’ 37.76”	133
SPG	02^o 57’ 7.35”/101^o 34’56.67”	248
GBK	03^o 13’43.92”/101^o 42’ 39.51”	1085
PJ	03^o 02’ 17.03”/101^o 38’19.91”	3012
KL	03^o 7’ 23.58”/101^o 39’ 10.29”	7089
UBON	15^o 39’ 27.33”/105^o30’ 3.39”	111.5 *
CM	18^o 29.288’/ 98^o32.925”	91.5 *

1982). Inter-modulation products are a problem for VLBI. A good approach to overcome this problem is to adopt the system with cryogenic filters in the LNA system (Tuccari et al., 2005).

In Malaysia, the selected sites include University of Malaya (UM) in Kuala Lumpur and Universiti Pendidikan Sultan Idris (UPSI) in Perak. In Thailand the chosen sites are Doi Inthanon in Chiang Mai (CM) and Pha Tam in Ubon Ratchatani (UB). These four sites were chosen due to the recently proposed plan to build a radio telescope on them. UM is located about 10 km from the city of Kuala Lumpur, while UPSI is about 100 km from Kuala Lumpur and also 6 km from the suburban city of Tanjung Malim. The UPSI site is conveniently shielded by several mountains around its area at around 20 km radius. The population density of the UM and UPSI sites is 7089 ppl/km^2 and 70 ppl/km^2, respectively. In Thailand, the candidate sites are selected by the National Astronomical Research Institute of Thailand (NARIT). Both sites, CM and UB are selected mainly due to their low population densities (refer Table 4.1), high altitude and shielding by terrain areas. The population density of CM and UB is 91.5 ppl/km^2 and 111.5 ppl/km^2, respectively. CM site is located about 100 km from the city of Chiang Mai and at about 1050 *m* altitude. UB is located near the border of Thailand and Laos. It is also a remote area and located 80 km from the Ubon city and is at about 150 m in altitude. This site is located in the national reserve forest.

4.2.1 Measurement procedure/protocol

Measurement protocol are divided into two classes: Mode 1 and Mode 2.

1. Mode 1

   This mode is applied for the measurement of strong RFI signal. The protocol specified that flux at horizon (zero elevation), S_{0h}. Of the RFI signal which is necessary to induce a signal of $-100dBm$ at the terminal of antenna. S_{0h} formula accordingly calculated from Eq. 4.1,

   $$S_{0h} = \frac{4\pi k T_{sys} f^2}{c^2 \varepsilon} \tag{4.1}$$

   and the power induces at the terminal can be determined from,

   $$P_s = S_{0h} B_s \varepsilon c^2 \tag{4.2}$$

   and the total time taken to perform measurement is calculated by using the following equation,

   $$t_{total} = \frac{(f_1 - f_2) t_d Reps}{RBW} \tag{4.3}$$

   where f_1 and f_2 are upper and lower frequency, t_d is dwell time, $Reps$ is number of measurement cycles and RBW is resolution bandwidth.

2. Mode 2

   This mode is applied for the measurement of weak RFI signals. This mode of measurement is define as a sensitive level. This mode could give bad effect to the detection of cosmic signal. Our analysis used both in mode 1 and mode 2.

4.3 The Predicted RFI Map

In order to construct the radio astronomy observatory such as SKA project, there are several key factors which need to consider. It is governed by

1. the cost of building telescope (dish), and

2. identification and location of RFI free site.

The chosen site for a radio astronomy observatory is very important in order to find a site with low level of RFI. The aim of this stage is to produce the predicted map illustrating the profile of RFI in peninsular Malaysia using GIS technique. This may also benefit the selection of the best possible candidate for radio astronomical observation sites. The study was implemented in the Peninsular of Malaysia, which expected is suitable for astronomical site observatory facilities with its appropriate climate properties and weather conditions. Eleven factors were considered, splitting into two categories; geographical factor and anthropogenic factor. The geographical factors which have taken into account are:

1. Slope of the hill
2. Rainfall
3. River

The anthropogenic factors which also means the human made RFI is the biggest contributor of interference sources. They are:

1. Population density
2. Road network
3. Land used (e.g: commercial, plantation, industry etc.)
4. Second-generation of mobile communication(2G)
5. Third-generation of mobile communication(3G)
6. Amplitude modulation (AM) radio
7. Frequency modulation (FM) radio
8. Television (TV) transmitters

All of these factors are essential to create the RFI profile in peninsular Malaysia. They are defined based on the study done by Koc-San et al. where the astronomical observatory site selection in Antalya province, Turkey was conducted by the team (Koc-San et

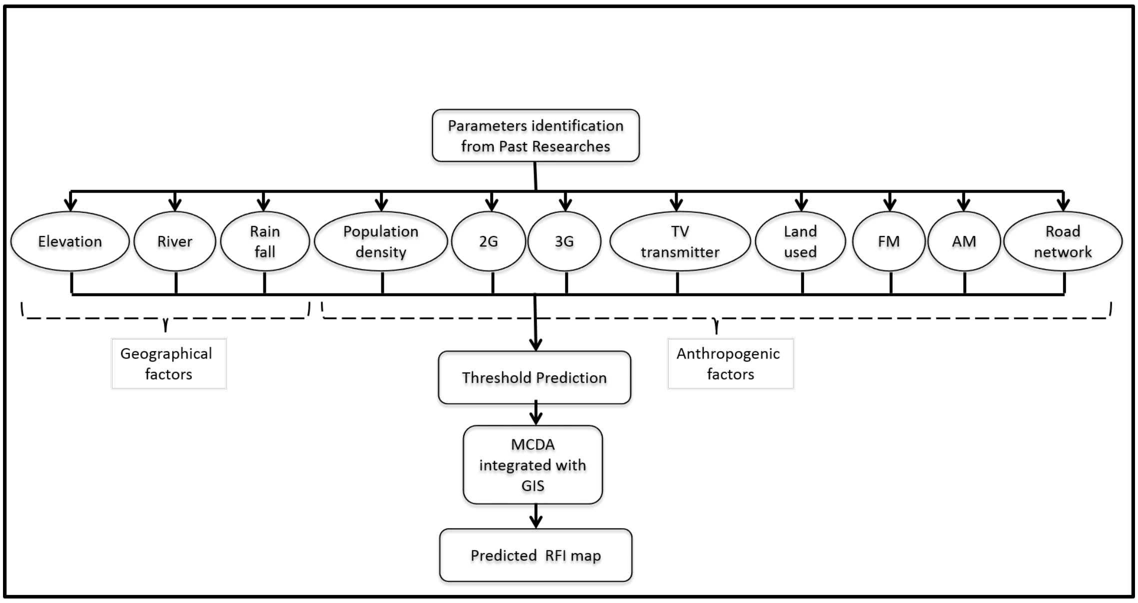


Figure 4.6: The preparation of a predicted RFI profile in peninsular Malaysia

al., 2013). They used MCDA method integrated with GIS and remote sensing technologies. However, they have classified the factors determined into 3 categories which are meteorological, geographical and anthropogenic criteria. The factors they have reviewed are cloud cover, precipitable water, earthquake zones, geology, landslide inventory, active fault lines, Digital Elevation Model, city lights, mining activities, settlement areas and roads.

4.3.1 Geographical Information Systems (GIS)

A GIS is a decision aid tool that can be applied in many ways to many problems. We can print out some potential applications as: transportation, political activities, water resources, environment, security and public lighting. GIS is an automatic system that merges data from various sources. It collects, organizes, stores, manages, analyzes and visualizes information geographically localized to enrich the knowledge of the addressed space (Faiz & Krichen, 2012).

In this section, the focus will be on how the selection of parameter RFI identified and it is applied to the GIS database. In summary, a number of parameters related to the RFI were identified, the threshold levels for each parameter are taken and entered into the GIS system. The system uses AHP method that helps in the selection of the parameter weights. All of the parameters are then combined layer by layer to produce a map that displays the RFI profiles in Peninsular of Malaysia. RFI map aims to assist astronomers in the site selection for radio astronomy observation.

GIS briefly focus on two parts, technology and problem solving. By definition technology, it serves as a set of tools for input, storage, retrieval, manipulation, analysis and output of spatial data. On the other hand, in terms of problem solving GIS can do various tasks for spatial and attribute data. GIS can also be integrated with other technologies such as geography and remote sensing, global positioning systems and computer-aided systems. Besides, it also could support system for decision-making in which it can assimilate the spatial reference data in a problem solving environment. Four main components of GIS data input, data storage and management, data manipulation and data output. Systems AHP also be referred as a weighted system to determine each parameter based on the importance of certain values.

4.3.2 Multi-Criteria Decision Analysis (MCDA)

Multi-criteria decision analysis (MCDA) is a popular and useful technique that explicitly considers multiple criteria in decision-making environments. If one need to make a choice which deal with multiple conflicting criteria, he has to consider the factors that may influence or affect the final result. He has also need to evaluate the ability of various activities and then the corresponding attributes or indicators are identified to fulfil a given objective. The indicators are often defined based on scores achieved, rank and weightage. This method is capable to support decision makers facing such problems.

In this study, the MCDA technique is the best, well known structured approach to be practiced. As a result, the region in all around peninsular Malaysia will be ranked out from the lowest RFI(the best site) to the highest RFI(the most inappropriate place to consider for siting of radio telescope).

The step-by-step process of the prediction of the RFI map is shown in Fig.4.6. Once the parameters have been set up, the Multi-Criteria Decision Analysis(MCDA) plays the role to produce the predicted RFI map. In this analysis, three main step are involved: determine the threshold value for each of the parameters, combine the data to produce a map for each parameter, and perform an Analytical Hierarchy Process(AHP) method. The MCDA integrated with the GIS process is illustrated in Fig.4.7.

The threshold value is determined based on random assumptions so the map of RFI

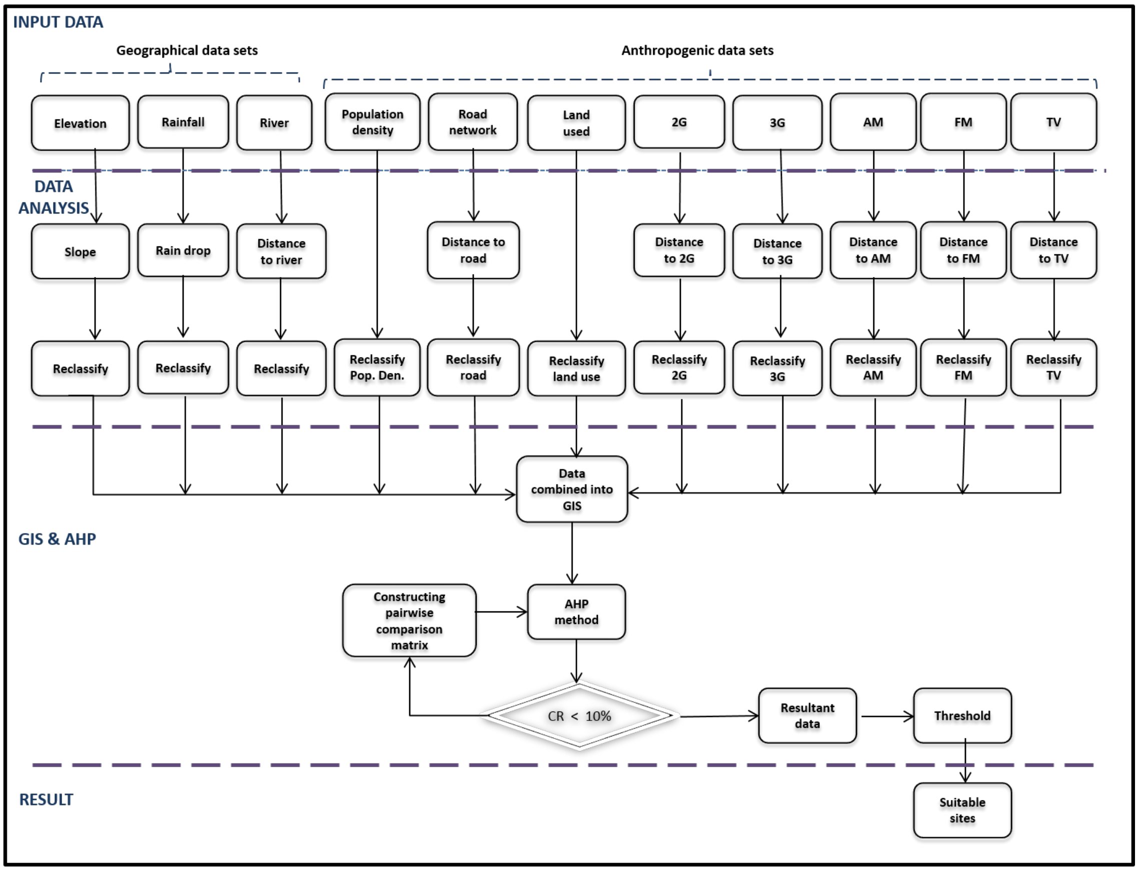


Figure 4.7: The process of MCDA integrated with GIS.

can be predicted. The eleven criteria are stored as a layer each into a GIS. The layers are then evaluated using AHP method to determine the weightage for each factor. Thus, the layers are combined and RFI map is produced to be utilized as a reference map for further study.

4.3.3 Analytical Hierarchy Process (AHP)

The AHP method is a well known and the best practice in multi-criteria analysis approaches which has been developed by Thomas L. Saaty (Saaty, 1980). It allows the weightage to be asessed relative to the given criteria. This method proposes such pairwise comparisons based on the importance of one criterion to another (eg: A is more important than B but less than C). The degree of importance is expressed into a set of numbers ranging from 1-9 representing the relative priority of each of the criteria. The basic scale of pairwise comparison is shown in Table 4.2.

These numbers were assigned to each pairwise in an intuitive manner by considering how the particular criteria affect the radio signal. The AHP matrix which contains

Table 4.2: Basic scale of pairwise comparison

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demostrated importance	An activity is favored very strongly over another ; its dominance demostrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

grade of importance between pair of criteria need to be constructed. The decision maker has to rate the criteria priority compared to other assigned criteria. Let say we chose a pair of data to be evaluated, we put the value of 1 if both reference and compared data have equal importance. However, when the reference data are more important than the compared data, the value of 9 is given. The reciprocal of this value is assigned to the rest of the criterion in the pair. The average weight for each criteria is then determined by normalizing the weighing and averaged them.

In order to construct a matrix for AHP evaluation based on pairwise comparison technique, the matrix element determination is the first step we need to consider. The equation is

$$a_{ij} = (1/a_{ji}) \tag{4.4}$$

The diagonal values of this matrix are equal to one ($a_{ii} = 1$, $a_{jj} = 1$, $a_{nn} = 1$ etc.) as the fact that column and row data layers are equal to each other. The grading values of all pairs are normalized to one using maximum absolute eigenvalue (Eqs. 4.5 and 4.6).

$$\lambda_{\max} \frac{1}{n} \sum_{w_i}^{n} \frac{(AW)_i}{w_i} \tag{4.5}$$

referring to Eq.4.5 based on a report by (Van Driel, 2009)

$$AW = \begin{bmatrix} a_{l_1} & \cdots & a_{l_n} \\ \vdots & \ddots & \vdots \\ a_{n_1} & \cdots & a_{nn} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ \\ w_i \end{bmatrix} \tag{4.6}$$

where A is a pairwise comparison matrix while W and $w_i(i = 1,2,...,n)$ stands for corresponding eigenvector of $\lambda_{\max}$ and the value of weightage, respectively. n defines the number of criteria or parameter involves, which is in this study, the value is $n = 11$. $\lambda_{\max}$ is the largest eigenvalue of the matrix

In the process of RFI prediction map construction, the pairwise comparison matrix was built based on the effect to a radio signal, which are shown in Table 4.3. Weights were computed for each parameter right after the matrix was completed. For these eleven criteria used in this study, we obtained the value of $\lambda_{\max} is 12.2269$. The consistency index (CI) was calculated using Eq. 4.7, hence we get the value of 0.12269. This index is important to control the consistency of the pairwise decided.

$$CI = \frac{\lambda_{\max} - 1}{n - 1} \tag{4.7}$$

The consistent ratio(CR) was calculated using the formula given in Eq. 4.8. This ratio is used to test the consistent of matrix we construct. If the value falls below 0.10, then the value of consistency generated by pairwise comparison is reasonable (Saaty, 1980)

$$CR = \frac{CI}{RI} \tag{4.8}$$

We obtained CR value by deviding CI with RI (which defines as random inconsistency), thus we got the value of $CR = 0.08072$ which means this pairwise constructed was acceptable for further analysis. If this CR value is more than0.1, then the matrix needs a revision and reconstruct until we get the value not larger than 0.1. We noted that the RI value for $n = 11$ was 1.52.

The completed pairwise matrix constructed in this study for eleven parameters is illustrated in Table 4.3(Used data sets; population density (A), road network (B), slope/elevation (C), rainfall (D), land used (E), river (F), 2G (G), 3G (H), AM (I), FM (J), and TV (K)).

From the table, the calculated value obtained are $CI = 0.122$, $\lambda_{\max} = 12.22, RI = 1.52$ and $CR = 0.08$. The pairwise matrix is acceptable since CR value is less than 0.1.

4.3.4 Predicted RFI profile map

In the final stage, each data for each parameter was combined to form a layer using GIS technique and produce a map of each.The weight coefficients were calculated to classify the region in all around the peninsular Malaysia based on the degree of criteria influence, accordingly. All layers of map for each criteria are shown in Fig. 4.8 - Fig. 4.18. Finally, each layer is combined to produce the RFI profile map of peninsular Malaysia as can be seen in Fig. 4.19 and Fig. 4.20. The figures show that the darker the area the weaker the RFI. Therefore, the most suitable site for radio astronomy is located around east coast of peninsular Malaysia.

Table 4.3: AHP pairwise comparison matrix and computed weights.

	A	B	C	D	E	F	G	H	I	J	K	Weight
A	1	1	1	1	1	1/9	1/7	1/9	1/7	1/3	1/9	0.01828
B	1	1	1	1	1	1/9	1/7	1/9	1/7	1/3	1/9	0.01828
C	1	1	1	1	1	1/9	1/7	1/9	1/5	1/3	1/9	0.01874
D	1	1	1	1	1	1/9	1/7	1/9	1/5	1/3	1/9	0.01874
E	1	1	1	1	1	1/9	1/7	1/3	1/5	1/3	1/9	0.02095
F	9	9	9	9	9	1	1	1	1/3	1	1	0.14336
G	7	7	7	7	7	1	1	1/3	1	1/3	1/7	0.09921
H	9	9	9	9	9	1	3	1	1/4	1	1	0.15358
I	7	7	5	5	5	3	1	4	1	1	1/7	0.14948
J	3	3	3	3	3	1	3	1	1	1	1/9	0.08200
K	9	9	9	9	9	1	7	1	7	9	1	0.11621

The predicted RFI profile map is used to povide a reference map before the observation is done. The value obtained from observation is the actual value and then will be gone through the MCDA approach once again to obtain the genuine profile of RFI in peninsular Malaysia. The explanation on observation process will be describe later.

As a conclusion, region classification studies are very important to decide where to conduct the observation to avoid high RFI places. It is also beneficial for the decision makers to propose where to build an astronomical observatory, especially in radio astronomy with a maximum efficiency. It involves multi criteria parameters and will undergoes a long and complicated processes.

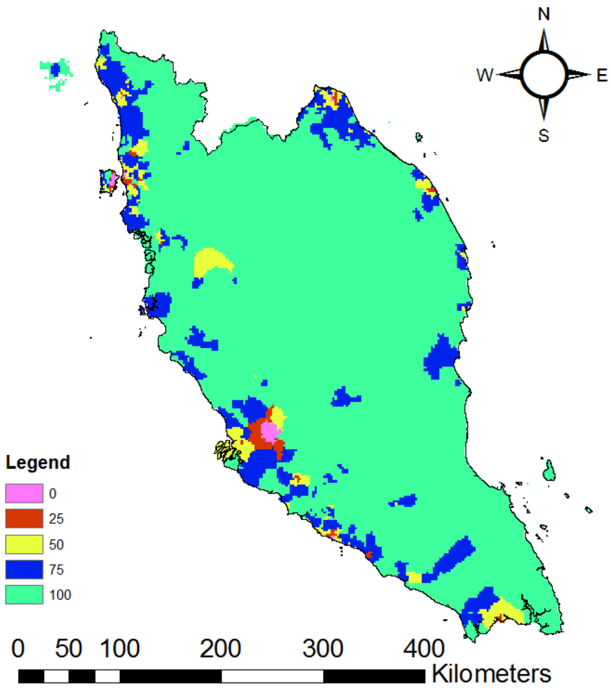


Figure 4.8: An RFI profile map for population density factor

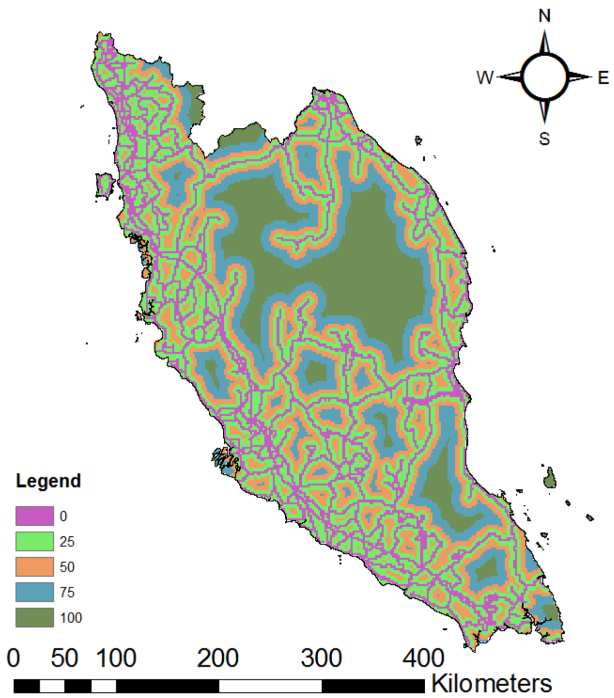


Figure 4.9: An RFI profile map for road network factor

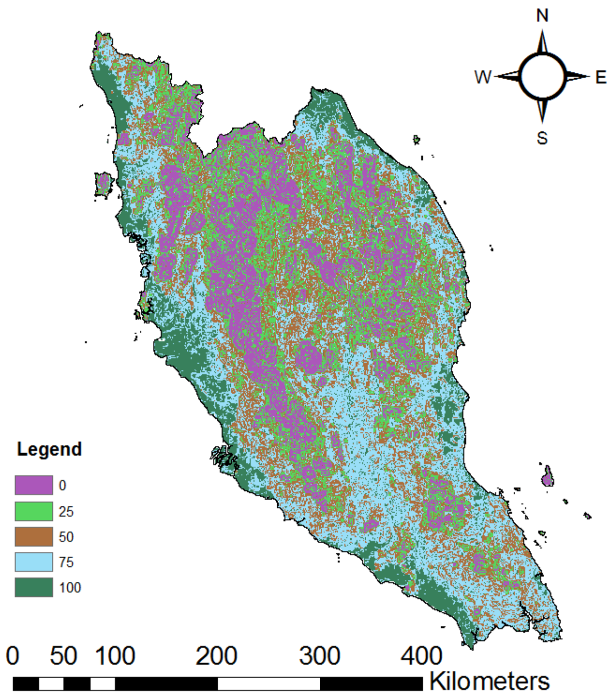


Figure 4.10: An RFI profile map for contour factor

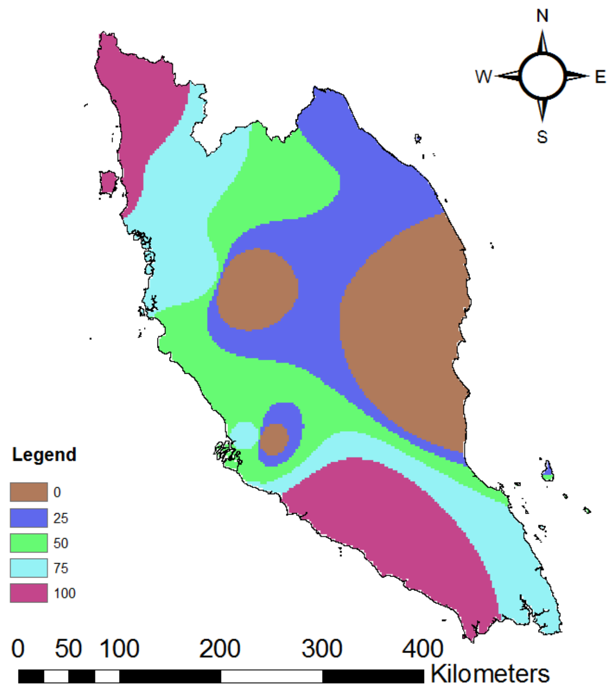


Figure 4.11: An RFI profile map for rainfall factor

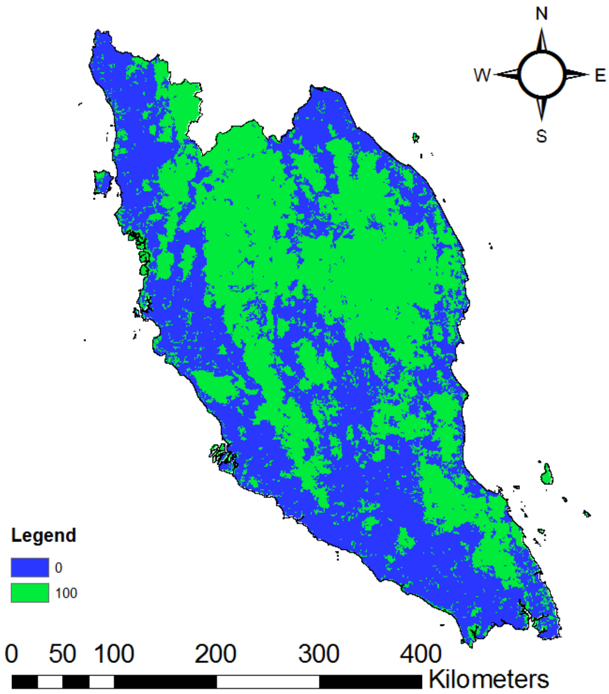


Figure 4.12: An RFI profile map for land use factor

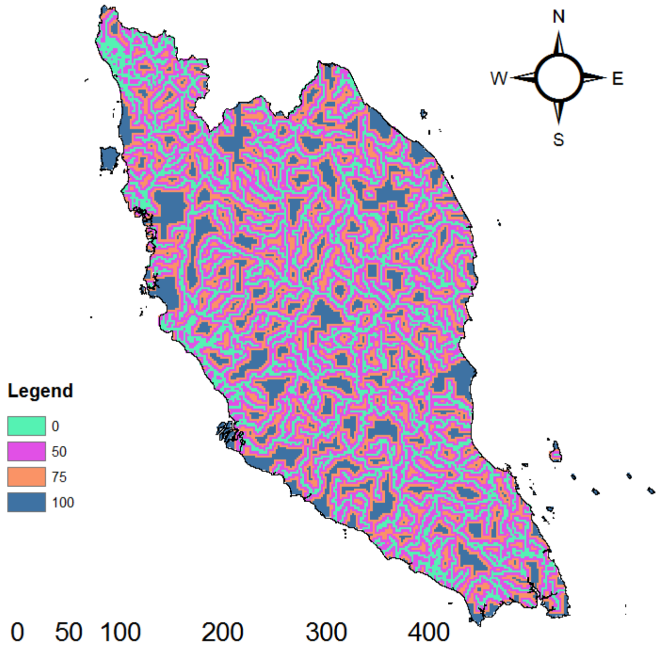


Figure 4.13: An RFI profile map for river line factor

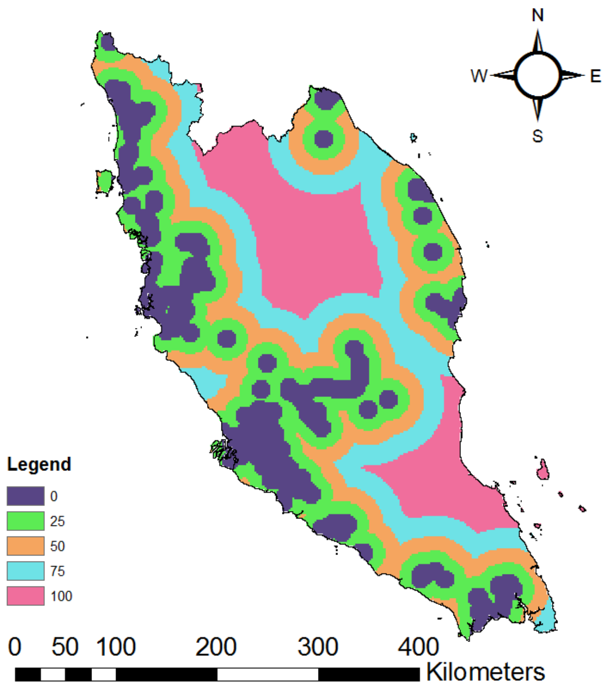


Figure 4.14: An RFI profile map for 2G transmitter factor

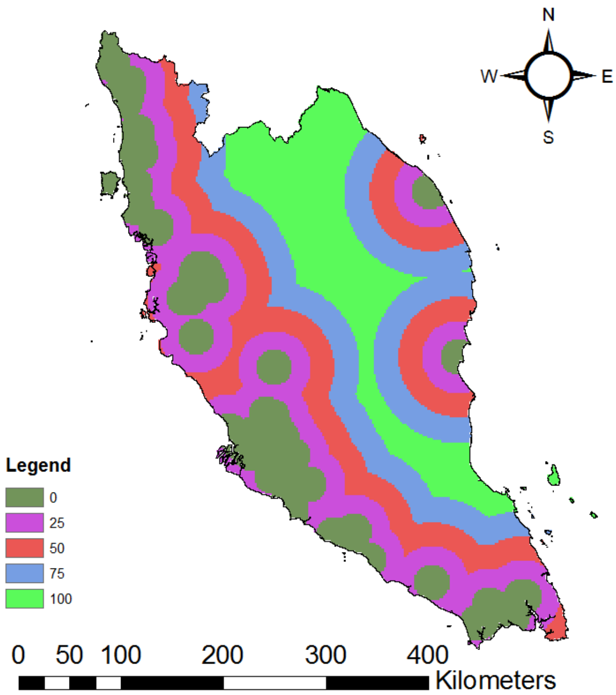


Figure 4.15: An RFI profile map for 3G transmitter factor

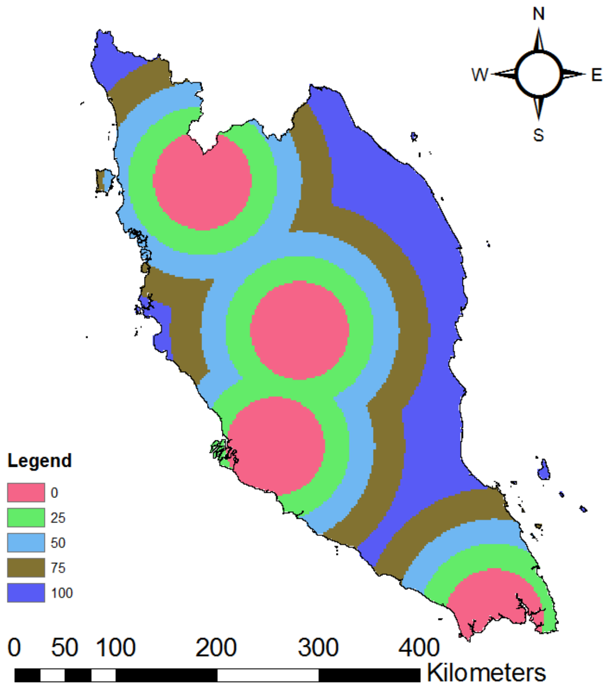


Figure 4.16: An RFI profile map for AM radio factor

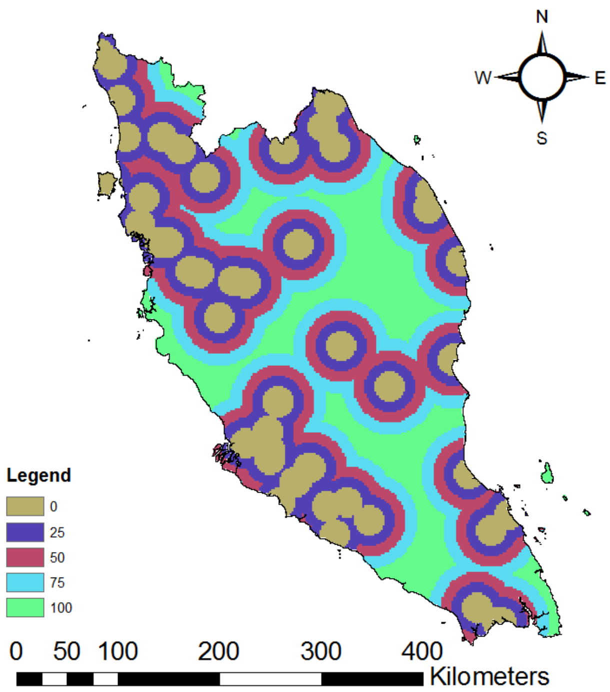


Figure 4.17: An RFI profile map for FM radio factor

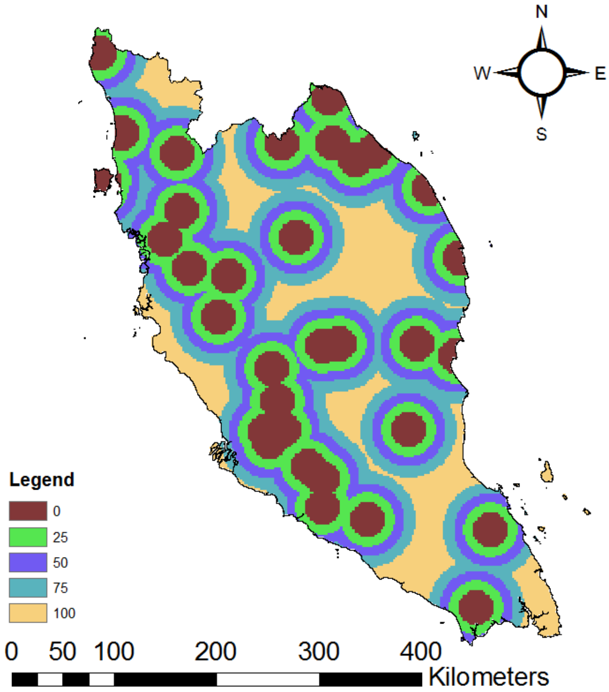


Figure 4.18: An RFI profile map for TV transmitter factor

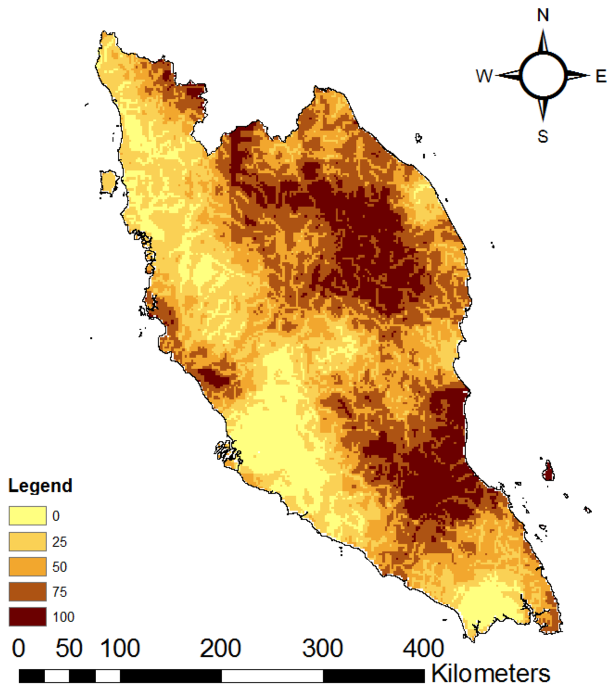


Figure 4.19: RFI predicted map for eleven parameters

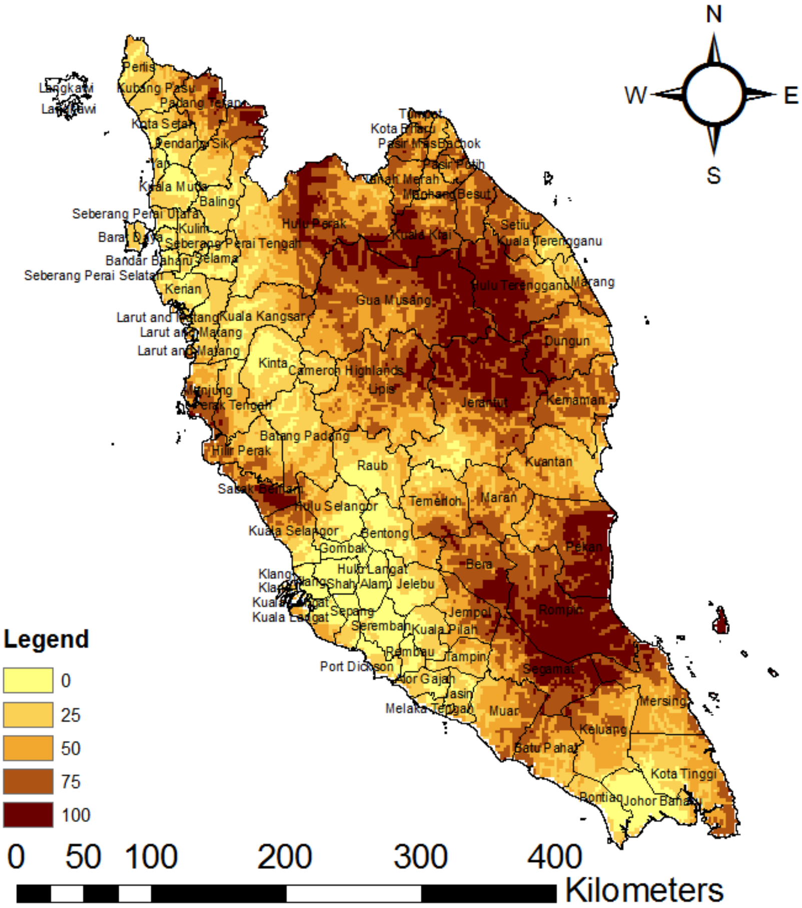


Figure 4.20: RFI predicted map for eleven parameters(including the location name)

4.4 Observation and Data Analysis

Fig. 4.21 shows the process of how the observation is conducted for each parameter studied. From the previous section, we have identified eleven parameters to be studied, however, due to the time constraint, we managed to perform four out of eleven parameters which are population density, road network, rainfall and contour effect. Each parameter is assumed to give a significant effect to radio signal, thus it will disturb the RFI observation.

Each of four parameters has been observed at different place depends on the environment and the parameter attributes. After the observation site has been identified, the suitable date and time need to be decided. This is important for road network effect study and rainfall observation.

The first step is to make sure the instruments have been assembled completely as

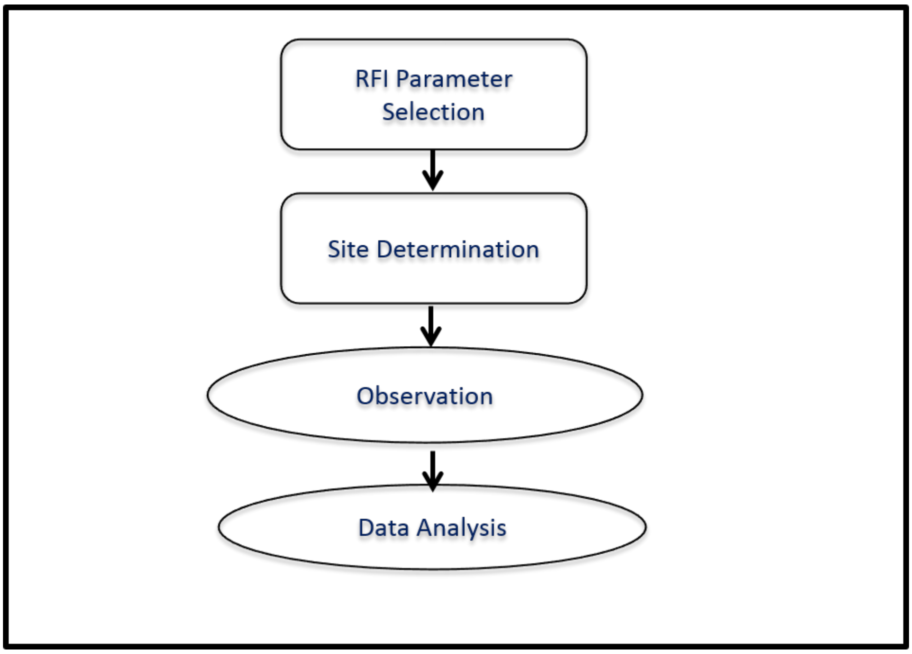


Figure 4.21: Step-by-step procedure of observation for each parameter

clarified in section 3.1 earlier (Fig. 4.22). In this study, the antenna is stands still at 2m high from the ground. The location information is gathered such as the latitude, longitude and elevation using GPS. The environmental factors are also recorded to consider the side effect, such as

1. Weather,
    - rainy
    - windy
    - misty
    - sunny and etc
2. Cloud cover,
3. Blockage,
    - hills
    - forest
    - plantation etc
4. Area usage,

- residential
- commercial
- plantation etc

5. Electrical or power sources nearby.

Figure 4.22: Researcher doing an observation using instruments

The observation begin once the previous checklists are done. Then the data was recorded and the analysis takes place to give the final result and outcome. The details of each parameter observation is as in the following subsection.

4.4.1 Population density

There are eight sites selected for this study with population density ranging from $58 ppl/km^2$ to $7089 ppl/km^2$. They are Setiu (Terengganu), Tapah (Perak), Teluk Intan (Perak), Banting (Selangor), Klang (Selangor), Petaling Jaya (Kuala Lumpur), Gombak (Kuala Lumpur) and Kuala Lumpur City Center. The selected sites are located in the centre of town or nearby to consider the effect of human generated frequency which disturbs the radio signal we observed. We assumed that the nearer the location to the city centre or residential area, the higher RFI sources is detected.

The observation procedures are referred to the RFI measurement protocol for SKA candidates site (Ambrosini et al., 2003). The average RFI level for the eight site were plotted againts their population density. The threshold were determined by calculating the tangent of the increasing and the flatened part of the curve. The average RFI level in this threshold windows was compared with the reference ITU level and we identified how much these RFI exceeded ITU limit.

4.4.2 The contour effect

We believe the blockage factor also put an effect on RFI measurement. In order to prove the assumption, we manage a trip to Cameron Highland which is located at the Titiwangsa mountain range near the top of Berinchang mountain. There are six sites selected for this study ranging from 1419m to 1495m in an elevated position. They are two sites at Puncak Arabella, near MARDI building, around JKR building, near Robinson Fall and near TELEKOM quarters. The observation work at Puncak Arabella can be seen in Fig. 4.23. These sites also present a various type of contour shielding (the blockage is expressed in percentage, for example 80% surrounded by the hills). These selected areas are surrounded by hills, trees, forest, and plantation site. These surrounding factor leads to the RFI attenuation occurence. We also consider the roadway nearby and residential factors lead to acquire a complete view of the problem.

Figure 4.23: A view from Puncak Arabella while making an observation for contour sheilding effect

The observation took 1 hour for each site. The collected data is then analysed and the linear fitting of the power level(dBm) versus frequency(MHz) is plotted to see the pattern. We have plotted a graphs for power level versus altitude to conclude the effect of elevated position and type of contour shielding to the RFI for each line of deuterium, hydrogen, hydroxyl-1 and hydroxyl-2. Then we have also plotted the average value of frequencies.

4.4.3 The road network

To study the effect of road network to RFI, we make the observation at Behrang, Perak nearby Universiti Pendidikan Sultan Idris (UPSI). We believed that the electromagnetic radiation produced from running vehicles on the road may interrupt the radio frequency observed in radio astronomy studies. We had managed ten observations with various distances ranging from $0m$ to $212m$ measured from the road selected as the RFI source.

The last working day of the week (Friday) is selected at time $1700hrs$ until $2000hrs$, near the North-South Expressway to observe the RFI to study the effect of road network parameter. This particular day, time and place are chosen because they were the peak hours for Malaysian citizen to get back home from their workplace and at the same time they may plan to have the weekend in their hometown. So we will see the busiest time on highway with many vehicles will utilize the road on the way home.

We choosed Behrang because there is a bridge cross over the highway and the place is far from residential areas. It is located in the oil palm plantation area so the RFI sources are predicted to come from the running vehicles on the highway. The picture in Fig. 4.24 show the view on the road from the bridge over the highway.

Figure 4.24: A view from top of the highway for the distance of $0m$

Observations were taken for one hour for each site similar to the previous parameter observation. The average RFI level for the ten sites were plotted against their distances from highway. The thresholds were determined by projecting the line to the x-axis to see the distance when noise level equal $to99.7dBm$.

4.4.4 The rain effect

The observation apparatus was set up at Bandar Kinrara, Selangor to study the effect of rainfall and raindrop to the radio signal. Another supporting apparatus for this experiment are raindrop simulator and rain gauge. We had managed two types of observation: inside observation and outside observation. While raining, we placed the discone inside the building for inside observation. For outside observation, we put the discone in contact with different size of raindrop.

For inside observation, we tend to study how the radio wave attenuate by the rain. We used rain gauge and placed near to the antenna to record the rain rate. The rainfall ranging from $0mm/hr$ to $120mm/hr$. We then average the power level of and were plotted against the rainfall.

For outside observation, we used rain simulator to simulate various raindrop sizes which ranging from $0.5mm$ to $5mm$ as shown in Table **??**. Power level or called wet antenna was used and determined. The rate of wet antenna define as the difference between the receiving signal level in dry and wet condition. The formula is written as:

$$A_{wet} = P_{rdry} - P_{rwet} \tag{4.9}$$

Where, A_{wet} is wet antenna, P_{rdry} is received power of dry antenna and P_{rwet} is received power of for wet antenna. We then calculated the average power level of wet antenna and were plotted against their raindrop sizes.

4.5 RFI Mapping

Finally, once the RFI observations for all parameters were done, a set of accurate threshold values of the factors were determined. All of these value was then used in RFI profiling and to produce the RFI map of peninsular Malaysia. It is then compared with the predicted map produced earlier. The process of mapping was gone through once again using MCDA technique intergrated with GIS to form layers for each parameter and then combined altogether to obtain the actual RFI map. The AHP approach also used in this stage to gain the weightage of the parameter.

This technique helps to find and monitor spectrum occupancy in identifying and recognizing the most intense sources of interference, particularly from terrestrial transmitters.

Eleven factors are identified to give effect to radio signal and have been used to create a reference map. However only four factors were done for observation to get the real and actual value of the threshold. The RFI profile map for these four factor can be seen in Fig. 4.25. This study offers tough, precise, cost a time effective procedure for preliminary selection for a radio astronomy observatory.

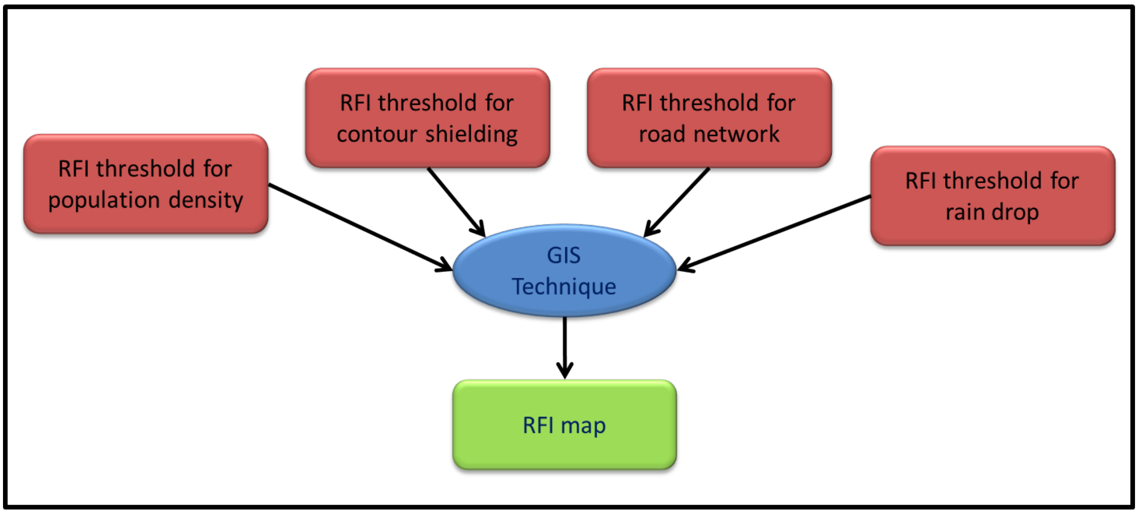


Figure 4.25: The preparation of actual map based on parameters observed

4.5.1 Source of datasets

The data were requested directly from various agencies such as Malaysia Geo-Spatial Data Infrastructure (MyGDI), Department of Statistics Malaysia, Malaysian Meteorological Department, Malaysian Communications and Multimedia Commission (MCMC), and Department of Survey and Mapping Malaysia (JUPEM). The data requested were include spatial and attribute data. Spatial data is a map of Peninsular Malaysia, which we get from the Department of Survey and Mapping Malaysia. Other sources of support also in the spatial data, including topology maps to high places in Malaysia and GIS maps obtained from previous studies of the Faculty of Social Sciences and Humanities (FSSS), University of Malaya.

4.5.2 Processing of datasets using GIS

In this section we will split data with two sets of anthropogenic and geography. In anthropogenic data, we have the population density and road. However, we have a set of geographic data and raindrop contour. A set of data associated with human activity, for example distance to roads, and population densities are the anthropogenic factors. They directly affect the quality of the observations; this is the same as in the case of optical observation. Another important parameter is the geographical situation near the observatory. As we know that the expensive equipment in the observatory should not be built in areas that are not safe in terms of geological conditions such as landslides and earthquake zone. Geography can help to reduce the level of interference as we know that the contour and raindrops become one of the options parameter by the ALMA and SKA project to protect from the interference, for example.

4.5.3 Anthropogenic datasets

4.5.3 (a) Population density data

There is a parameter which is much related to human activity; that is population density. This population density represents the residential and commercial. This population density data were digitized as raster data and reclassify from 0 to 100. The data were reclassified to five groups, namely 0, 25, 50, 75 and 100 as shown in Figure 4.8 (a). In Peninsular of Malaysia, population density ranges between $(58ppl/km^2 - 7089ppl/km^2)$. The highest value (100) for the lowest population density $(52ppl/km^2)$ and the lowest value (0) represent the highest population density $(7089ppl/km^2)$ and the lowest population density was $(58ppl/km^2)$.

4.5.3 (b) Road network data

Another important variable need to consider is the road network. Road information was present the usage of vehicle and develop the area as well. When we are discussing the road network, it also presents the type of vehicle used on the highway. Vehicle is well known produces internal interference around or below 1000 MHz. In Green Bank, for example, they do not allow petrol vehicle cross the road instead of diesel vehicle. This is due to the petrol car used spark plug which is one source of internal interference to radio observatory. In this study, we have looked for a site which is very far in distance from the road network or highway. Using distance analysis technique in Arc GIS 9.3 we reclassify (separated) the value to five groups, namely 0, 25, 50, 75 and 100. The farthest area from the road we define as value of 100 which is most suitable site and the closest to the road was 0 representing the least suitable site.

4.5.4 Geographical datasets

4.5.4 (a) Contour data

In locating of radio telescopes to avoid spectrum pollution most of radio observatories are often placed in valleys to further shield them from ground interference. So that altitude is one of the factor in the site selection of radio observatory. Most of radio observatory in the world, especially for high frequency study located on highest site. Meanwhile, radio observation of low frequency normally located at lower altitude. In this study, we use elevation data and converted to slope data. The slope or contour was a good parameter in order to find the most flat location. The contour data in Peninsular of Malaysia were in elevation range between 0 and $3047m$ over the study area. After converting to slope raster data, this data converted to the slope and reclassify into a range between$0-100$. Using data conversion to raster in Arc GIS 9.3 we categories (reclassify) the data to 0, 25, 50, 75 and 100.

4.5.4 (b) Rainfall data

Rainfall is one of important factor affect the radio propagation. It will interfere the penetration of radio wave propagation, where the water occupied in the atmosphere will reflect, refract and attenuate as well when the signal travel. We need to find driest places in peninsular of Malaysia. In this study, rainfall range in Malaysia is from $164cm^3 - 241cm^3$. So using GIS, value 0-100 where 0 is less suitable and 100 is most suitable site for radio observation. The map was generated and converted raster map using interpolated analysis. The data converted to raster and we categories (reclassify) the data to 0, 25, 50, 75 and

100 and quantile method is applied. The map was rescaled into a range between 0-100 representatives for $241cm^3 - 164cm^3$ as shown in Figure 4.11(b). The most suitable site was the driest location in the peninsular of Malaysia.

CHAPTER 5

RESULTS AND DISCUSSION

It is very important to select a site with very low RFI in radio astronomy observation (Umar, Abidin, & Ibrahim, 2011). This study was implemented in the Peninsular of Malaysia, which is convenient for astronomical site observatory facilities with its appropriate climate properties and weather conditions. Eleven factors (slope, raindrop, river, population density, road network, land used, 2G or second-generation wireless telephone technology, third-generation (3G), amplitude modulation (AM), frequency modulation (FM) and television (TV) transmitters) were identified, split into two categories; anthropogenic factor and geographical factor. However, in this study, we have reported the observation measurement of four selected factors. They are population density, contour shielding, road network and raindrop. The site selection study is the most crucial part for decision makers to propose where to build an astronomical observatory, especially in radio astronomy with a maximum efficiency.

5.1 Population Density

In this section, we discuss the influence of the population density factor of the RFI environment affecting radio astronomy. We use a new method in quantifying the threshold limit of the population density in order to determine the upper limit for RQZ site selection. We found that there is a certain trend in the population density-RFI graph that increases rapidly at a lower value and slows down to almost a flat at higher values. We present the result from the preliminary study on population density done in Malaysia-Thailand, and the threshold determination study of population density in Peninsular Malaysia for RFI profile map.

5.1.1 Preliminary Study on Population Density

The RFI spectra observed in the selected sites are listed and analysed in Figure 5.1 to 5.5. For the frequency band $1-2900MHz$, the average RFI level at the CM site is $-93.6dBm$ (with standard deviation or SD as $6.7dBm$) shows a high RFI level (see Figure

5.1) when compared to UB, which is $-97.6dBm$ (with standard deviation of $4.4dBm$). In the L-band window, i.e. $1300MHz - 1500MHz$ (see Figure 5.2), it is evident that UB site has lower RFI levels when compared to the CM in the four windows. The average RFI level in the L-band at CM is $-96.6dBm$ (with standard deviation of $4.1dBm$), however, in UB, this value is $-97.4dBm$ (with standard deviation as $2.2dBm$). The RFI level in the frequency allocation in L-band shows much lower RFI value when compared to the value within $1 - 2900MHz$.

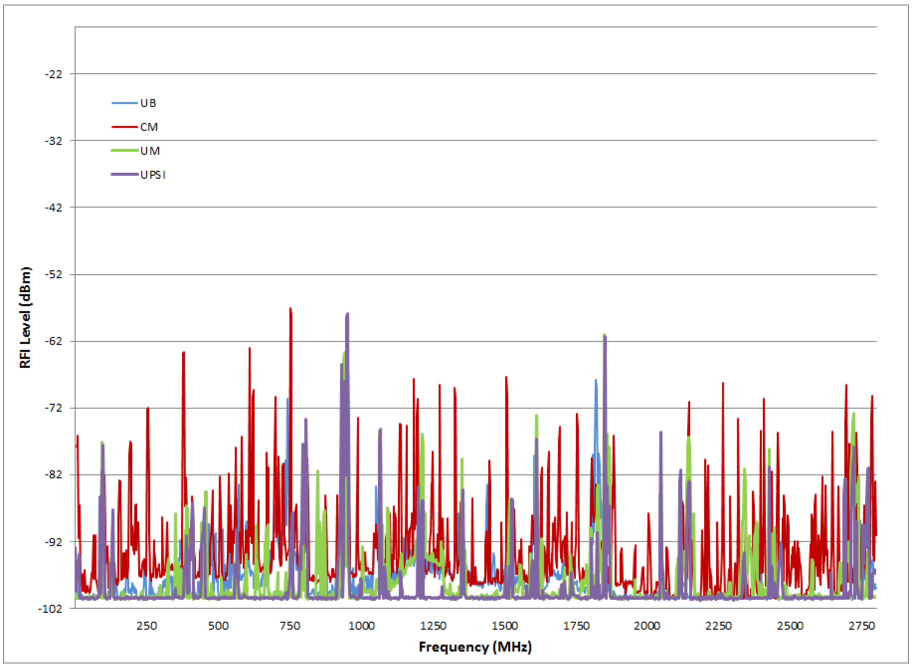


Figure 5.1: Spectrum of RFI of sites in Malaysia and Thailand frequency ranges from $0 - 2.8GHz$

The average RFI value in windows B at Chiang Mai is at $-98.1dBm$ (with standard deviation of $0.6dBm$). However, averaged RFI level in window B in Ubon is $-98.6dBm$ (the standard deviation is $0.6dBm$) shows even lower averaged RFI level. In conclusion, the RFI levels in all 3 categories in UB is much lower than in CM.

In the UM and UPSI sites, the overall ($0 - 2900MHz$) averaged RFI levels are $-97.9dBm$ (with standard deviation of $5.0dBm$), and $-98.7dBm$ (with standard deviation of $5.0dBm$), respectively. The averaged RFI level in L-band (Figure 5.3) for the two sites are $-99.7dBm$ (with standard deviation of $2.7dBm$), and $-100.3dBm$ (with standard deviation of 1.1 dBm), respectively, while the averaged RFI level in windows B for the two sites are $-100.3dBm$ (with standard deviation of $0.3dBm$), and $-100.5dBm$ (with

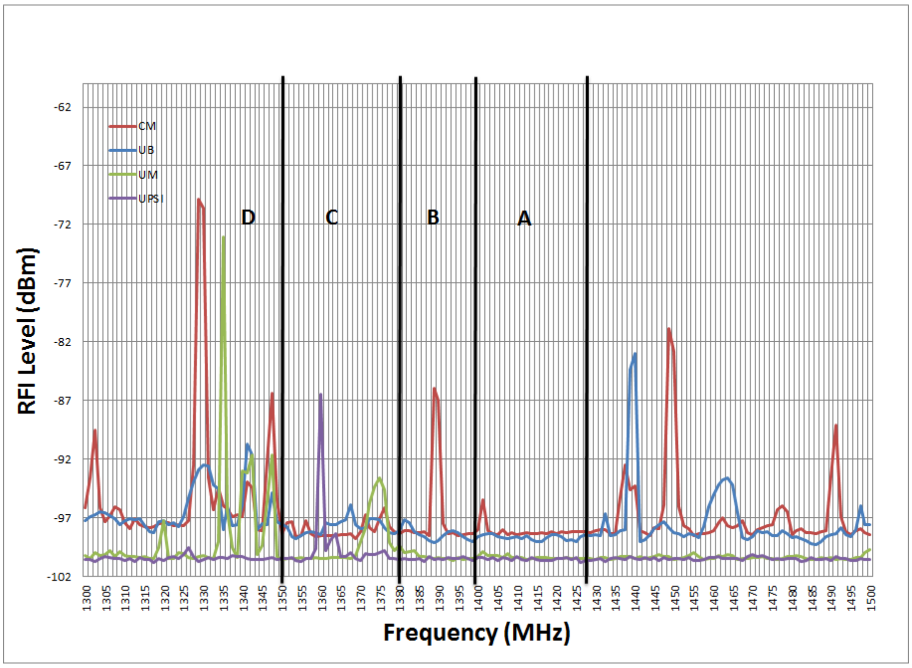


Figure 5.2: Spectrum of RFI of sites in Malaysia and Thailand in L-band (1300 – 1500MHz)

standard deviation of 0.1dBm), respectively. It is clear that the RFI levels in all 3 categories are lower for the UPSI site. A summary of these values can be seen in Table 5.1.

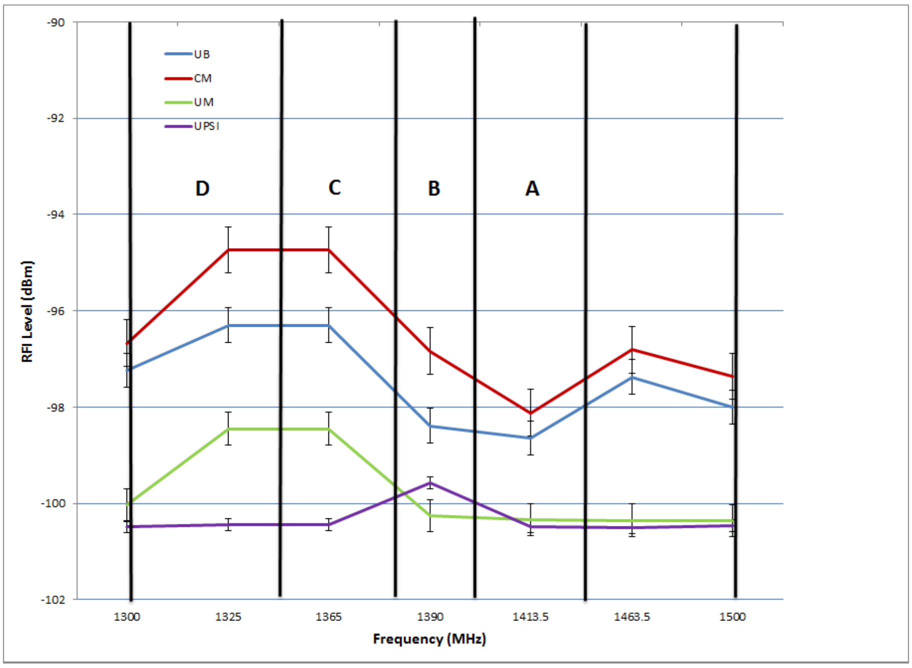


Figure 5.3: RFI level in Malaysia and Thailand for the all windows at L-band

In order to see the relationship between population density and RFI, especially in window B, spectra at seven sites in Malaysia were obtained (Figure 5.4). Two sites are

Table 5.1: Averaged RFI levels in the 3 frequency categories at the 4 selected sites

Sites	Overall ($0-2.9GHz$)	SD	L-Band ($1300-1500MHz$)	SD	Window B ($1380-1400MHz$)	SD
UB	$-97.6dBm$	4.4	$-97.4dBm$	2.2	$-98.4dBm$	0.5
CM	$-93.6dBm$	6.6	$-96.6dBm$	4.1	$-96.8dBm$	3.9
UM	$-97.9dBm$	5.0	$-99.7dBm$	2.7	$-100.3dBm$	0.3
UPSI	$-98.7dBm$	5.0	$-100.3dBm$	1.1	$-100.5dBm$	0.1

very high in RFI level namely Petaling Jaya (PJ) and Kuala Lumpur (KL) with average RFI levels in L-band as $-83.5 \pm 1.4dBm$ and $-80.5 \pm 2.4\ dBm$, respectively. This is due to the high commercial and residential densities in these sites. Figure 5.5 shows the average RFI levels in each windows for the 7 sites.

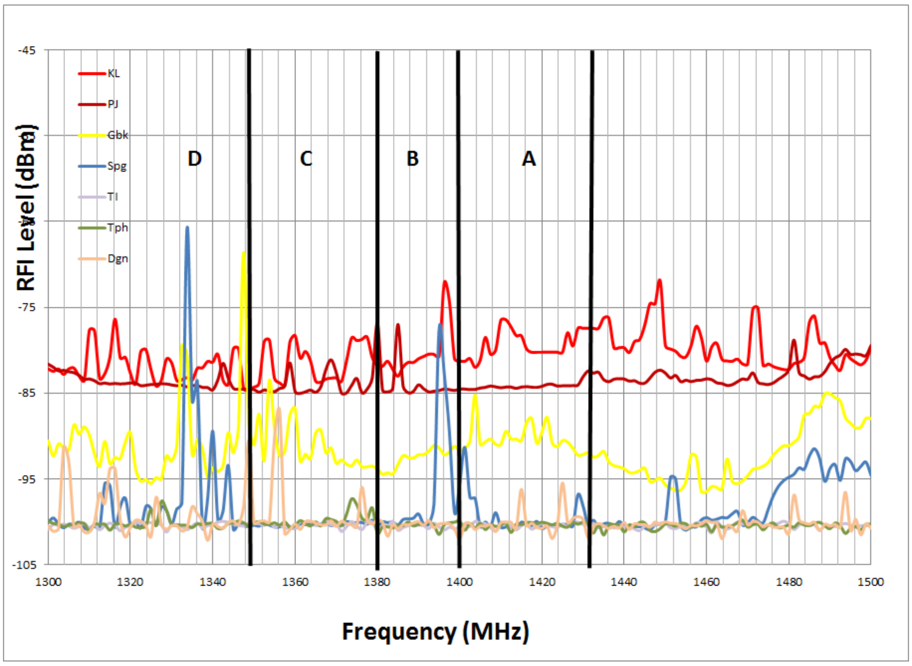


Figure 5.4: RFI level for seven sites in Malaysia

By referring to Table C for the measurements of the spectrum in the L-band down to $1300MHz$, it has been determined that the RFI are produced mainly by radio determination service in radio location ($1300-1400MHz$), fixed service for point-to-point apparatus ($1350-1400MHz$, $1427-1429MHz$ and $1429-1452MHz$), GPS paging system ($1381.05MHz$), mobile service for repeaters, base and mobile/walkie talkies used in mobile services and maritime and aeronautical mobiles (1350-1400MHz, 1427-1429MHz

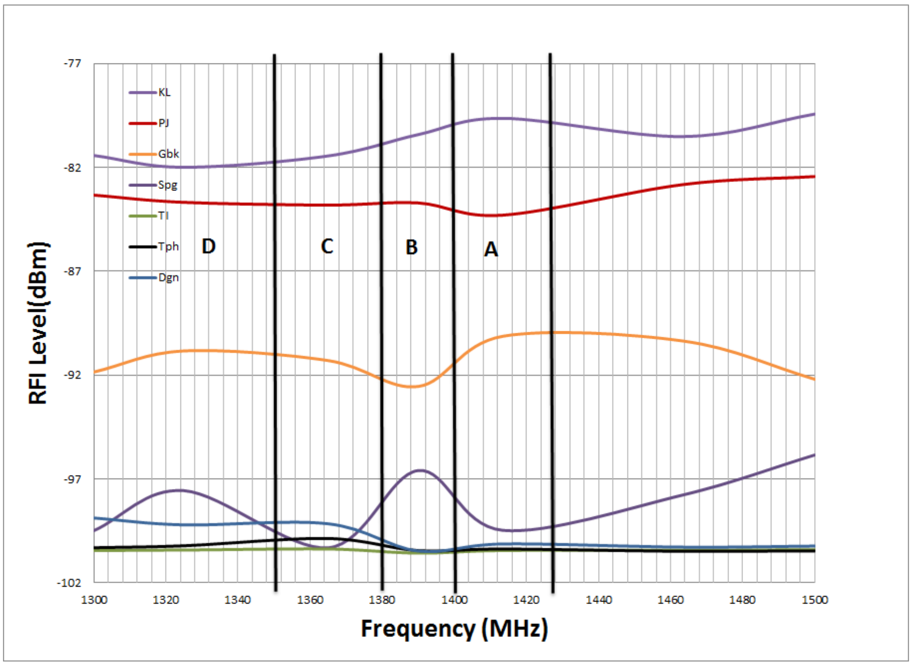


Figure 5.5: Averaged RFI level within the four windows for the 7 selected sites, in increasing values (i.e. from Dungun (DGN) to KL)

and 1429-1452MHz), wireless medical telemetry services ($1391-1400MHz$) and Digital Sound Broadcasting (assigned to MEASAT Network satellite at 1452-1492MHz). We found that the department of Civil Aviation of Malaysia is assigned in the frequency range of 1215-1427MHz, which is transmitted within the four windows and inside the allocated frequency for radio astronomy.

For RFI measurements in Thailand, we found two significant peaks at $1388.75MHz$ (at $-85.9dBm$) in window B and $1401MHz$ (at $-95.4dBm$) in window A (this peak is used for radiolocation which is a big spike as shown in Figure 5.2). This frequency belongs to the 46 point to point radio link which is a telecommunication usage (narrowband signal between 1385 and 1389MHz). The Free Space Power Loss (FSPL), defined as,

$$FSPL = 20\log\left(\frac{4\pi df}{c}\right) \tag{5.1}$$

is proportional to the square of the frequency of the radio signal ($f = 1420MHz$) and to the square of the distance between the transmitter and receiver (d). Distance during RFI measurements between the antenna and the device $(d = 5m)$ in our case gives a contribution to a power level of $-50.5dBm$. The power of the RFI seen as the antenna focus will then be -85.9 + (-50.5) = $-136.4dBm$ = $-166.4dBW$. Therefore, this peak in the CM site generated an RFI exceeding the ITU-R RA.769-2 threshold level ($-215dBW$)

by $48.6dBm$. Using the same calculation technique, the second peak (in Window A) at the CM site (at $-95.4dBm$) exceeded the ITU-R RA.769-2 threshold level by about $39dB$. However there is no significant peak in the Malaysian sites in any of the windows except for the Civil Aviation of Malaysia ($1215-1427MHz$). This is not detected in our measured spectra but it is allocated for this organization in the MCMC spectrum management. From this research, we also conclude that based on the RFI level, the UB site is better than the CM site for the purpose of building a radio telescope facility. While in Malaysia, we can conclude that the UPSI site is better than the UM site for the same purpose.

As a conclusion, the frequency window B (with frequency between $1380MHz$ and $1400MHz$) is a very important window for radio astronomers on the ground for HI observation. We found that there exists some RFI sources being transmitted in this window and we would like to press on the suggestion that we should protect this window before it is used for other RFI sources in the future. If this happens, the important radio sources listed in this paper, particularly in this window, will not be such good candidates for ground-based radio astronomy observations for many observatories in the world. It is also important to raise the awareness of people around the world about ITU Radio Astronomy Regulation. As determined in this study, it is important to avoid any emissions in the passive band from unwanted emissions due to active services in lower and upper bands at $1400-1427MHz$ (Oliva et al., 2012). Although, RFI can be removed (Ellingson & Hampson, 2008), it is better, albeit more difficult to actually realize it, if we can prohibit users from emitting these RFI in the first place.

5.1.2 RFI Profile for Population Density in Peninsular Malaysia

We use this trend to identify the threshold for the population density effect on RFI. Using this method we found that up to $2.8GHz$ low, medium and high population density affecting radio astronomy are below $150ppl/km^2$, between $150ppl/km^2$ and $5125ppl/km^2$, and above $5125ppl/km^2$ respectively. We also investigate the effect of population density on the RFI environment in three astronomical windows, namely Deuterium, Hydrogen and Hydroxyl lines. We find that the population density polynomial fitting produces a similar trend, giving a similar threshold window for the population density effect. We then compare our interference values to theITU threshold standard level within these spectrum windows.

Table 5.2: Population densities for eight sites (Department of Statistics 2007).

Sites	Population density (ppl/km^2)	Distance from small town (km)	Distance from city center (km)
Setiu	58	13 (from Setiu)	30 (from Kuala Terengganu)
Tapah	70	6 (from Bidor)	30 (from Ipoh)
Teluk Intan	133	7 (from Langkap)	28 (from Ipoh)
Banting	248	5 (from Jenjarom)	20 (from Shah Alam)
Gombak	1085	2 (from Sentul)	5 (from Kuala Lumpur)
Klang	1309	1 (from Klang)	6 (from Shah Alam)
Petaling Jaya	3012	5 (from Kuala Lumpur)	8 (from Shah Alam)
Kuala Lumpur	7089	0 (from Kuala Lumpur)	0 (from Kuala Lumpur)

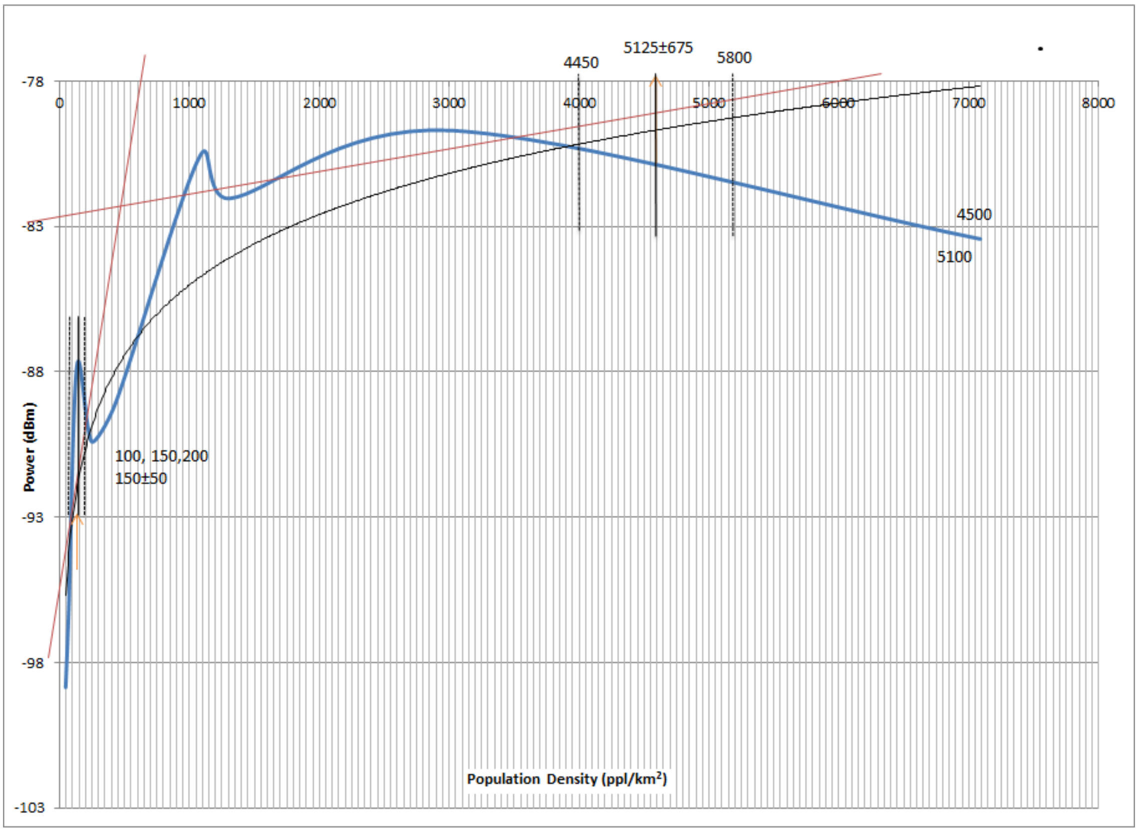


Figure 5.6: RFI profile for all windows $(1-2800MHz)$

We have selected eight sites representing various types of population density. It is stated in Table 5.2 including the distance from the nearest city. We determined the population density affect the threshold level from $0-2.8GHz$ and we also calculated this threshold level in all radio astronomical windows up to $2.8GHz$. The polynomial fitting

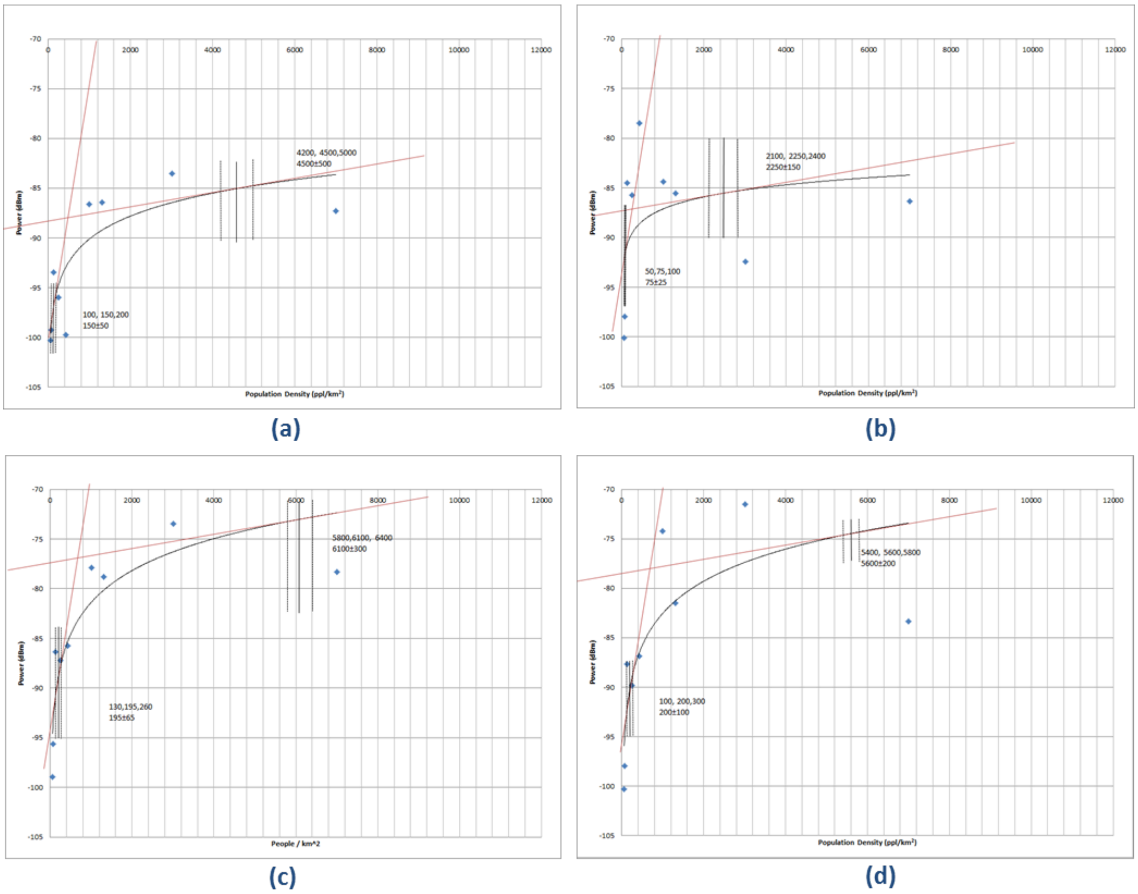


Figure 5.7: RFI profile for (a) Deuterium line $(322-328.6MHz)$, (b) Hydrogen line $(1400-1420MHz)$, (c) Hydroxyl line-1 $(1610-1675MHz)$ and (d) Hydroxyl line-2 $(1718.8-1722.2MHz)$

Table 5.3: Average RFI $(below 2.8GHz)$

Group	Population density (ppl/km^2)	Average RFI level (dBm)	RFI at the antenna (dBm)	ITU Threshold level (dBW)	Exceed ITU by (dB)
A	0-150±50	-94±9	-28		177
B	150-5125±675	-83±6	-17	-205	188
C	5125 and above±675	-83±7	-17		188

was used on the graph (Figure 5.6 and Figure 5.7). The threshold level that we have calculated within astronomical windows is summarized in Table 5.3-5.7. The average RFI up to $2.8GHz$ gives us three population density threshold windows that represent low, medium and high population densities ie below $150ppl/km^2$, between $150ppl/km^2$ and $5125ppl/km^2$ and above $5125ppl/km^2$ respectively. We also calculated the total RFI received by our spectrum analyser. We used the average RFI level in the threshold windows, for example, at $-94dBm$ for low population density within 0 to $2.8GHz$ (see

Table 5.4: Average RFI survey for Hydrogen line $((1400-1427MHz))$

Group	Population density (ppl/km^2)	Average RFI level (dBm)	RFI at the antenna (dBm)	ITU Threshold level (dBW)	Exceed ITU by (dB)
A	0-75±25	-100±1	-34		186
B	75-2250±150	-90±1	-24	-220	196
C	2250 and above±150	-90±1	-24		196

Table 5.5: Average RFI survey for Hydroxyl-1 line $(1610-1675MHz)$

Group	Population density (ppl/km^2)	Average RFI level (dBm)	RFI at the antenna (dBm)	ITU Threshold level (dBW)	Exceed ITU by (dB)
A	0-150±50	-94±6.1	-27		193
B	150-4500±300	-81±6.0	-14	-220	206
C	5125 and above±675	-78±7	-11		209

Table 5.6: Average RFI survey for Hydroxyl-2 line $(1718.8-1722.2MHz)$

Group	Population density (ppl/km^2)	Average RFI level (dBm)	RFI at the antenna (dBm)	ITU Threshold level (dBW)	Exceed ITU by (dB)
A	0-195±65	-95±2	-28		192
B	195-6100±300	-79±1	-12	-220	208
C	6100 and above±300	-83±1	-16		204

Table 5.3). For a receiver to antenna distance, d we determined a power level using a formula (Ambrosini et al., 2010);

$$FSPL = 20\log 10 \times \left(\frac{4\pi d f}{c}\right), \tag{5.2}$$

We calculated the value of the FSPL power level for these windows as $50dBm$. The total RFI seen at the antenna focus was $-94+(50) = -44dBm = -74dBW$. However,

Table 5.7: Average RFI survey for Deuterium line $(322-329MHz)$

Group	Population density (ppl/km^2)	Average RFI level (dBm)	RFI at the antenna (dBm)	ITU Threshold level (dBW)	Exceed ITU by (dB)
A	0-200±100	-94±1	-41		174
B	200-5600±200	-87±2	-34	-215	181
C	5600 and above±200	-86±1	-33		182

we need to add correction values as recommended by ITU using the following formula (Ambrosini et al., 2010):-

$$Correction = 10\log\left(\frac{6.6\times10^{6}}{180\times10^{3}}\right) \tag{5.3}$$

We calculated this value as $16dB$. Therefore, the total RFI power generated at this particular site is expected to be the difference between the total RFI at the antenna and the correction value by ITU which is $-28dBW$. This threshold is about $177dB$ higher than the recommendations limit set by ITU. By using the same method we calculated all the power level for radio astronomical windows and then also compared to the ITU threshold level. These are listed in Tables 5.3 to 5.7.

As a conclusion, we found that these polynomial fitting is useful in identifying limits for determining threshold for population density that affect RFI for radio astronomy. We suggest that the threshold between low and medium population density is $150ppl/km^2$ (Umar, Abidin, Ibrahim, Rosli, & Noorazlan, 2014). The suggestion of the limit between medium and high population density is $5152ppl/km^2$. This can roughly can be used for the Deuterium, Hydrogen, and Hydroxyl spectral lines as well. A more precise threshold can be referred to Table 5.4 to Table 5.7. The average RFI power levels in these categories are $-97dBm$, $-97dBm$, $-89dBm$ and $-81dBm$, respectively. The frequency with the highest peaks in these categories are at $1860MHz(-55dBm)$, $945MHz(-55dBm)$ and $947.5MHz(-54dBm)$, respectively (Umar et al., 2014).

Our conclusion is that to build a radio telescope, one has to find a site with a population density of below $150ppl/km^2$. The population density that will be very detrimental to radio astronomy observation above $5125ppl/km^2$. When we investigate the population density around the telescope in Table 2.1 we can see that most of these radio telescopes are located in a very low populated area. These radio telescopes are located in very less densely populated area and they are mostly located in lower then the threshold that we suggest in this study (i.e.$150ppl/km^2$).

We also compared on the possible RFI sources that might be used by humans that might contribute to the RFI as present in an appendix F.1. The typical sources of ground RFI contamination can be referred in Appendix F. We noticed that most of the 'personal' RFI sources from humans are short-range RFI and it will not affect radio astronomical observations within perhaps beyond 100 to 200 $meters$. These sources are unintentional interference that might be of more important if they exist in the observatory itself. We recommend these equipment to be Faraday caged.

5.2 The Contour Effect

In contour effect, we have studied the impact of the contour line and contour type on the radio signal observation. The contour line represents the elevation of the site. We have classified the contour form into several types as shown in Table 5.8, in order to clarify the best contour shape that gives the lowest RFI value. The contour view at the observation sites from the Google map application is shown in Fig. 5.8. When we plot the graph of power level in dBm versus frequency, we found that there is a certain trend that the RFI increases and decreases depend on the contour type. We use this technique to identify the thresholds for the contour effect on RFI. We also expand the investigation of the effect of contour on the RFI environment into four astronomical windows, namely Deuterium, Hydrogen and Hydroxyl lines. We then compare our interference values to the ITU threshold standard level within this spectrum windows. The RFI value is not just due to the elevation position, but also influenced by the surrounding factors such as hill blockage, tree, residential area and plantation area.

We have plotted graph of power level versus frequency for various sites around Cameron Highland. They are Puncak Arabella (PA), Puncak Arabella-up (PAU), Quarters of Telekom (QT), Jabatan Kerja Raya (JKR), Malaysian Agricultural Research and Development Institute (MARDI) and Robinson Fall (RF). The cross section for each of these sites are illustrated in Fig. 5.9. Blockage features for each location are as shown in Table 5.9.

The RFI profile up to $2.8GHz$ by various sites and types of blockage are illustrated in the graphs in Figure 5.10. As we can see from the graphs, the highest RFI value is presented in contour type-I and type-II, while contour type-III and type-IV are moderate level. The lowest value of RFI is presented by the blockage type-V. Average power level for blockage type-V is about $-100.093dBm$. The average RFI levels for the rest of the type are shown in Table 5.9.

To see the effect of contour within the radio astronomical windows of interest, we also plot graphs of RFI level versus the altitude for 4 spectral lines which are Deuterium line, DI (Fig. 5.11(a)), Hidrogen line, HI (Fig. 5.11(b)), Hydroxyl-1, OH-1 (Fig. 5.12(a)) and Hydroxyl-2, OH-2 (Fig. 5.12(b)) and the average contour effect on RFI level is shown in Figure 5.13. We can see that most of radio astronomical windows show that the power level is proportional to the altitude of sites. The frequencies with the highest peaks in these categories are at $383MHz(-60.6dBm)$, $166MHz(-79.5dBm)$ and $1089MHz(-83.6dBm)$.

Table 5.8: Types of blockage at observation site

Types of blockage	Surrounding factor
V	- almost completely surrounded by the hill and trees, - jungle area as well
IV	- almost block by the hill and plantation area
III	- block by the hill and near the road way
II	- block by the hill, trees and residential area (etc. apartment)
I	- open site, high land and residential area (etc. apartment)

We identify the prominent lines and possible sources, marked as 1,2,3,4,5; 1’,2’,3’,4’,5’; 1”’,2”’,3”’,4”’,5”’; 1””,2””,3””,4””,5””; 1””’,2””’,3””’,4””’,5””’ and 1”””,2”””,3”””,4”””, 5””” as shown in figure 5.10. The list of frequencies of the prominent lines and their possible sources is shown in Table 5.10. This frequency belongs to radio broadcasting (102.5 MHz), mobile communication (390 MHz, 947.5 MHz and 1852.5) and radio navigation (2720 MHz) (see appendix C). We also compared the strength of the prominent lines for all sources in Table5.11 until Table 5.15.

As we have done in previous section, we also calculated the total RFI received by the spectrum analyser. We used the average RFI level in the threshold windows,

Table 5.9: Six observation sites selected (in Tanah Rata, Cameron Highland, Pahang).

Sites	Altitude (m)	Power Level (dBm)	Blockage types
Robinson Fall (RF)	1419	-100.093	type-V
MARDI	1421	-99.5783	type-IV
JKR	1429	-98.6197	type-III
Quarters of Telekom (QT)	1455	-99.1997	type-II
Puncak Arabella (PA)	1474	-97.8593	type-I
Puncak Arabella-up (PAU)	1495	-95.2904	type-I

Figure 5.8: Contour view at selected sites using Google map at Tanah Rata, Cameron Highland : area cover less than $1km^2$

Table 5.10: A selected prominent lines and possible sources of RFI

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
102.5 MHz	-70.6	-62.5	-82.7	-62.5	-68.7	-80.3
390.0 MHz	-76.8	-68.3	-88.4	-89.7	-91.8	-100.6
947.5 MHz	-67.3	-62.6	-71.3	-70.8	-71.2	-71.7
1852.5 MHz	-73.7	-99.0	-67.6	-78.7	-100.0	-81.1
2720.0 MHz	-71.6	-80.1	-84.8	-763	-100.0	-100.7

Table 5.11: Prominent lines for102.5 MHz

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
102.5 MHz	-70.6	-62.5	-82.7	-62.5	-68.7	-80.3
Different from open site	0	8.1	12.1	8.1	1.9	9.7

for example, at $-97dBm$ for average within 0 to $2.8GHz$ (see Table 5.16). We can determine the power level using Equation 5.2. We calculated the value of the FSPL power level for these windows as $50dBm$. The total RFI seen at the antenna focus was $-97dBm + (50) = -47dBm = -77dBW$. However, we need to add a correction value as recommended by ITU using Equation 5.3. As we calculated before, this value was $16dB$. Therefore, the total RFI power generated at this particular site is expected to be the difference between the total RFI at antenna and the correction value by ITU which is $-61dBW$. This threshold is about $144dB$ higher than the recommendations limit set by ITU. By using the same method we calculated all the power level for radio astronomical windows and then also compared to the ITU threshold level. These are listed in Table 5.16.

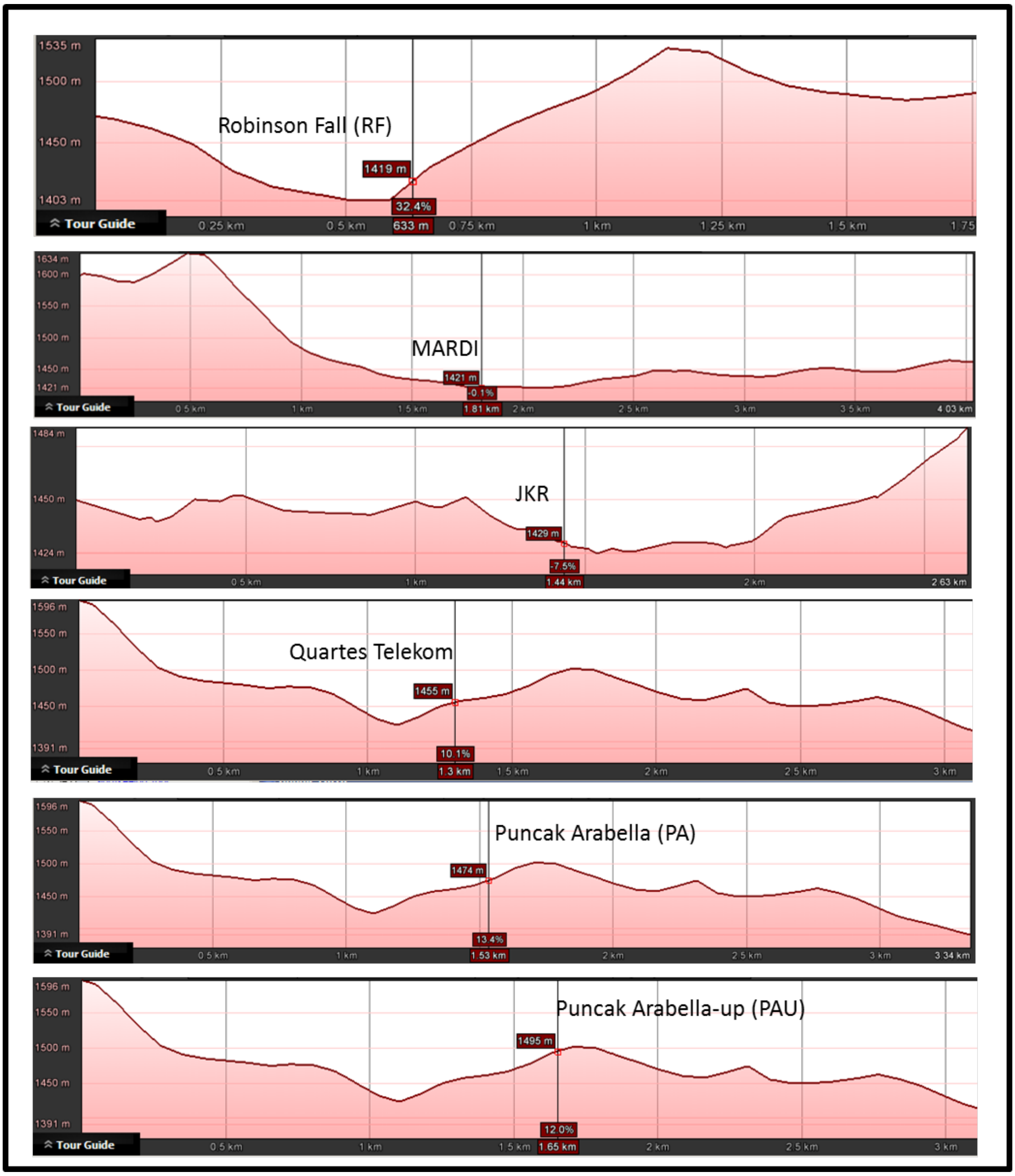


Figure 5.9: Cross section of each observation site

Table 5.12: Prominent lines for390.0 MHz

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
390.0 MHz	-76.8	-68.3	-88.4	-89.7	-91.8	-100.6
Different from open site	0	8.5	11.6	12.9	15.0	23.8

We concluded that this technique is useful in identifying the limits for determining threshold for elevation position that affect the RFI for observation site. We found that the Type-V contour provides the lowest RFI with the elevation of 1419m. Meanwhile, we found that the elevation value of Type-IV is 1421m. The strong RFI is detected at

Table 5.13: Prominent lines for 947.5 MHz

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
947.5 MHz	-67.3	-62.6	-71.3	-70.8	-71.2	-71.7
Different from open site	0	4.7	4.07	3.5	3.9	4.4

Table 5.14: Prominent lines for 1852.5 MHz

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
1852.5 MHz	-73.7	-99.0	-67.6	-78.7	-100	-81.1
Different from open site	0	25.3	6.1	5.0	26.3	7.4

Table 5.15: Prominent lines for 2720.0 MHz

Freq./Power level (dBm)	PAU	PA	QT	JKR	MARDI	RF
2720.0 MHz	-71.6	-80.1	-84.8	-76.3	-100.0	-100.7
Different from open site	0	8.5	13.2	4.7	28.4	29.1

the locations of Type-I which the elevation position is $1474m, 1495m$, while Type-II and Type-III contour have the elevation value of of $1455m$ and $1429m$ respectively (refer Table 5.9). This contour type recommendation (type-V) is based on the RFI results obtained during the observation. This is because of the location is sheltered by the hills and surrounded by trees and plants. As we mentioned before, type-V refers to the area that 80 % surrounded by hill and trees and approximately a jungle area as well. Completely covered, shielded or 100 % surrounded by mountain could be a good possibility for radio astronomy observation.

We can say that to locate a radio telescope, one has to find a site with suitable elevation position and good contour types such as type-V as we recommended. This type is very suitable to locate a radio telescope; this due to obstacle such as hills or mountains will attenuate radio wave signal. A location with a valley type also has the same advantage, but a proper selection must be done to cover as much sky view in order to receive more signals from the universe.

5.3 The Road Network

Observations have been conducted away from the commercial and industrial domain, since they will produce electromagnetic spectrum at longer wavelengths (centimetres to meters) which will affect the radio signal's observed (Jessner, 2013). In the meantime, the

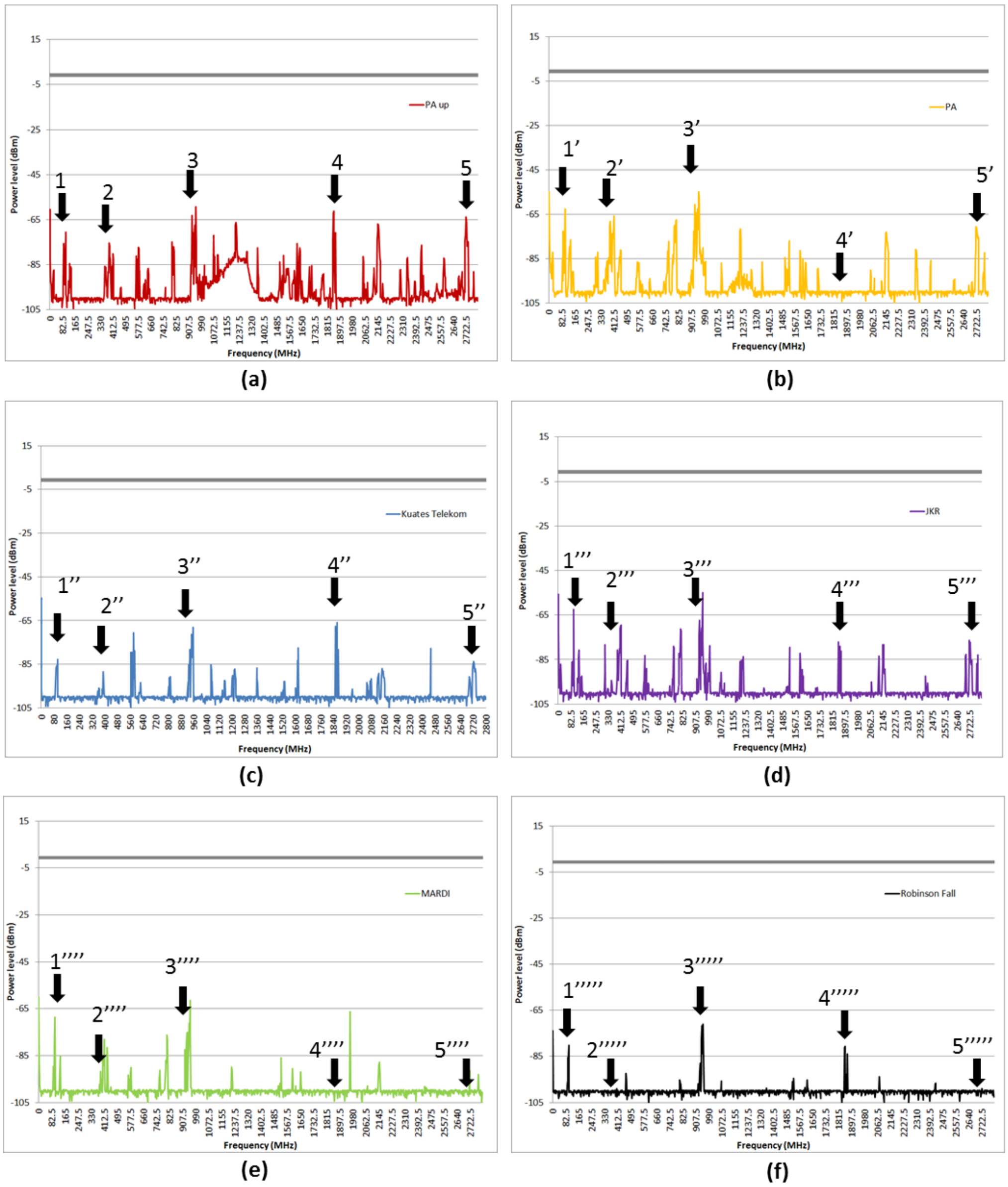
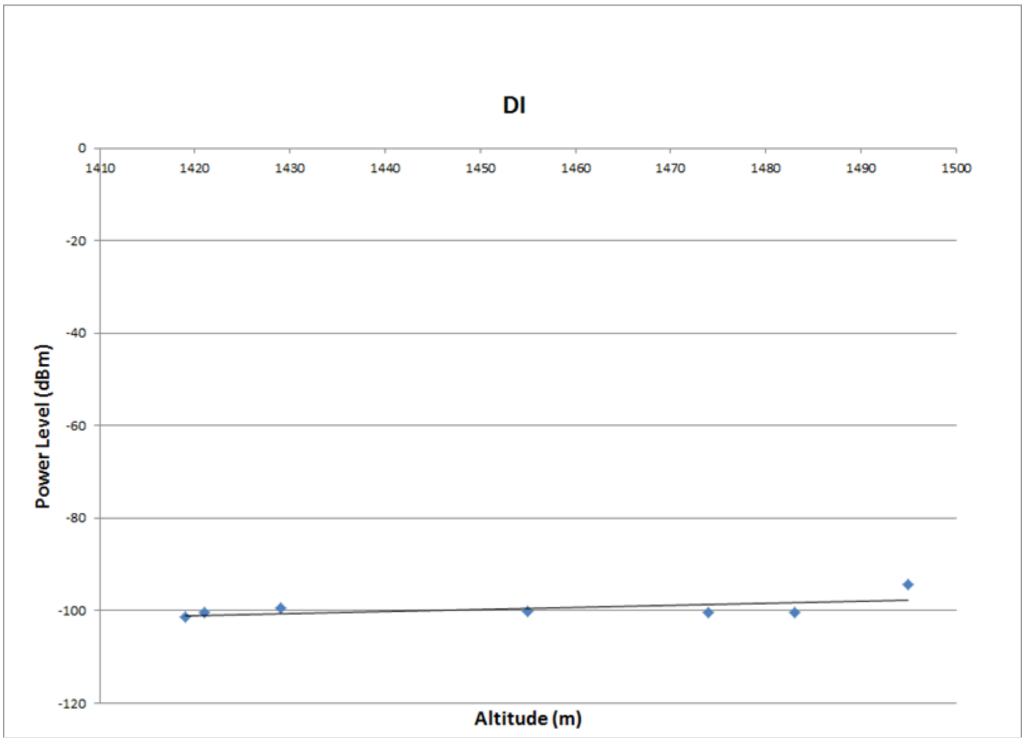


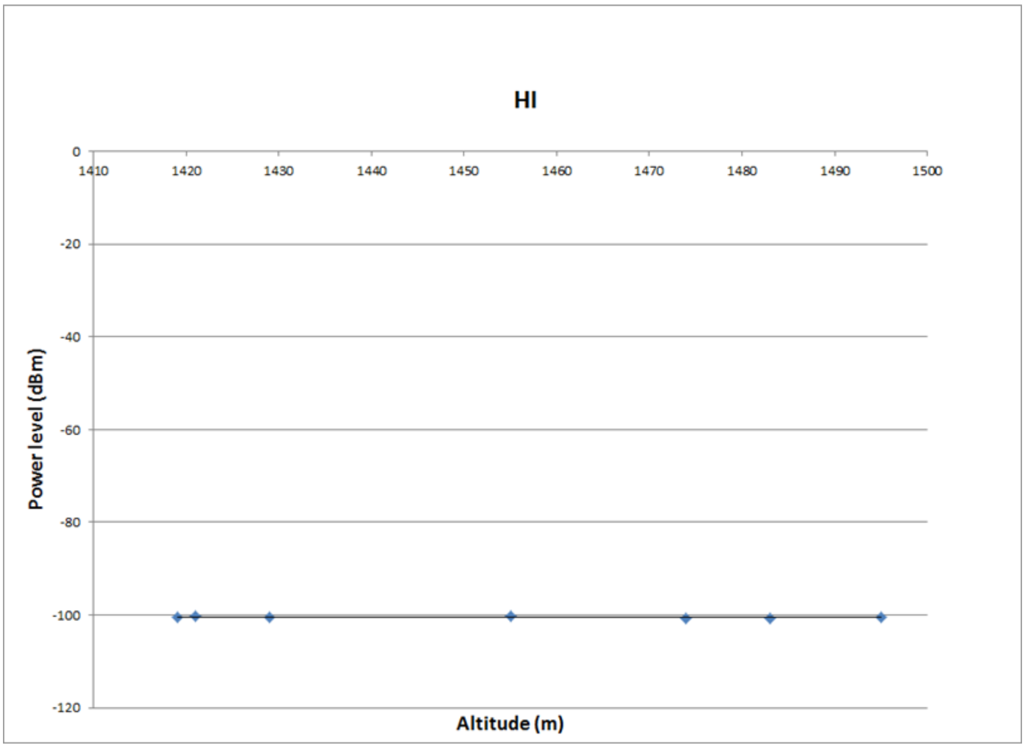
Figure 5.10: Detected radio spectrum at various type of contour: (a)Type-I (b)Type-I (c)Type-II (d)Type-III (e)Type-IV (f)Type-V

resulting radio emission from running vehicles can easily interfere the radio signal from outer space, since the signal penetrate the earth atmosphere is already weaken. Therefore, many observatories are protected from harassment by limited delivery zone, where the limit or ban the transmitter and industrial activities (Baars, D'Addario, & Thompson, 2009).

In this section, we discuss the effect of road network (highway) to radio astronomy observation. As we noted, the road network is related to the vehicles running on the road or highway. We assume that the active engines and electronic system from the vehicles may disturb the radio signals detected. We manage to make an observation at



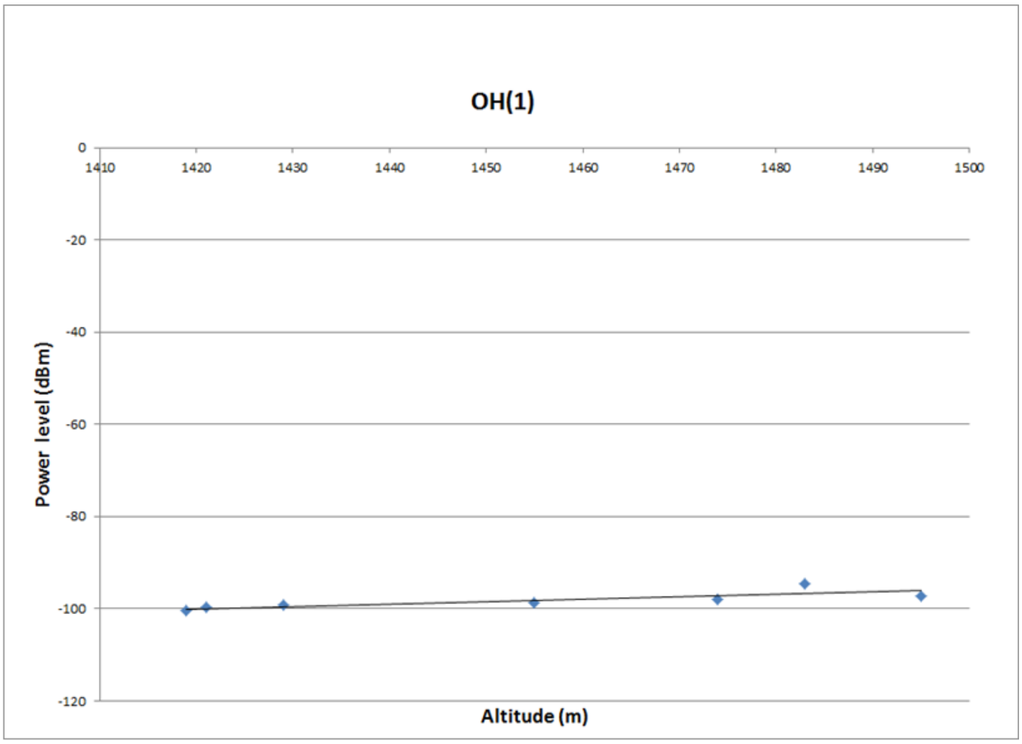
(a)



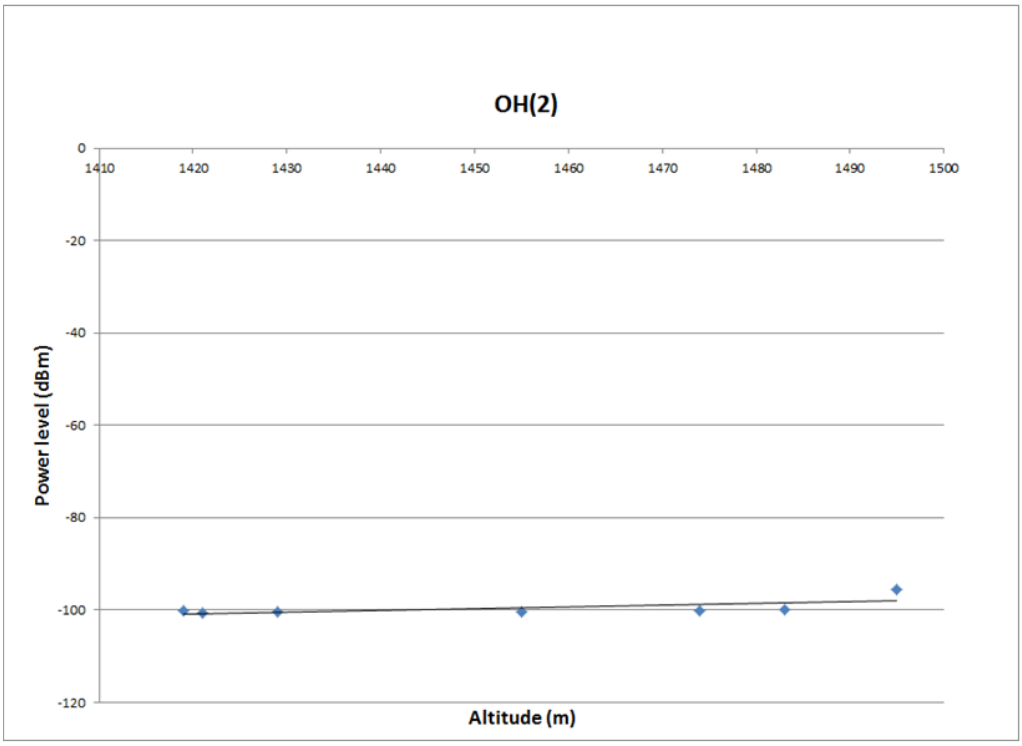
(b)

Figure 5.11: Contour effect for (a) Deuterium and (b) Hydrogen

several points of places ranging from 0 to 212m away from highways to see how the RFI influence by unintentional interference produced from the highway. We choose the most common highway used in peninsular Malaysia called Projek Lebuhraya Utara Sela-



(a)



(b)

Figure 5.12: Contour effect for (a) Hydroxyl-1 and (d) Hydroxyl-2 lines

tan (PLUS) nearby Universiti Pendidikan Sultan Idris (UPSI) in the province of Tanjung Malim, Perak as shown in Figure 5.16. We use the same method applied in the popula-

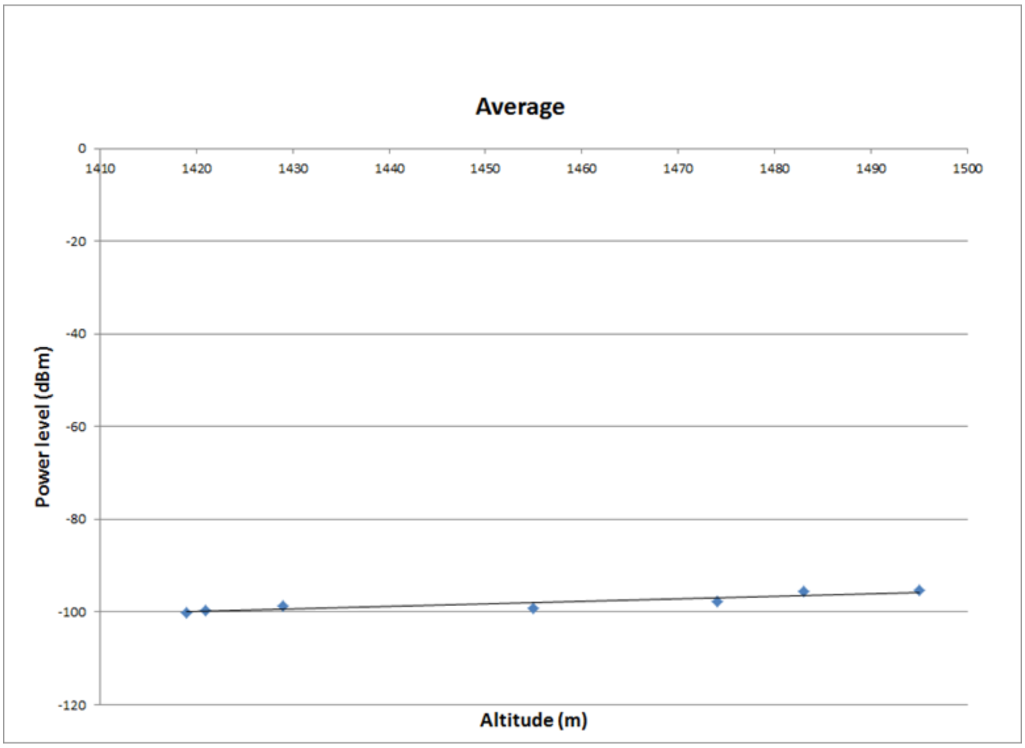


Figure 5.13: Contour effect for average

Table 5.16: Power level radio astronomy windows compared to ITU threshold

Average RFI (dBm)	Windows	RFI at Antenna(dBm)	ITU Threshold (dBW)	Exceed ITU by (dB)
-98 $\pm$ 0.4	DI	-45	-215	140
-100 $\pm$ 0.1	HI	-34	-220	156
-98 $\pm$ 0.9	OH-1	-31	-220	159
-99 $\pm$ 0.9	OH-2	-32	-220	158
-97 $\pm$ 0.7	Average	-31	-205	144

tion density factor which is quantifying the threshold limit of the road network in order to determine the most suitable lower limit for radio observation site selection.

We determined how the distance from the source highway affects the threshold levels from $0-2.8GHz$ and we also calculated these threshold levels in all radio astronomical windows up to $2.8GHz$. As we can see that in Figure 5.14, we found that unintentional interference that affected to radio astronomy at three regions, there are between 250 to $625MHz$,$880MHz$ to $1312MHz$ and 1500 to $1875MHz$.

The threshold level that we have calculated within astronomical windows is summarized in Figure 5.15. From the graph, we can conclude that the power level of RFI is inversely proportional to the distance, d. And then when we do the projection to see the appropriate distance, at noise level $(99.7dBm)$, we obtained $d = 520m$. We also use this

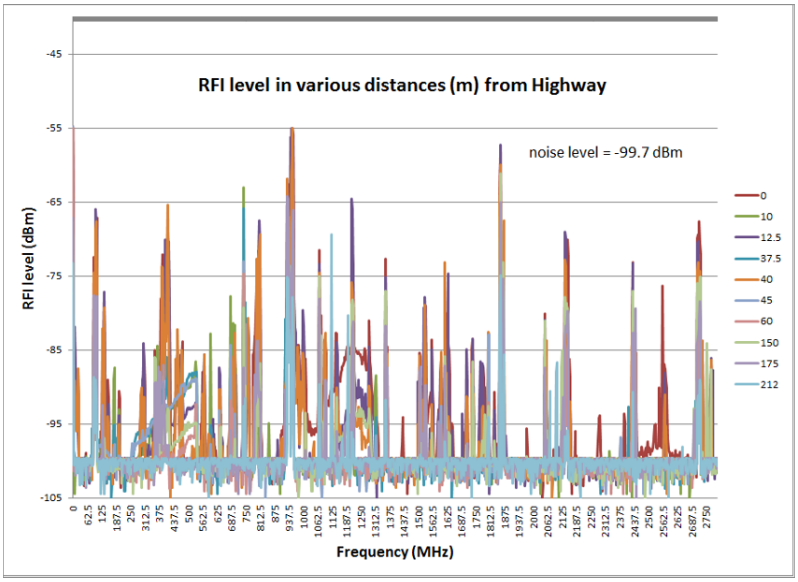


Figure 5.14: RFI profile in various distances from 0 to 2800MHz

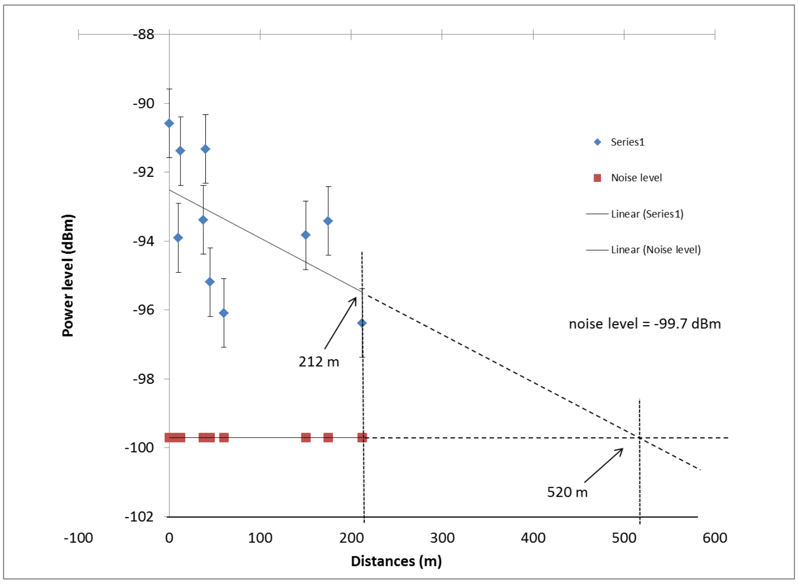


Figure 5.15: The projection of road network distance

technique to identify the thresholds for the road network that produces the RFI. Using this method we found that, for frequencies up to 2.8GHz, the high, medium and low road network distance affecting radio astronomy are below 212m, between 212m and 520m, and above 520m respectively. We also investigate the effect of road network distance on the RFI environment in three astronomical windows, namely the Deuterium, Hydrogen and Hydroxyl lines. We then compare our interference values to the RFI threshold standard levels within these spectrum windows.

As we explained in previous section, we have obtained the total RFI received by our spectrum analyser in this parameter. We used the average RFI level in the threshold

Figure 5.16: A satellite view from google map of the location for road network observation (nearby UPSI)

Table 5.17: Road network distance from ten sites

Sites	Distances from highway (m)
S1	37.5
S2	12.5
S3	10
S4	0
S5	40
S6	60
S7	45
S8	150
S9	175
S10	212

windows which is at $-98dBm$ for average within 0 to $2.8GHz$ (see Table 5.18). Using same distance, d from receiver to antenna, we have determined a power level using the same formula in Equation 5.2. We have calculated the value of the FSPL power level for these windows and we got $FSPL = 50dBm$. The total RFI seen at the antenna focus was $-98dBm + (50) = -48dBm = -78dBW$. However, we need to add the correction values as recommended by ITU using the Equation 5.3. As we mentioned before, this value was $16dB$.

Therefore, the total RFI power generated at this particular site is expected to be the difference between the total RFI at antenna and the correction value by ITU which

Table 5.18: Average RFI (road network) at radio astronomy windows compared to ITU threshold

Average RFI (dBm)	Windows	RFI at Antenna(dBm)	ITU Threshold (dBW)	Exceed ITU by (dB)
-99 $\pm$ 1.0	DI	-46	-215	139
-100 $\pm$2.2	HI	-34	-220	156
-99 $\pm$ 0.8	OH-1	-32	-220	158
-100 $\pm$ 0.7	OH-2	-33	-220	157
-98 $\pm$0.8	Average	-32	-205	143

is $-62dBW$. This threshold is about $143dB$ higher than the recommendations limit set by ITU. By using the same method we calculated all the power level for radio astronomical windows and then also compared to the ITU threshold level. These are listed in Tables 5.18. The frequency with the highest peaks in these categories are at $412.5MHz(-65dBm)$, $1857.5MHz(-57.25dBm)$ and $955MHz(-54.9dBm)$, respectively.

Finally, we found that this technique is useful in identifying the limits for determining the threshold level of road network that affect RFI for radio astronomy. We suggest that the threshold between high and medium road network distances is $212m$. The suggestion of the limit between medium and low road network distance is above $520m$. The average RFI up to $2.8GHz$ gives us three road network distances threshold windows that represent high, medium and low effect of road network, which is below $212m$, between $212m$ and 520 and above $520m$ respectively.

From this study, we can also conclude that the RFI produced by vehicles (ignition system) disturb the radio astronomy observation in certain windows, for example, $250MHz$ to $625MHz$, $880MHz$ to $1312MHz$ and $1500MHz$ to $1875MHz$ (refer Figure 5.14(a)). We also can conclude that most of the unintentional RFI (ignition system) tends to detriment in low frequency especially in L-band window.

We can summarize that, to build a radio telescope, one has to find a site with the distance from the road network is far away. The interference from ignition system will be very detrimental to radio astronomy observation below or near $212m$. However, to protect interference it is not just only $520m$ but more than $16km$ as established and recommended by NRAO this due to the cost of building this radio telescope is very high.

5.4 The Rain Effect

Rain affects the transmission of an electromagnetic signal in three ways: (1) attenuate signal, (2) it has increased the system noise temperature; and (3) it change the polarization. All these three mechanisms will degrade the signal quality (Nelson, 2000). At C- band the effect of rain is minor and while in the Ku-band the rain effect is significant. However, in L-band window, theoretically, we can say that the effect is too small. Rainfall or raindrop is one of the important factors affecting the propagation of the waves in the millimetre waveband (Hassan, Ali, & Alhaider, 1985).

The condensed forms of water in the atmosphere can come in several sizes, they are mostly scattered visible light, but absorb over a broad range of infrared wavelengths. Water appears in the atmosphere in a variety of forms usually referred to by the term hydrometer, which includes particles as diverse as cloud, raindrops, snowflakes, ice crystals, hail and graupels. The effect that hydrometer have on radio astronomical observation system depend on the type of particle present (Barclay, 2003).

The theoretical work by Ryde and Ryde in the early 1940s represents seminal research in this field (Okamura & Oguchi, 2010). The attenuation in radio path depends on to the number of the raindrop and not explicit upon their speed or direction. Since rain rate is a product of density and velocity, it can be express as a vector.N_D Drops of vector per cubic centimeter with diameter, D and velocity V_D, the fraction define as (Buthroff, 1970),

$$\rho_D = \frac{\pi}{6} N_D D^3 \tag{5.4}$$

The attenuation signal increase as the wavelength approach the size of a typical raindrop size, which is about 1.5 millimetres. As we know that wavelength and frequency are related by the equation,

$$\lambda = \frac{c}{f} \tag{5.5}$$

where λ, is the wavelength, f is the frequency and c is the speed of light (approximately equal to $3x10^8 ms^{-1}$). In this section, rain effect on the frequency below 2.8 GHz in tropical forest is further studied in details. Rain water on the antenna surface can cause additional significant signals attenuate. We investigate the influence of the rainfall factor and the size of raindrop as well on the RFI environment affecting radio astronomical windows.

Radio frequency which uses frequencies above $1GHz$ experience other losses to be taken into account as designing the system: atmospheric absorption. Attenuation depends on three main factors when it rains: (1) the rain falls, (2) frequency of wave propagation and (3) the length of the rain cell wave must propagate through. The average rainfall rate also varies from one part of the country, rainfall is common. The specific attenuation (Barringer & Springer, n.d.);

$$\gamma_r = KR_r^{\alpha} dB/Km \tag{5.6}$$

where R_r is the rainfall rate in milimetres per hours, and terms K and α are found as:

$$K = [3(F-2)^2 - 2(F-2)] \times 10^{-4} \tag{5.7}$$

$$\alpha = [1.143 - 0.07(F-2)^{\frac{1}{3}}] \times [1 + 0.085(F-3.5)e^{(-0.0066f^2)}] \tag{5.8}$$

where F is the frequency in GHz. These equations give a good approximation to attenuation curves published by ITU-R for frquencies below $50GHz$. Furthermore attenuation can also be caused by water vapor and oxygen present in the air. Attenuation due to water vapor and oxygen is less compared to rain and can usually be ignored.

In this section, we attempted to characterize and see the profile with the effect of rain in frequency $0-2.8GHz$, we suggest that rainfall is a very important factor and need to consider even for L-Band study. The rainfal characteristic is shown in Table 5.19. The objective of this study is to investigate the rainfall and the raindrop effect on radio astronomy observation in frequency $0-2.8GHz$ especially in four radio astronomy windows (Deuterium, Hydrogen and two Hydroxyl lines). In methodology section, experimental work for this investigation of raindrop is reported first. The raindrop effect on each radio astronomy windows are then studied and discussed.

We use the same method of quantifying the threshold limit in order to determine the most suitable lower limit for radio observation site selection. We had managed two type of observations: inside observation and outside observation. We placed the discone inside the building for inside observation while we put the discone in contact with different size of raindrop for outside observation. A rain simulator was used to simulate various raindrop sizes. We also investigate the effect of raindrops on the RFI environment in three radio astronomical windows, namely the Deuterium, Hydrogen and Hydroxyl lines. Table 5.20 shows the calculated drop shapes of 6 water drops whose equivolume radii range from 0.5*mm* to 5*mm*.

Table 5.19: Characteristic of rainfall factor

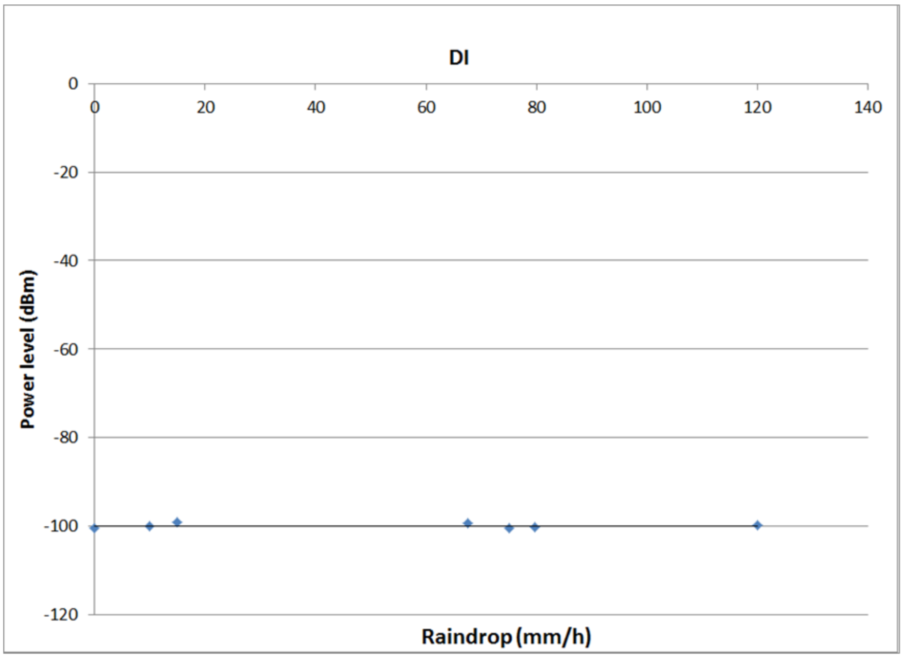
Types of rain	Rainfall (mm/hr)
no rain	0
drizzle	9
light rain	15
medium heavy rain-1	67
medium heavy rain-2	75
medium heavy rain-3	79
heavy rain	120

Table 5.20: Characteristic of raindrop factor

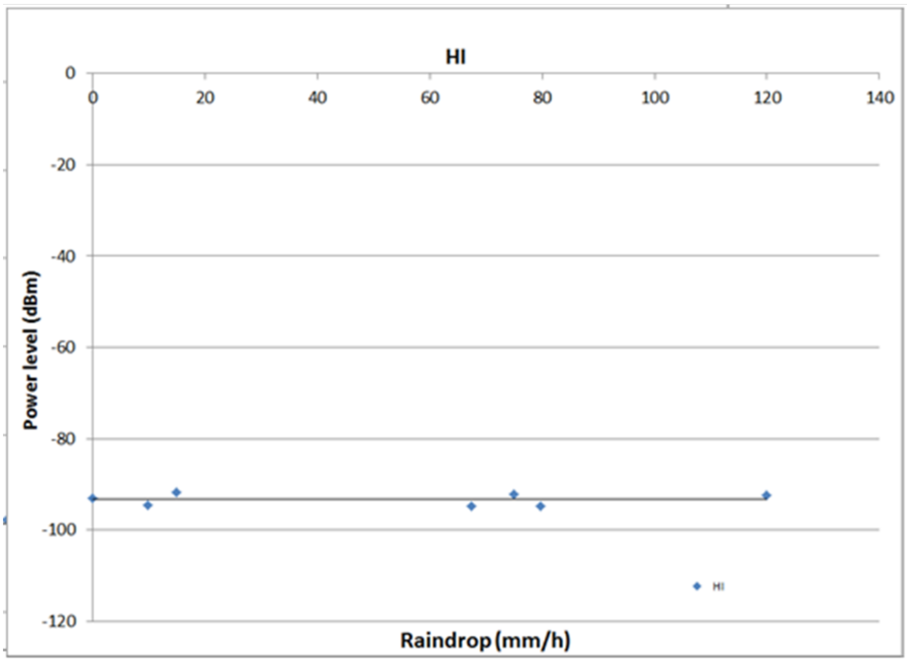
Types of raindrop	Size(mm)
I	0.5
I	0.8
II	1.2
III	2
III	3
IV	> 3
V	$\gg 3$

Firstly, for the inside observation analysis in Figure 5.17 and Figure 5.18 which is for all radio astronomical windows, shows that rain gives no effect to radio signal. We also have combined all of the graphs and we can see the signal increase and also dropped, but the value are very small (about $\pm 2dB$) as shown in Figure 5.19. As the value is too small, it can be considered has no significant effect.

Another case (outside observation), we have plotted the graph of power level versus the raindrop size to see an effect signal and noise by a raindrop. We also found that, there is no significant attenuate for both signal and noise as shown in Figure 5.20, Figure 5.20 and Figure 5.20.



(a)

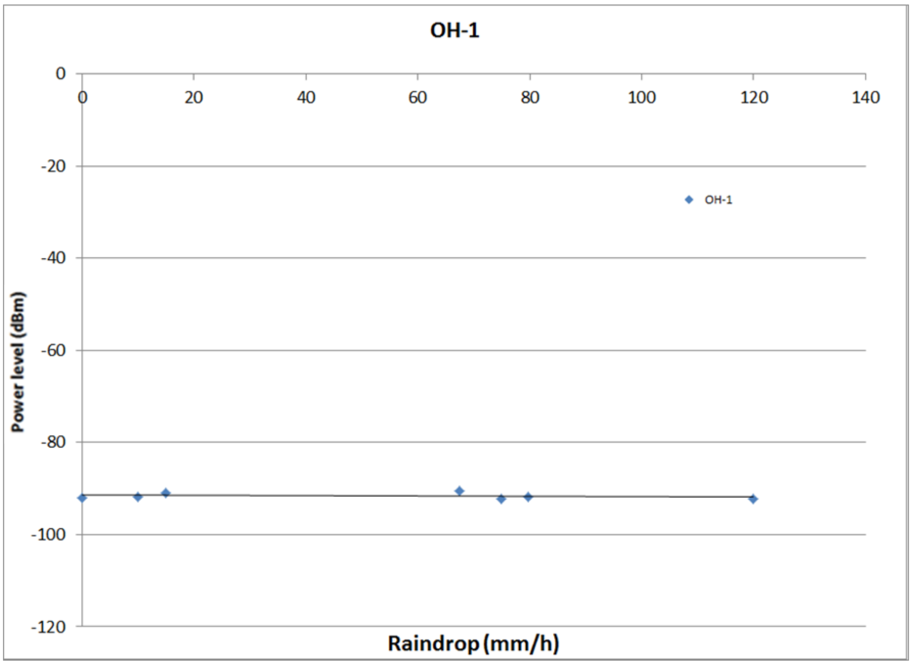


(b)

Figure 5.17: Rain effect for inside observation for (a) Deuterium line, (b) Hydrogen line,

We can say that there is no trend in all graphs plotted and we found that the raindrop factor gives no effect to the radio signal for both observations (inside and outside). We also can conclude that the size of a raindrop is not significant to frequency below $2.8GHz$. In this section, we did not find the threshold level to compare to the ITU threshold level.

For the future, new equipment such as spectrum analyzer with higher frequency is needed to study the effect of rain to radio astronomy observation especially frequency



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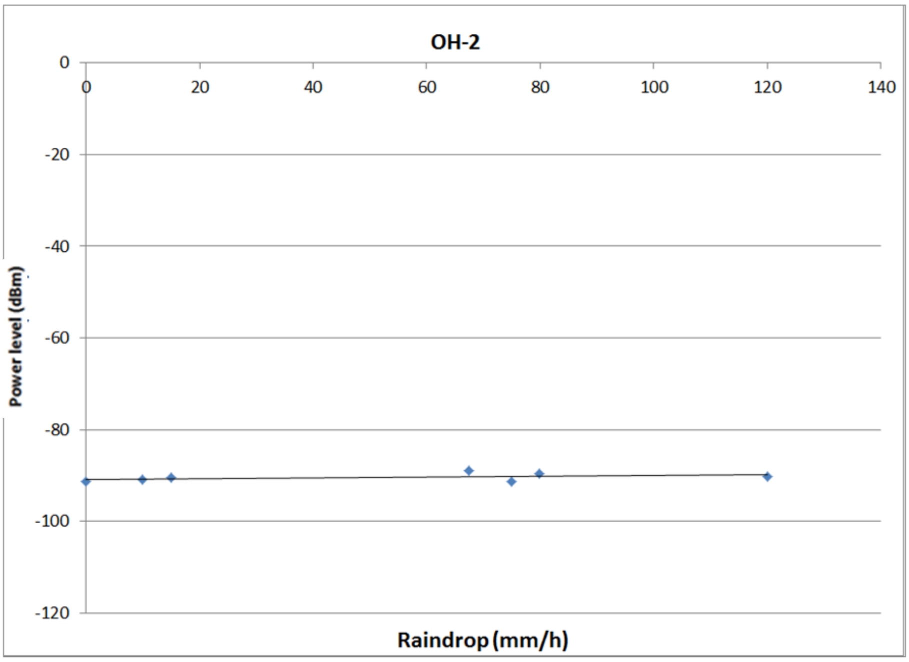


(b)

Figure 5.18: Rain effect for inside observation for Hydroxyl line-1 and (d) Hydroxyl line-2

above $3GHz$. Based on the past studied show that in the effect of rain to the radio signal is significant when frequency higher than about $7GHz$. This study should be repeated in highest frequency to obtain the threshold level and compared to the ITU.

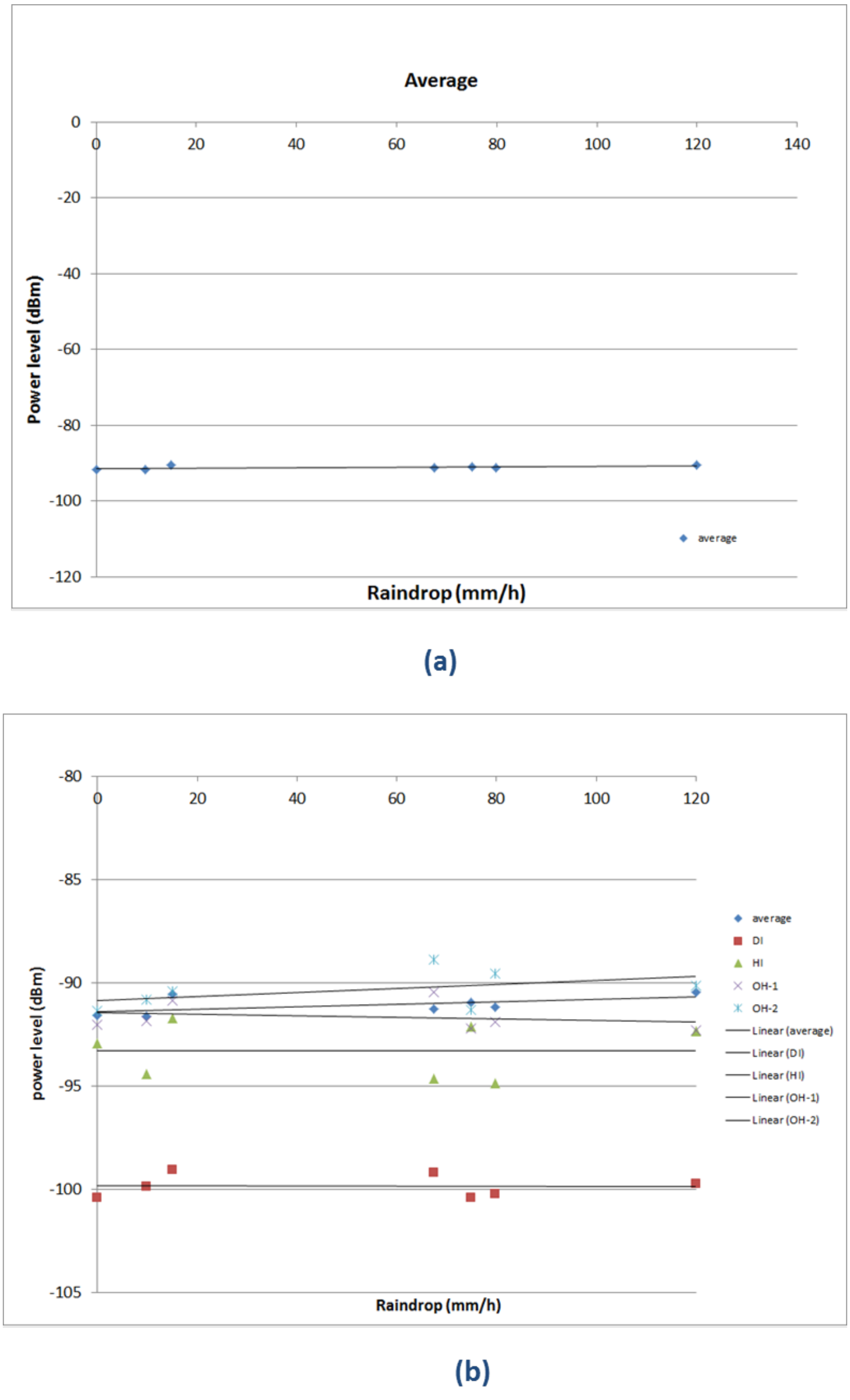
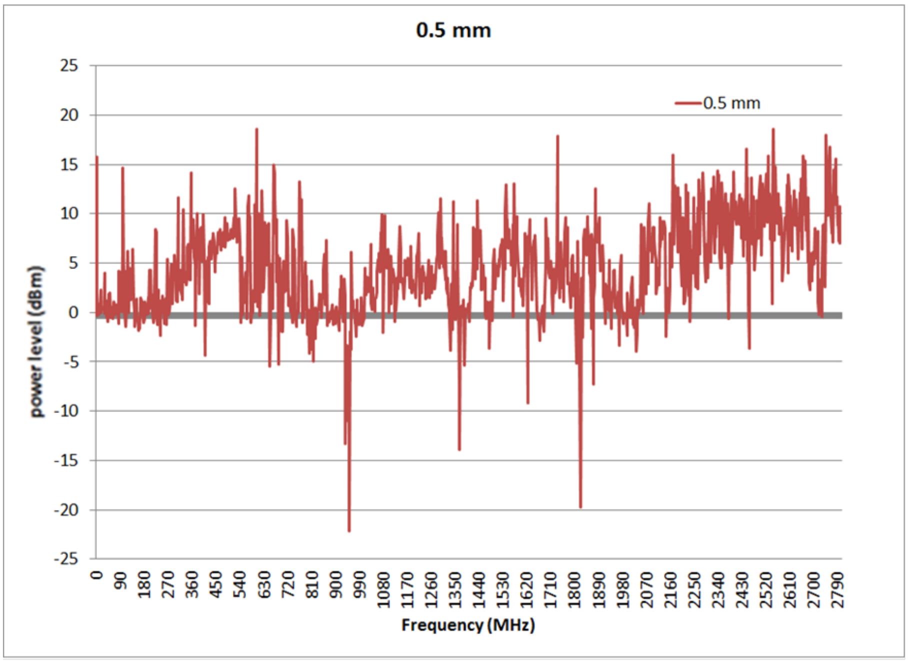


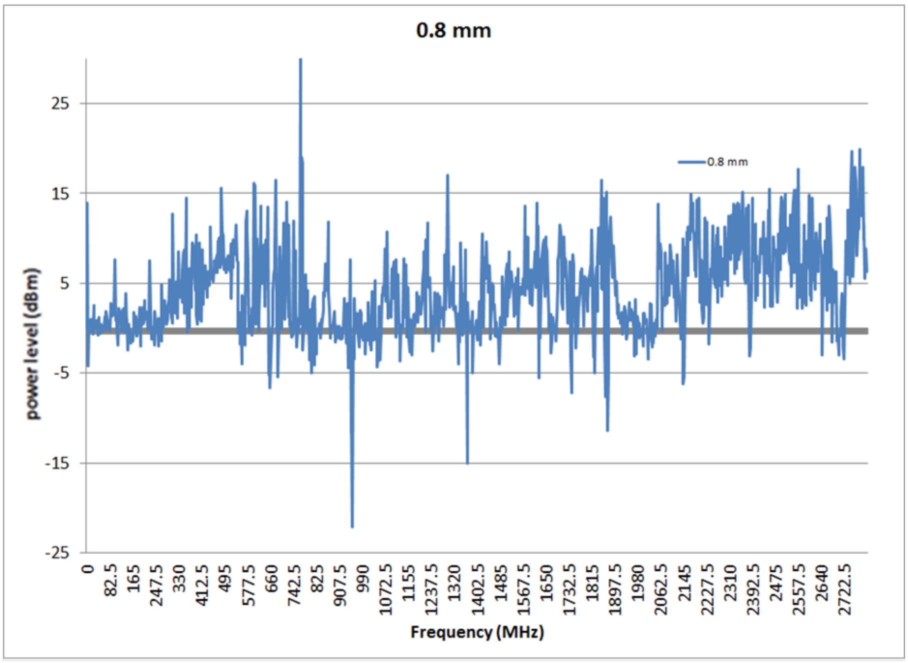
Figure 5.19: All spectral line combine

5.5 RFI Mapping

After we have done the observation for four parameters, the analysis show that rain does not affect the RFI observation. In this study, the RFI observation of an effect of different sizes of raindrop also performed to see is there any significant result of our RFI profile. Earlier in this study, we have predicted that the rainfall should effect the radio



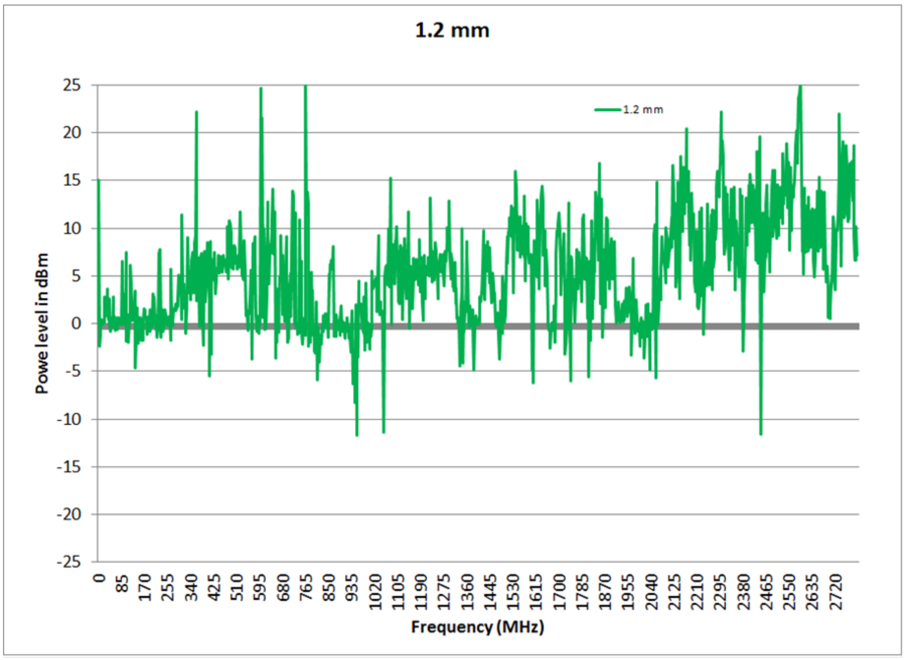
(a)



(b)

Figure 5.20: Rain effect for outside observation for various size of raindrop (a) 0.5*mm* and (b) 0.8*mm*

astronomy observation and the predicted threshold level is as shown in Table 5.21. However, after the observations are conducted, neither rainfall nor raindrop size can interfere the radio signals observed, thus, there is no change in the RFI value. So we have decided to exclude the rain effect in this analysis. As a result, the final multi-layer map considers only three parameters.



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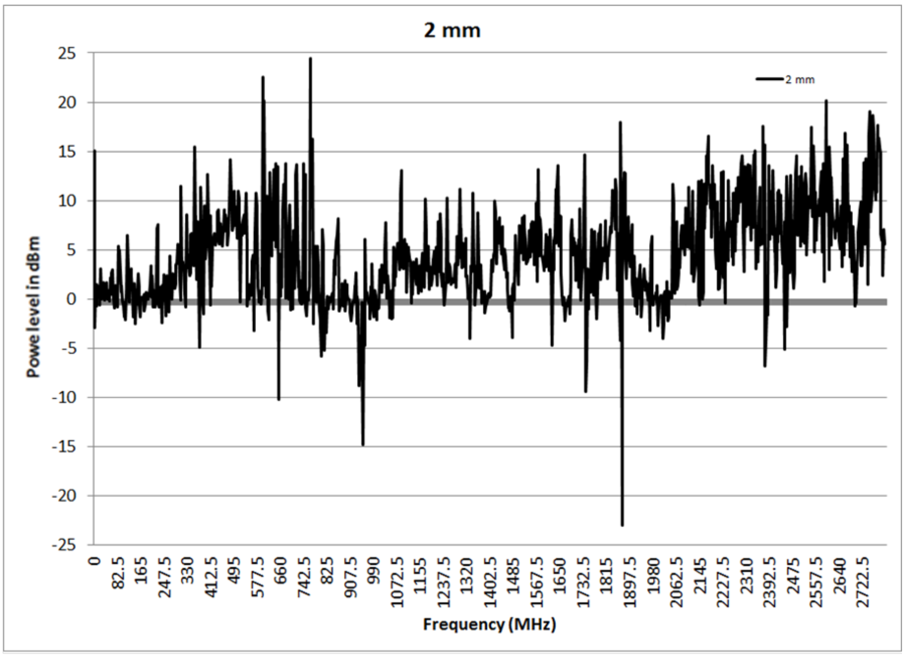
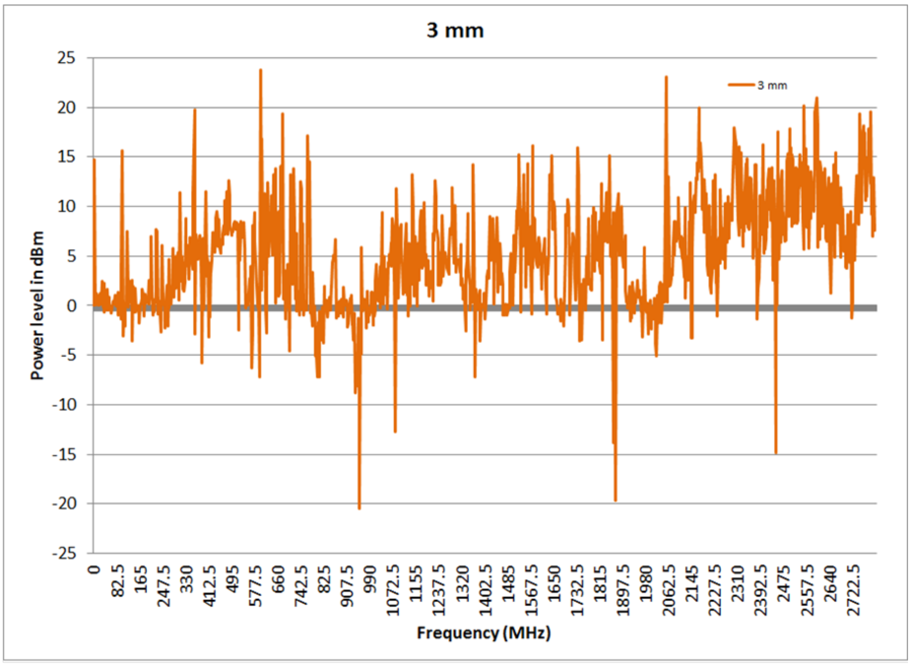


(b)

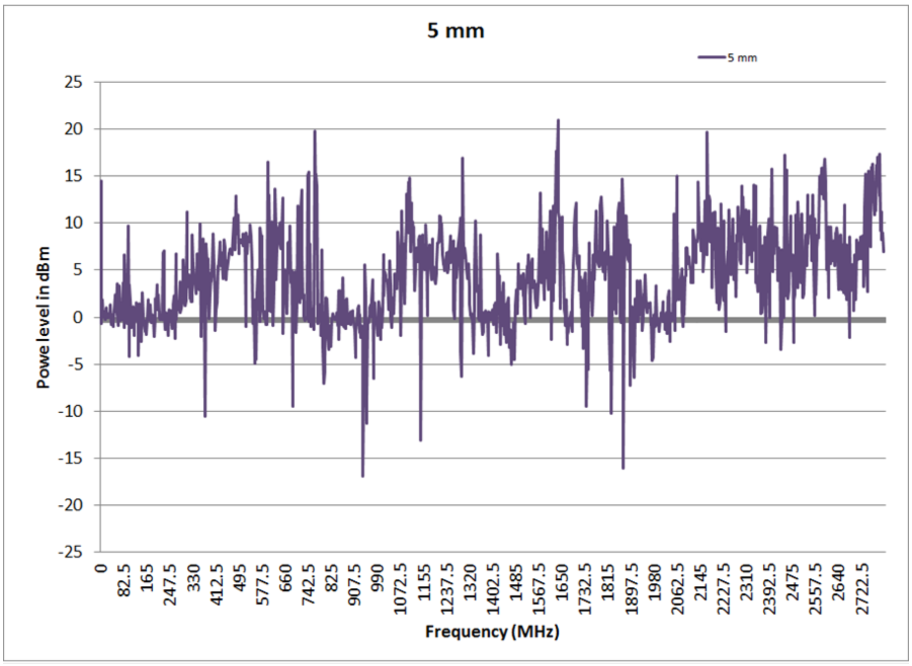
Figure 5.21: Rain effect for outside observation for various size of raindrop (a) 1.2*mm* and (b) 2.0*mm*

5.5.1 The Final RFI Map

By using the RFI mapping technique discussed in previous chapter, we obtain weightage for each of the three parameters as shown in Table 5.22. As calculated in the previous chapter, where *CI* is the consistent index and *RI* is random Inconsistency (Saaty, 1980), we have obtain the value of weightage is less than 0.10. The value of consistency gener-



(a)



(b)

Figure 5.22: Rain effect for outside observation for various size of raindrop (a) 3.0*mm* and (b) 5.0*mm*

ated by pairwise comparison is reasonable. We noted that the RI value for $n = 3$ is 0.58, while $CI = 0.02$ and $\lambda_{\max} = 3.04$. This value is given by Saaty and Tran (2007). We obtained the value of $CR = 0.04$ in this study, so that means our pairwise for matrix is acceptable. Table 5.22 is produced using the values of $CI, \lambda_{\max}, RI$ and CR calculated. In the final stage, each data layer that we analyzed will be combined using the calculated

Table 5.21: Predicted threshold level

Value	population density	Contour effect	Road network	Rain effect
100	0-150	17-140	17-70	164.33-188.1
75	150-568	140-365	9-17	188.1-202.9
50	568-1472	365-676	5-9	202.9-211.987
25	1472-3385	676-1093	1-5	211.987-223.5
0	3385-7851	1093-2061	0-1	223.5-241.01

weight coefficients to obtain the best sites result for radio observatory, using the GIS tools as shown in Figure 5.23.

Table 5.22: AHP pairwise comparison matrix and computed weights. * A: Population density; B: Contour and C: Road network

	A	B	C	Weight
A	0.692	0.6	0.714	0.668
B	0.076	0.066	0.047	0.063
C	0.230	0.333	0.238	0.267

The resultant map that indicates the candidate sites was produced after performing the dense computation for obtaining weights of corresponding criteria and multiplying each criterion with these weights using AHP and GIS. The suitable sites in terms of geographical and anthropogenic conditions, are extensively located in East Coast part of Peninsular Malaysia. The best possible sites that were obtained by applying a threshold value determined in this study are illustrated in Figure 5.23. We classified the suitability of the sites in three regions; 0, 50 and 100. The most suitable is 100, 50 is moderate and 0 is less suitable.

If we compare the resultant map for three parameters with the predicted map with 11 parameters that have been produced from GIS software, we can spot the difference. As we can see in the map of 11 parameters, the most appropriate sites are located in the North Eastern and South Eastern of Peninsular Malaysia as shown in Figure 5.24.

New radio telescopes are normally built in rural sites (Van Driel, 2009), the purpose is to minimize the risk of interference or to avoid from residential and commercial sites. However, there is no such sites can fully avoid interferences created by human being. This is because the signals are spread all around the atmosphere for mankind's benefit, for example, the aircraft communication purposes. Another source of interference is provided by the mobile network, for example the iridium mobile communications system, which

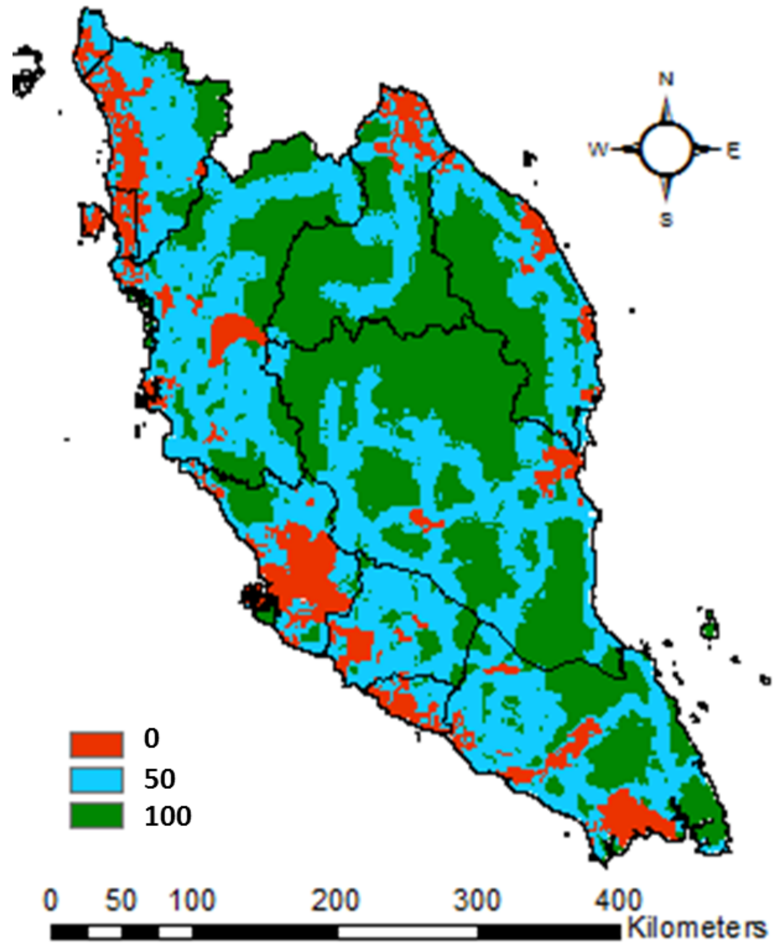


Figure 5.23: RFI map for three parameters

has a group of satellites transmitting signals to every point on the surface of the Earth. Unfortunately, in this case, there is some leakage into the passive band about $1612MHz$, with signal levels up to 1011 times as strong as signals of sources from the early universe (Ekers & Bell, 2000).

As we notice, the transmitters' satellites update yearly whereas hundred satellites launched every year (R. J. Cohen, 2003). In determining the prime candidate sites for radio astronomy and RQZ as well, we need to consider as much parameter as possible that affected to radio astronomy. This study is very important to avoid the RFI disturbance in radio astronomy observation especially from human activity. Human RFI is one of the main threats in selection of suitable sites for the installation of a new radio telescope. Human made RFI, for example, microwave oven, mobile phone, radio and television transmitters and population density as well need to be addressed in this case. The RQZ was determined by transmission losses, there are two important parameters which are free

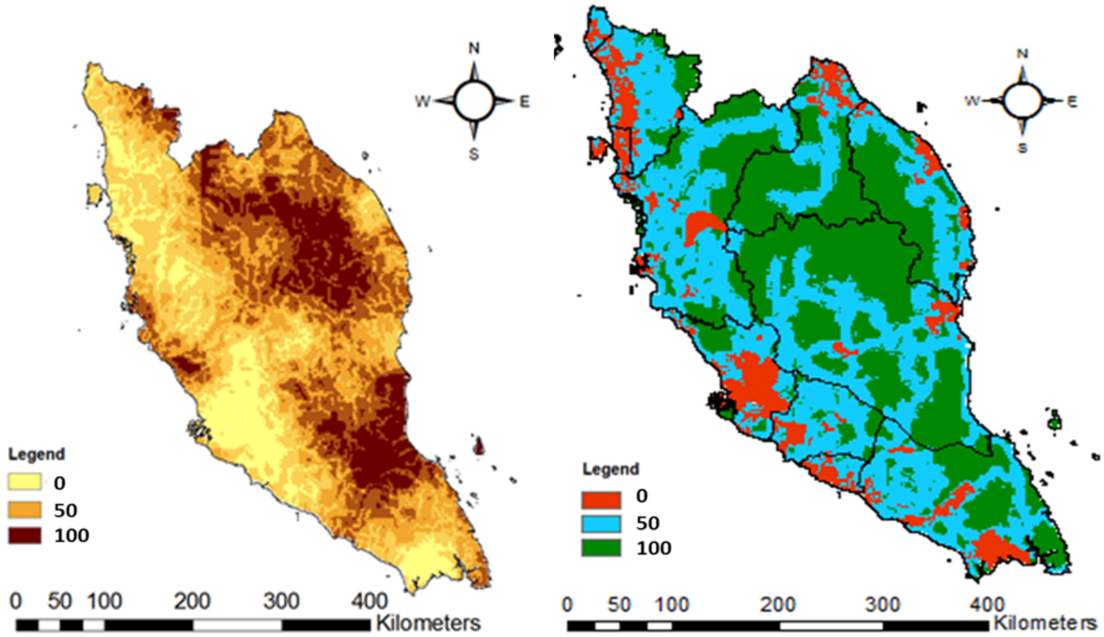


Figure 5.24: Both map (a) Eleven parameters and (b) Three parameters

space loss and diffraction loss (Peng & Han, 2009). In determining the prime candidate sites for the radio astronomy and RQZ as well, we need to consider not only the population density but also another factor such as meteorology. After the location determination using GIS, we need to visit the selected sites. Then we need to make the observation and perform the RFI measurement. From the data analyzed, we can decide whether the particular site is suitable for radio observations.

Moreover, for future works, more sites, parameter, techniques and sensitive equipment can be managed to produce a better results in finding the best site for radio astronomy observation in Malaysia. There is a range of technique that can make some passive use of other bands possible for example screening, decoding, calibration, cancellation and adaptive beam forming(Ekers & Bell, 2000).

5.6 Conclusion

Various threshold values for each parameter were found. Parameters selected are population density, contour, road networks and raindrop. In the case of population density, we obtained a value of $0-150ppl/km$ as shown in Table 5.23. This threshold value indicates the lowest RFI observed, which normally falls in the area of rural sites.

In the contour case, we find that, in an area that has a V-type of contour detects a weak RFI, or RFI power devaluation. This is based on the study conducted around Cameron Highland area with the various types of contours selected.

The observation on the road network factor shows that the further the distance, the better site is obtained to mitigate the effects of RFI produced from the running vehicles on the roadway. This can be seen from the linear graph plotted.

The last parameter is the raindrop and rainfall effect. From the observation conducted at Kinrara residence, this factor shows no significant effects in this study. We can state that raindrop and rainfall do not play any role at low frequencies which below $3GHz$. However, further research on the high frequency band, for example, frequencies more than $3GHz$ are required to ensure that the impact is documented. From the study by several researchers showed that the rain gave a significant effect for an observation at frequencies above $10GHz$.

This threshold level is necessary for those in the field of radio astronomy to select the ideal place to do the radio observations. Threshold data will be used as the value for inclusion in the GIS system to produce RFI map's profile in Peninsular Malaysia.

Table 5.23: Threshold level four parameters obtained from obseravation

Group of RFI	Population density (ppl/km^2)	Contour Shileding Types	Road network (m)	raindrop
Low	0-150±50	V	>520	
Medium	150-5125±675	IV	212-520	-
High	5125 and above±675	I,II and III	<212	

CHAPTER 6

SUMMARY AND OUTLOOK

6.1 Introduction

In recent years, radio signals from the universe are difficult to be observed. This is due to much disruption or interference consequences of human technology, especially when it involves the telecommunications activities. Satellites from several countries around the world are launched almost every year. Not only are satellites from outer space, but with the advent of human devices such as mobile phones, microwave ovens, and other gadgets pose radio astronomical observations are very limited, particularly at low frequencies. These low frequencies are mostly utilized by telecommunications systems and satellite systems. Therefore, this fast-growing communication technology is put in concern because it may someday redshifted and disturbs the radio astronomical spectral range allocated such as hydrogen at $1420MHz$ frequency. This should be protected from certain quarters.

There are ranges of the spectrum actually used in radio astronomy activities, but unfortunately most of the frequencies are reserved for other uses and utilities. There is only 2% of all available spectrum are allocated for radio astronomy purposes which is below $50GHz$ of frequency. As we know we can't stop or ban the technology improvement due to the need for a better life of humankind nowadays. However, we could propose ideas on how to reduce the interference and disturbance to the radio astronomy window. A discussion is needed to solve this issue, and it requires the implementation and allocation from various responsible parties such as local, regional and international authorities. So the clash between science purposes and a better technology for human daily life needs can be solved by creating a win-win situation for both sides.

The radio astronomy field is new to the research environment in Malaysia. The nature of studies of astronomy among Malaysian researchers is normally directed to the optical observation rather than radio. So the RFI profile is needed to determine the best place to conduct an observation. This will lead to the optimal quality of radio signals detected and the radio telescope may operate at its maximum efficiency.

Several factors affecting the radio signals have been recognized and monitored to determine the degree of impact imposed on the signal of interest. All of these factors can attenuate and weaken the signals from outer space, thus the observation is very tough. So the map produced will avoid all these affecting factors based on the threshold decided along this study. We believe that this RFI profile will be very helpful for further research in radio astronomy. This study demonstrates the potential of GIS and MCDA in profiling the RFI, therefore selecting a suitable site for a radio astronomy observation in Peninsular of Malaysia is easier.

6.2 Final Conclusions

RFI study is very important and will give a pretty good impression on the selection of a place to do radio observations. This will provide a suitable environment in an RFI. This is a good start in the study of radio astronomy in Malaysia, where we are expecting to be the first of the countries in Southeast Asia developing the radio astronomy observatory. In Southeast Asia, radio astronomy field is still in its early stage. The site selection is also one of interest in this study and these data could be the basis for the next generation.

Threshold levels are separated into two parts, the threshold level prediction and obtained from observations. At the beginning of this study, the threshold levels are first predicted to produce the initial map. The value that was obtained after the observation will be used at the end of the study. Both of these will be compared and summarized to see the real picture on the study.

Prediction threshold initially consists of parameters such as the slope of the hill, rainfall, river, population density, road network, land used, mobile phone transmitter (2G and 3G), radio and communication transmitter (AM, FM and TV). Meanwhile, for parameters used for observation is population density, rain effect, contour effect and road network. Time constraints resulted in only four of these parameters carried out this observation. After observation, we have done only for three parameters which play an important role in this study. Selected parameters are population density, contour and road network while the rain effect did not give any significant effects in this study. Prediction threshold values specified can be seen in the Table 6.1.

Table 6.1: Predicted and actual Threshold level

Factors	Predicted	Actual value
Population density	0-150 ppl km^{-1}	0-150 ppl km^{-1}
Contour effect	-17 - 365 m	Type-V
Road network	17 - 70 km	> 520 m
Rain effect	164.33 - 202.91 cm^3	-

As we can see in Fig. 5.23 from the previous chapter, a selected area concentrated were North East and South East region of Peninsular Malaysia. Furthermore, these areas are about 300*km* and 200*km* away from the center of Kuala Lumpur. This makes the areas may have low indication in the RFI. Good facilities such as road accessibility and shielding by mountain are an advantage.

This study provides a good example of GIS application in the site selection of radio observations. By using complex criteria approach, it is proved to be an efficient and powerful method for selection of radio astronomy facility with low RFI environments in Peninsular Malaysia

6.3 Future Plan

By referring to the methodology in chapter 3, we had determined eleven parameters that may affect the radio signals of interest. However, in the observation stage, due to the time constraint, we managed to perform four RFI factors which are population density, contour, road network and rain effect. In the future, we will continue the study for the rest of parameters to complete the profile map.

Further research on the threshold determination should be done to improve the results and to alter the value as we are expecting a reduction in upper threshold value in population density. More types of contour and elevation position could be included. The surrounding area also plays a significant role for example the plantation such as palm tree could reduce more signal since it contains palm oil and it attenuate the signals. In this study, we classified the area randomly regardless the type of plants in the surrounding area. From our opinion, we believe that the elevation position are not enough parameter to characterize the RFI. We should also put the consideration on the contour shielding and the blockage effect for a better result. It is necessary to cover more types of contour, and distances from the road of interest to gain a better result.

Beside the RFI contribution from the road network, others unintentional RFI, such as power grids and rail way may also produce internal RFI to the measurements. For future work, we suggest that the RFI measurements should be repeated with consider others unintentional RFI varies due to human activities. In the current work the site selection is taken only road network. A different type or vehicle such as petrol, diesel, electric and hybrid vehicles also need to consider since in our observation we took vehicle randomly from the highway.

To build the observatory, we believe that we should avoid sites which is having a maximum value of rainfall or big size of raindrop in order to reduce the effect on radio signal attenuation. In the future we should consider others parameters such as wind and thunder effect of radio wave propagation.

Furthermore, this study should be extended to involve more parameters related. It is also important to consider that the land use in surrounding area, for example trees, plantation, hill and mountain, and other factors or obstacles during locating the radio telescope. Other parameters such as power grids, railway and airplane routes transmitter should be considered. A weather reports are also very important and can be used as parameters in the study of the RFI. It is because of these factors are constantly changing and often occurs unexpectedly. The use of GIS is also very important in mapping the interference disrupted throughout Malaysia. Further study should include Sabah and Sarawak to have a full view of Malaysia's RFI profile. Malaysia has a big potential of research study in the field of astronomy because of its strategic position and free from earthquake and volcanoes.

Appendices

APPENDIX A

LIST OF PUBLICATIONS

Journal Articles

1) Published

R. Umar, Z. Z. Abidin, Z. A. Ibrahim, Z. Rosli and N. Noorazlan. Selection of radio astronomical observation sites and its dependence on human generated RFI. *Res. Astron. Astrophys.* 14 (2). IOP Publishing. ISSN 1674-4527. doi:10.1088/1674-4527/14/2/012. **ISI Indexed**.

Z.Z. Abidin, **R. Umar**, Z.A. Ibrahim, Z. Rosli, K. Asanok and N. Gasiprong. 2013. Investigation on the Frequency Allocation for Radio Astronomy at the L Band, *Publications of the Astronomical Society of Australia* 30 (1), Cambridge University Press. ISSN 1448-6083. (DOI: 10.1017/pasa.2013.25). **ISI Indexed**.

R. Umar, Z.Z. Abidin, Z.A. Ibrahim, N. Gasiprong, K. Asanok, S. Nammahachak, S. Aukkaravittayapun, P. Somboopon, A. Prasit, N. Prasert, Z.S. Hamidi, N. Hashim and Ungku Ferwani Salwa Ungku Ibrahim. 2013. The Study of Radio Frequency Interference (RFI) in Altitude Effect on Radio Astronomy In Malaysia And Thailand, *Middle-East Journal of Scientific Research* 14 (6): 861-866, IDOSI Publications. ISSN 1990-9233. (DOI: 10.5829/idosi.mejsr.2013.14.6.2185). **ISI Indexed**.

Hamidi, ZS and Shariff, NNM and Monstein, C and Abidin, ZZ and Ibrahim, ZA and Hashim, N and **Umar, R** and Aziz, NAI. 2013. Space Weather: The Role of Solar Radio Monitoring in Malaysia and Implications of Sun Activities to the Earth. *International Journal of Fundamental Physical Sciences* 3(4): 57-63, IJFPS Publications. ISSN 2231-8186. (DOI:10.14331/ijfps.2013.330056). **Scopus Indexed**.

2) Accepted (Waiting to publish

R. Umar, Z.Z. Abidin, Z.A. Ibrahim, N. Gasiprong, K. Asanok, S. Nammahachak, S. Aukkaravittayapun, P. Somboopon, A. Prasit, N. Prasert and Z.S. Hamidi. 2013. A Preliminary Study of Radio Quiet Zones for Thailand and Malaysia, *Chiang Mai Univer-*

sity Journal of Natural Sciences 30 (1), Chiang Mai University Press. **Scopus Indexed**.

3) Will Be Submitted

R. Umar, Z. Z. Abidin and Z. A. Ibrahim. Radio Frequency Interference (RFI) Mapping for radio astronomy in Peninsular of Malaysia.

Proceeding

1) International Conference

Roslan Umar, Zamri Zainal Abidin and Zainol Abidin Ibrahim. The Importance of Site Selection for Radio Astronomy. 2014. Conference of Theoretical Physics and Nonlinear Phenomena (CTPNP) 2014: ”From Universe to String’s Scale”. Surakarta, Indonesia. 15 February 2014. **ISI Cited Publication**.

Roslan Umar, Zamri Zainal Abidin, Zainol Abidin Ibrahim, Mohd Saiful Rizal Hassan, Zulfazli Rosli and Zety Shahrizat Hamidi. Population Density Effect on Radio Frequencies Interference (RFI) In Radio Astronomy. 2011. Proceedings of International Conference on Physics and its Application 2011 (ICPAP2011). Bandung, Indonesia. 10-11 Nov 2011. **ISI Cited Publication**.

R. Umar, Z.Z Abidin and Z.Z Ibrahim. 2011. Implementing the Technique for RFI Mapping for Radio Astronomy in Malaysia. Proceedings of International Conference on Space Science and Communication 2011(IconSpace2011). The Gurney Resort Hotel and Resident, Penang, Malaysia.12-13 July 2011. **IEEE Publication**.

Z. S. Hamidi, Z. Abidin, Z.Z Ibrahim, N. N. M. Shariff, U.F.S.U Ibrahim and **R. Umar**. 2011. Preliminary Analysis of Investigation Radio Frequency Interference (RFI) Profile Analysis at Universiti Teknologi Mara. Proceedings of International Conference on Space Science and Communication 2011(IconSpace2011). The Gurney Resort Hotel and Resident, Penang, Malaysia.12-13 July 2011. **IEEE Publication**.

R. Umar, Z.Z Abidin, Z.Z Ibrahim, N. Gasiprong, K. Asanok, S. Nammahachak, S. Aukkaravittayapun, P. Somboopon, A. Prasit and N. Prasert. 2012. The Study of Radio Frequency Interference (RFI) in Altitude Effect on Radio Astronomy In Malaysia And Thailand. Proceedings of The 7th Siam Physics Congress (SPC2012). Krungsri River Hotel, Phra nakhon Si Ayutthaya, Thailand.9-12 May 2012.

N. Hashim, Z.Z. Abidin, U.F.S. Ungku Ibrahim, **R. Umar**, M.S.R. Hassan, Z. Rosli, Z. S. Hamidi and Z.A. Ibrahim. 2011. Radio Astronomy in Malaysia: Current Status and Outreach Activities Proceeding of 9th Pacific Rim Conference on Stellar Astrophysics (PRCSA2011), Lijiang, China. 14-20 April 2011

2) National Conference

Roslan Umar, Zamri Zainal Abidin and Zainol Abidin Ibrahim. 2012. The Importance of Radio Quiet Zone (RQZ) for Radio Astronomy. PRoceeding of National Conference on Physics 2012 (PERFIK2012), Colmar Tropicale, Bukit Tinggi, Pahang. 19 - 21 November 2012. **ISI Cited Publication**.

R. Umar, Z.Z Abidin, Z.A. Ibrahim, M.S.R. Hassan and N. Noorazlan. 2011. Altitude Effect on Radio Frequency Interferences (RFI) in Radio Astronomy. Proceeding of 7th Matemathics and Physical Science Graduates Congress (MPSGC), Faculty of Science, National University of Singapore (NUS), 12-14 Dec 2011.

Public Talk

R. Umar. Radio Frequency Interference (RFI) Mapping for Radio Astroniomy. Seminar on The Mystery of Dark Matter jointly organized by Dept of Physics, UM and Agensi Angkasa Negara (ANGKASA). National Planetarium, Kuala Lumpur. 19 May 2011.

R. Umar. Radio Astronomy Spectrum Pollution. PhD Seminar. Auditorium, Physics Department, University of Malaya. 4 October 2013.

APPENDIX B

THE ANALYTIC HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) is a multi-criteria decision making method that employs a procedure of multiple comparisons to rank order alternative solutions to a multi-objective decision problem.

By using three factors to calculate the weight, we must follow four step:

- Step 1 - Compare the factors
- Step 2 - Complete the matrix
- Step 3 - Normalization weight determination
- Step 4 - Calculate the Consistency Ratio(CR)

Step 1 - Compare the factors

To employing the pair wise comparison as done by Saaty 1980, the scale of measurement to rate the intensity of importance between two elements is adopted with a little modification which is given below:

- 1 Equal importance
- 3 Moderate importance
- 5 Strong importance
- 7 Very strong importance
- 9 Absolute importance

Detail see Figure 1.

Step 2 - Complete the matrix

	A	B	C
A	1	1/9	1/5
B	9	1	1/2
C	5	2	1

Step 2 - Calculate the Consistency Ratio (CR)

APPENDIX C

RADIO FREQUENCY ALLOCATION IN MALAYSIA

Table C.1: Radio spectrum allocation in Malaysia: 27.5 - 1427 MHz. This table was taken from MCMC (2011). Sources

Frequency Band (MHz)	Main Allocations
30.01-74.8	Mobile / Fixed / Amateur
74.8-75.2	Aeronautical Navigation
75.2-87.5	Mobile / Fixed
87.5-108 FM	Sound Broadcasting
108-137	Aeronautical Radionavigation / Aeronautical Mobile
137-138	Mobile-Satellite / Meteorological-Satellite / Space Operation
138-144	Mobile / Fixed
144-146	Amateur / Amateur-Satellite
146-148	Mobile / Fixed
148-149.9	Mobile-Satellite (E-to-S) / Mobile / Fixed
149.9-150.05	Radionavigation-Satellite / Land Mobile-Satellite
150.05-174	Mobile / Fixed / Maritime Mobile
174-230	TV Broadcast Channel 5 to 12
230-235	Mobile / Fixed
235-328.6	Mobile / Fixed
328.6-335.4	Aeronautical Radionavigation
335.4-399.9	Mobile / Fixed
399.9-400.5	Radionavigation-Satellite / Land Mobile-Satellite
400.5-400.15	Standard frequency and Time Signal
400.15-401	Mobile-Satellite / Meteorological-Satellite / Space Research
401-406	Meteorological Aids / Space Operation (S-to-E)
406-406.1	Mobile-Satellite (E-to-S)
406.1-430	Mobile / Fixed
430-440	Amateur Radio Allocation
440-470	Mobile / Fixed
470-798	TV Broadcasting Channels 21-47
798-862	Fixed 862-960 Mobile / Fixed
862-960	Mobile / Fixed
960-1215	Aeronautical Radionavigation
1215-1240	Radionavigation / Radiolocation / Satellite
1240-1260	Radionavigation / Radiolocation / Amateur
1260-1300	Radiolocation / Amateur
1300-1350	Aeronautical Radionavigation
1350-1400	Fixed / Mobile / Radiolocation
1400-1427	Radio Astronomy / Space Research

Table C.2: Radio spectrum allocation in Malaysia: 1427 - 2900 MHz. This table was taken from MCMC (2011). Sources

Frequency Band (MHz)	Main Allocations
1427-1452	Mobile / Fixed
1452-1518	Mobile / Fixed / Broadcasting
1518-1525	Mobile-Satellite (E-to-S) / Mobile / Fixed
1525-1559	Mobile-Satellite / Space Operation
1559-1610	Aeronautical Radionavigation / Radio Astronomy
1610-1710	Mobile-Satellite / Meteorological-Satellite / Radio Astronomy
1710-1930	Mobile / Fixed
1930-2025	Mobile / Fixed
2025-2120	Mobile / Fixed / Space Research / Earth Exploration
2120 -2170	Mobile / Fixed
2170-2200	Mobile-Satellite (E-to-S) / Mobile / Fixed
2200-2300	Mobile / Fixed / Mobile Satellite / Radio Astronomy
2300-2483.5	Mobile / Fixed / Radio Location / Amateur
2483.5-2500	Mobile / Fixed / Mobile Satellite / Radio Location
2500-2520	Mobile / Fixed / Mobile Satellite
2520-2655	Mobile / Fixed / Broadcasting
2655-2690	Mobile / Fixed / Mobile Satellite / Radio Astronomy
2690-2700	Earth Exploration / Radio Astronomy
2700-2900	Aeronautical Radionavigation / Radio Location

APPENDIX D

INTERNATIONAL ASTRONOMICAL UNION (IAU) LIST OF IMPORTANT SPECTRAL LINES

Table D.1: Astrophysically most important spectral lines

Substance	Rest frequency(MHz)	Suggested minimum bandwidth(MHz)
Deuterium (DI)	327.384	327.0 - 327.5
Hydrogen (HI)	1420.406	1370.0 - 1427.0
Hydroxyl radical (OH)	1612.231	1606.8 - 1613.8
Hydroxyl radical (OH)	1665.402	1659.8 - 1667.1
Hydroxyl radical (OH)	1667.359	1661.0 - 1669.0
Hydroxyl radical (OH)	1720.53	1714.0 - 1722.2
Methyladyne (CH)	3263.794	3252.9 - 3267.1
Methyladyne (CH)	3335.481	3324.4 - 3338.8
Methyladyne (CH)	3349.193	3338.0 - 3352.5
Formaldehyde (H_2CO)	4829.66	4813.6 - 4824.5
Methanol (CH_2OH)	6668.518	6661.8 - 6675.2
Ionized Helium Isotope (3HeII)	8665.65	8660.0 - 8670.0

APPENDIX E

ITU-R RECOMMENDATIONS ON RADIO ASTRONOMY

1. RA.314-8 Protection for frequencies used for radioastronomical measurements

2. RA.769-1 Protection criteria for radioastronomical measurements

3. RA.1513 L Levels of data loss to radio astronomy observations and percentage-of time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis

4. RA.1031-1 Protection of the radioastronomy service in frequency bands shared with other services

5. RA.1272 Protection of radio astronomy measurements above 60 GHz from ground based interference

6. RA.517-2 Protection of the radioastronomy service from transmitters in adjacent bands

7. RA.611-2 Protection of the radioastronomy service from spurious emissions

8. RA.1237 Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation

9. RA. 479-4 Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon

10. RA.1417 A radio-quiet zone in the vicinity of the L2 Sun-Earth Lagrange point

APPENDIX F

GROUND RFI CONTAMINATIONS

Table F.1: Typical sources of ground RFI contaminations (Umar et. al (2014))

RFI sources	Description	Solution/distances (m)
Electric lawn mowers	The motors used on electric lawn mowers are of the high-torque/high current variety	Use line filter on the motor.
Vacuum cleaners	Most of the modern vacuum cleaners are fairly well protecting from RFI/EMI. However, the inside of the motor will become fairly dirty since not all of the dust will stop by the collector bag	Use a capacitor at the brushes.
Electric shavers	Most of manufactured have built in RFI/EMI suppression capacitors	Use of external line filter.
Electric hot-water heaters	The typical electric hot-water heater has two heating coils controlled by separate thermostats. Since the coils draw large amount the current, thermostat switch contacts may become pitted over a period time	600$volt$ capacitor should be sufficient.
Gas oil-heat burners and thermostats	There are several places for interference generated in an oil or gas heating system. Two or many motors used in this system	Use bypass capacitor and line filter when necessary.
Electric heat thermostats	Most of electric heating system uses a combination thermostats/switch assembly for control of radiators	Bypass each set of contacts.
Doorbell transformers	Some doorbell systems are equipped with transformers that have a temperature-sensing shutdown mechanism	Find the problem of the system or replace the transformer.
Arc welders	Arc welders are capable of causing severe interference. Of course, there is no way to suppress the arc and leave the machine functions	A heavy duty line filter should be used directly at the transformer primary.
Electric fences	It is very common in rural area. A transformer step up the line voltage an automatic switch sends a pulse down the fence one every few second.	A resistor place in series with the fence wire will help to damp the pulse. Capacitor across the switch also helps $(5m)$.
Fluorescent lights /Neon sign	Noise from a fluorescent light is caused by the arc that excites the gas in the tube. Most of recently developerdoesn't use starters, which are the sources of many interference problems.	Keep distance about $3-6m$ (frequency from $10-100MHz$).
Television sets	The horizon and color burst oscillators are usually the cause. These amplifiers may malfunction and oscillate in the upper HF or VHF.	Add a high pass filter to theantenna terminal of the sets and use external line filter
Microprocessor and microcomputers	The use of microprocessor control of various appliances is relatively new.	Move away at least10m.

APPENDIX G

REC. ITU-R RA.769-2

Table G.1: Threshold levels of interference detrimental to radio astronomy continuum observations

Frequency, f (MHz)	Input power ΔPH (dBW)
13.385	–185
25.610	–188
73.8	–195
151.525	–199
325.3	–201
408.05	–203
611	–202
1 413.5	–205
1 665	–207
2 695	–207

Table G.2: Threshold levels of interference detrimental to radio astronomy spectral line

Frequency, f (MHz)	Input power ΔPH (dBW)
327	–215
1 420	–220
1 612	–220
1 665	–220

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