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The study on the effect of population density on radio frequency interference (RFI) analysis on dynamic spectrum at selected CALLISTO stations

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Radio Frequency Interference (RFI) has become a critical issue in radio astronomy observation in recent years. Compact Astronomical Low-Cost Instrument for Spectroscopy in Transportable Observatories (CALLISTO) is a worldwide network of spectrometer system for solar activity monitoring. The detection of solar radio bursts is being interrupted due to RFI as these stations are held on the ground. Since RFI signals are being detected from surrounding, this gives inaccurate data for ground base station observations. RFI sources are mostly from man-made devices. This paper study analysis of RFI level at selected CALLISTO stations by using Kurtosis Analysis. Data from Banting, Malaysia, Sumedang, Indonesia, Ooty, India and Daejeon, South Korea stations for two months (45–870 MHz) that contain solar burst and no solar burst had been selected. The kurtosis value is then compared with the population density to get the relationship between the population density and the RFI level. The highest average of kurtosis value indicates the lowest of radio frequency interference at these sites. MATLAB software was used for the data analysis and Microsoft Excel for the RFI profiling graphing. The results show that the high population density is not a main factor that contributes the interference towards the surrounding.

Key words: Radio Frequency Interference (RFI), radio astronomy, kurtosis analysis, e-CALLISTO.
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Introduction

Due to new developments in solar radio astronomy in Malaysia, which began in early 2011, the study of solar radio bursts has grown in recent years [1]. Radio astronomy is a young and vibrant science that is being studied in many different areas of the universe and makes many new discoveries. Quasars, pulsars, the Big Bang, and many other phenomena were first discovered by radio astronomers, to name a few examples of celestial objects captured [2, 3]. The celestial object is studied in radio astronomy observation by capturing radio waves [4] at all frequencies emitted from the celestial inside electromagnetic radiation. Radio Frequency Interference (RFI) is a significant step forward in the quest for new radio astronomical sources. This research is currently one of the most important sub-research in Malaysian radio astronomy [5]. To begin any radio astronomical observation, it is essential to investigate all potential RFI as RFI can interfere with any signal from celestial objects, posing a significant problem for radio astronomy [6].

In certain ways, there are several advantages to be found in radio wavelength. In ground observation, radio waves can be observed. The second explanation for conducting observations in radio waves is that certain objects and phenomena are invisible or difficult to detect in other wavelengths and can only be seen in radio wavelengths with greater sensitivity. The detection of radio astronomical lines has worsened due to increased RFI in the Ultra High Frequency (UHF) and Very High Frequency (VHF) bands, which affects the data in radio images [7]. RFI can come from both moving and non-moving devices, and it can come from either man-made or natural sources [8]. RFI waves are a form of energy that is generated from sources and includes both electric and magnetic properties. RF sources such as FM radio broadcasts, television, and telecommunication devices [9, 10]. Although RF signals are not radioactive, they can be harmful to people's health and have an impact on electrical circuits through electrical induction, electrostatic coupling, and conduction. Due to RFI, the detection of solar radio bursts is restricted since these stations are located on the earth. When using CALLISTO for observation, this RFI is a major obstacle. These man-made radio signals occur because the radio spectrum varies in time and frequency, and they are strong and high enough to be found and detected in the antenna primary beam response's far-out side lobes [11]. Based from [12] research on human population density on the RFI in radio astronomy, human-made radio frequency interference is accounted as it imposes harm towards solar radio observation and for CALLISTO site stations.

Data is obtained through e-CALLISTO, an official website for CALLISTO users from all over the world, and data is exchanged through this portal to enable this research to detect RFI sources for the profiling process. The CALLISTO spectrometer is a programmable heterodyne receiver for solar observation developed in the context of IHY2007 and ISWI by the former Radio and Plasma Physics Group (PI Christian Monstein) at ETH Zurich, Switzerland [13]. CALLISTO is a program that is part of the IHY/UNBSSI and ISWI instrument deployment program [14]. It is a network that can continuously monitor the solar radio spectrum. Since the 1980s, ETH Zurich has created a range of solar radio spectrometers [15]. The aim of e-Callisto is to create a global network that can continuously track solar radio bursts for 24 hours per day [16]. Figure 1 shows the global distribution of e-CALLISTO instruments [17]. With a frequency ranging from 45 MHz to 870 MHz, the spectrometer is used to detect solar radio activity [13]. The CALLISTO device has proved to be an extremely useful new method for tracking solar activity. Furthermore, it has evolved into a tool for determining solar radio emission from solar eruptions [14]. The goals of this study are to look into the levels of Radio Frequency Interference using e-CALLISTO stations, analyse it using the kurtosis process, and see if there is a relationship between population density and RFI level. As stated in [18], this kurtosis value was used as an "indicator" of radio environment level in this study. The highest average of kurtosis values indicates the lowest of radio frequency interference at these sites [7]. It is important to select low RFI sites when observing radio astronomical sources [19][20].

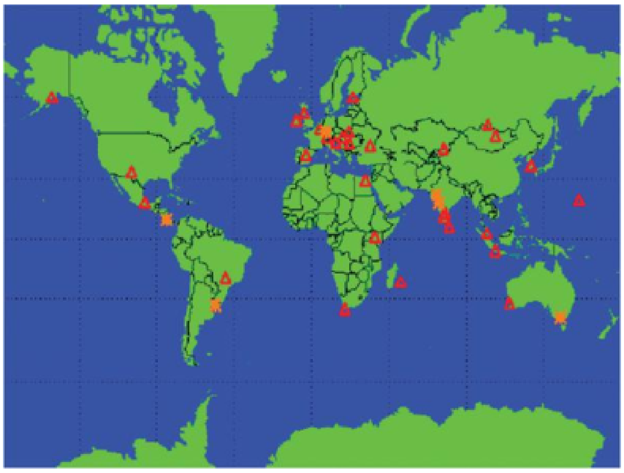

Figure 1 – CALLISTO Spectrometer Network Around the World.

Method of investigation

The data were collected from official CALLISTO site; e-CALLISTO. Two months data were collected from January 1 until 31 January 2017 and July 1 until July 31. These data were in a fit format. For 12 hours, each station provides 48 data spectrum per day, which gives the total 1440 data per month for one station. Banting, Ooty, Sumedang and Daejeon stations were selected because this county near each other and based on the same type of LPDA antenna. The conversion of the fit file is necessary to use the data, if not the data cannot be used for coding and profiling of the RFI versus frequency and human population, respectively. All stations use LPDA antennas, which are made suitable for the purposes for solar radio observation, as all stations use frequency from 45–870 MHz [21]. The fit file data collected were then extracted using zip file extract software. This extracted data then were analysed using MATLAB by converting the fit files into intensity data in decibels (dB). The average intensity level was obtained through coding. This step was repeated for all four stations for 'two months' worth of data. Each data from different sites varies due to the time the station was operated since sites were chosen from different countries. These stations were selected because the nearest stations such as Sumedang and Ooty can detect the solar burst however Banting station cannot detect it due to high in RFI. January and July data were selected because no burst detected on Banting in January but burst has been detected on Banting in July. The converted data were used to get the average intensity for each station sites.

The next step was analysis average intensity by using the kurtosis method. This kurtosis value act as an 'indicator' of radio frequency interference level at the selected stations. The highest in kurtosis value obtained indicates the lowest radio frequency interference. As such, the average of kurtosis value is computed to indicate the radio frequency interference without looking at the radio spectrum graph. Equation 1and 2 express the equation for kurtosis analysis.

$$a_4 = m_4 / m_2^2 \quad (1)$$

where

$$m_4 = \sum(x - \overline{x})^4 / n \, , m_2 = \sum(x - \overline{x})^2 \, / \, n \quad (2)$$

After data are analysed, RFI profiling takes place by comparing the data with their respective population density. By using Microsoft Excel, graphs were plotted to show as a result from the collected data. The sources of each station were then determined by its frequency bandwidth and its power level in decibels (dB) relating to their respective population density. Since RFI is primarily caused by humans indirectly, the population was chosen as the parameter. As the population density increases, the RFI increases with that as well. Human-made radio frequency interference is taken into account because it has a negative impact on solar radio observation and CALLISTO site stations. Radio frequency interference-free areas are described as areas where low signals and noises are proportional to the population density of the citizens. As a result, the population is chosen as one of the parameters because RFI caused by human activities is indirectly caused by population [22]. Assuming that with fewer amount of population of humans in an area, the less amount of RFI is contributed to the spectrometer. The population density data for Banting were obtained from the Department of Statistics Malaysia, and Ooty from Department of Economics and Statistics the Nilgris. Daejeon population data was obtained from Korean Statistical Information Service (KOSIS) and Sumedang population data was obtained from The Central Bureau of Statistics Sumedang. This data can be further reinforced through data obtained from Socioeconomic Data and Applications Centre (SEDAC), which was a data centre in NASA's Earth Observing System Data and Information System (EOSDIS) hosted by CIESIN at Columbia University.

Results and Discussion

The data for one month that contain solar burst and no solar burst occurrence had been analysed. The average value for RFI intensity in January 2017 was obtained and plotted against the frequency range 45 MHz to 870 MHz. Figure 2 until Figure 5 represents the average RFI intensity for one month starting from Jan 1 until Jan 31 2017 for each station. RFI profiling is necessary to show that the RFI intensity for each station is differently compared based on the level of the intensity. Based on the graph, the lowest radio frequency interference level is observed at Ooty, India as the lower in fluctuations is seen as compared to another three sites. To add to this analysis, the kurtosis value was calculated to determine the radio frequency interference level at these four sites. The highest in kurtosis value obtained indicates the lowest frequency interference level. Based on table 1, using the statistical kurtosis method, Ooty shows the highest kurtosis value of 2.0092 and Daejeon shows the lowest kurtosis value of 0.3019 while in 'Sumedang' the kurtosis value was recorded at 1.1807 and 0.3983 for Banting. Ooty was found as the best site of low radio frequency interference level with the highest kurtosis value in the wide band but it should compare with the standard deviation.

Daejeon differences between the kurtosis and the standard deviations were 28.2459 and Banting with -23.6768. Sumedang and Ooty with 6.7017 and 4.9835. As the Ooty was found as the best site compared with others because the difference value was the lowest. The interpretation of the standard deviation indicates the larger the value of standard deviation, the larger the curve to flat due to more data spread out. In the following part, the average values of radio frequency interference at four sites are also observed to strengthen the analysis. Based on the observation, the highest average value of radio frequency interference between the sites was found at Daejeon. It seems that the interference level was highest in Daejeon if compared to the other three sites. Since Daejeon has the lowest kurtosis value with the highest in the average value of radio frequency interference, we can certainly conclude that Daejeon as the worst site among the four sites observation.

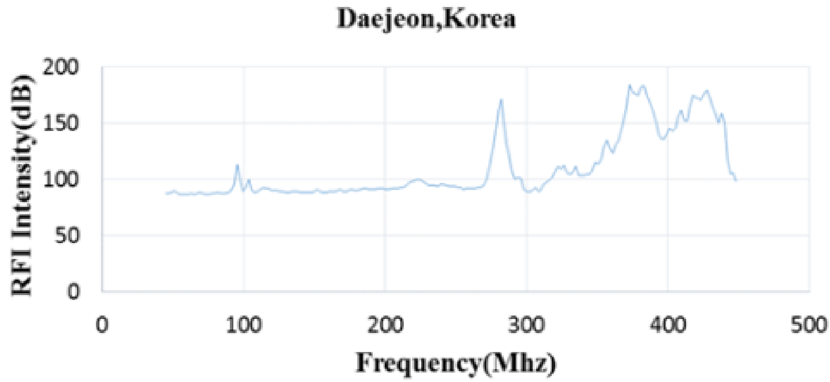

Figure 2 – RFI Profile Daejeon, Korea January 1–31, 2017.

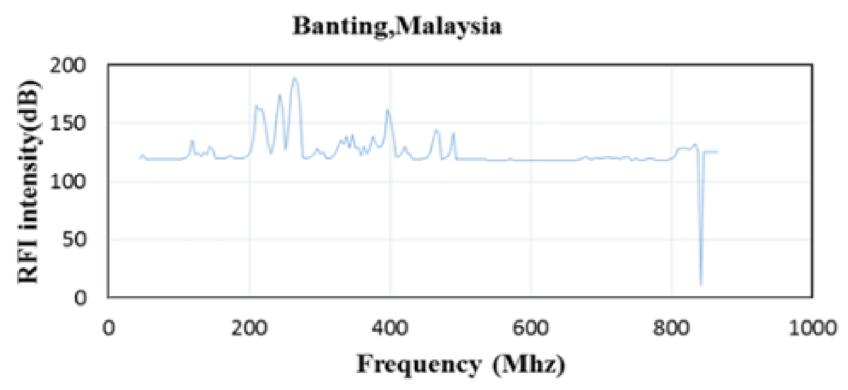

Figure 3 – RFI Profile Banting, Malaysia January 1–31, 2017.

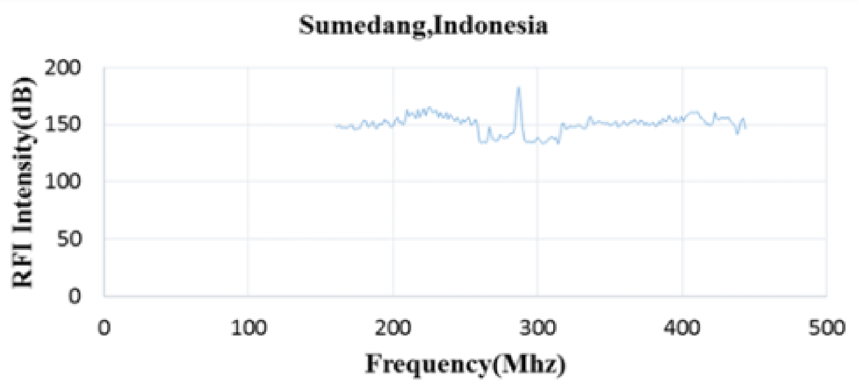

Figure 4 – RFI Profile Sumedang, Indonesia January 1–31, 2017.

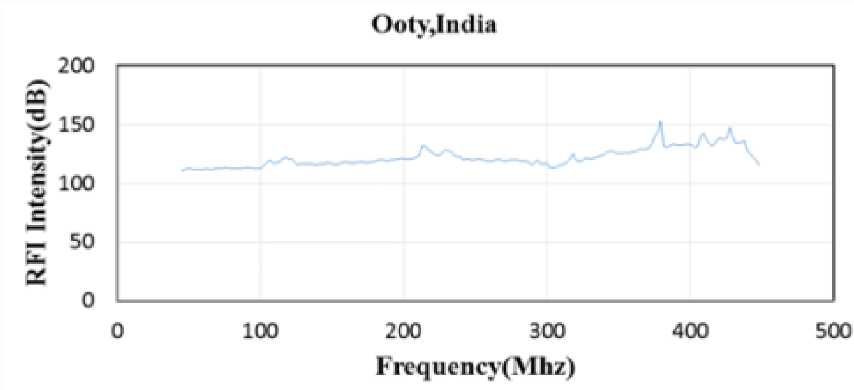

Figure 5 – RFI Profile Ooty, India January 1–31, 2017.

Table 1 – The Kurtosis Value, an Average of Radio Frequency Interference, Standard Deviation and Differences between Kurtosis and Standard Deviation at Four Sites in January 2017

Site	Kurtosis Value	Average of Radio Frequency Interference	Standard Deviation, σ	Differences between kurtosis and standard deviation
Daejeon, Korea	0.3019	150.3188	28.5478	28.2459
Banting, Malaysia	0.3983	117.0388	24.0751	23.6768
Sumedang, Indonesia	1.1807	109.5583	7.8824	6.7017
Ooty, India	2.0092	108.1202	6.9927	4.9835

The average value for RFI intensity on July 2017 was obtained and plotted against the frequency range 45 MHz to 870 MHz. Figure 6 until Figure 9 represents the average RFI intensity for one month starting from Jun 1 until Jun 30 2017 for each station. Based on the graph, the lowest radio frequency interference level is observed at Sumedang, Indonesia as the lower in fluctuations is seen as compared to another three sites. The highest in kurtosis value obtained indicates the lowest frequency interference level. Based on table 2, using the statistical kurtosis method, Sumedang shows the highest kurtosis value of 64.774 and Daejeon shows the lowest kurtosis value of 0.7623 while in Ooty the kurtosis value was recorded at 1.3715 and 0.8523 for Banting. Sumedang was found as the best site of low radio frequency interference level with the highest kurtosis value in the wide band.

Daejeon differences between the kurtosis and the standard deviations were 26.0361 and Banting with -22.0733. Ooty and Sumedang with 4.1113 and -63.7162. As the Sumedang was found as the best site compared with others because the difference value was the lowest. The interpretation of the standard deviation indicates the larger the value of standard deviation, the larger the curve to flat due to more data spread out. In the following part, the average values of radio frequency interference at four sites are also observed in order to strengthen the analysis. Based on the observation, the highest average value of radio frequency interference between the sites was found at Daejeon. We can conclude that on July, Daejeon also as the worst site with the highest of RFI value.

The graph in Figure 10 shows the RFI intensity based on kurtosis values accordingly to the population density of their respective stations. This result shows that the lowest kurtosis value has the highest population density. Daejeon with the kurtosis value 0.3019 has the highest population density, which is 104,501/80km2. The second lowest kurtosis value was Banting (Malaysia), 0.3983 with the population density 27,865/80km^2. Sumedang (Indonesia) has the kurtosis 1.1807 with the population density 58, 909/80km2. Ooty (India) has the highest kurtosis value, 2.0092 with a population density 37,119/80 km^2.

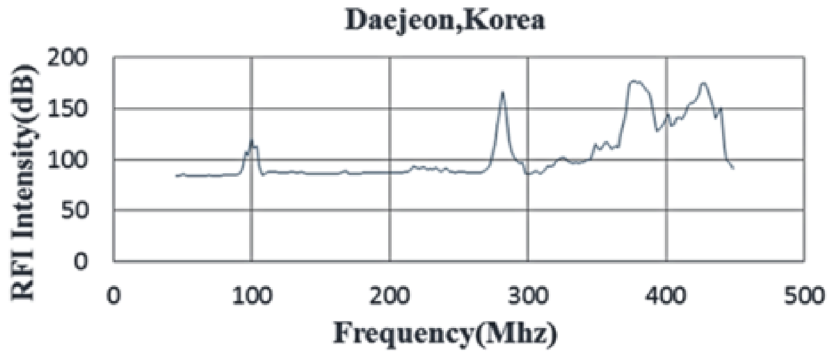

Figure 6 – RFI Profile Daejeon, Korea July 1–31, 2017.

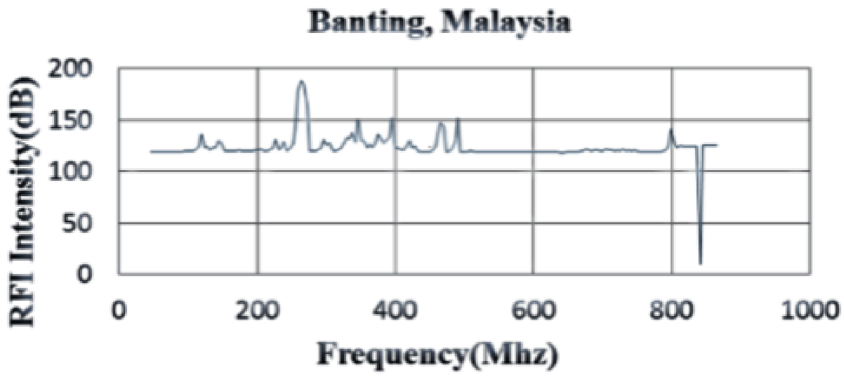

Figure 7 – RFI Profile Banting, Malaysia July 1–31, 2017.

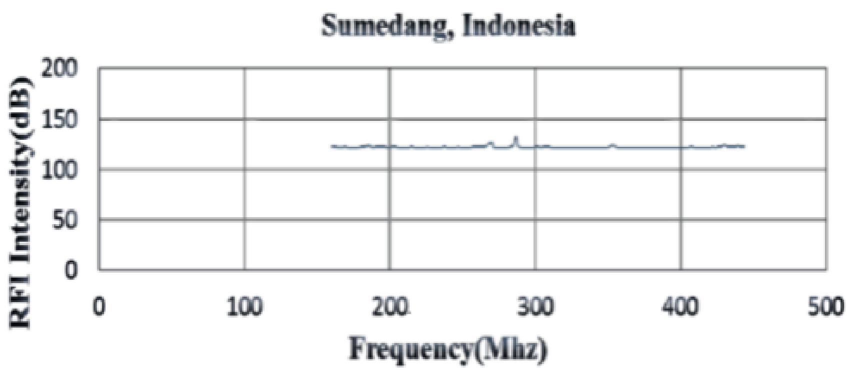

Figure 8 – RFI Profile Sumedang, Indonesia July 1–31, 2017.

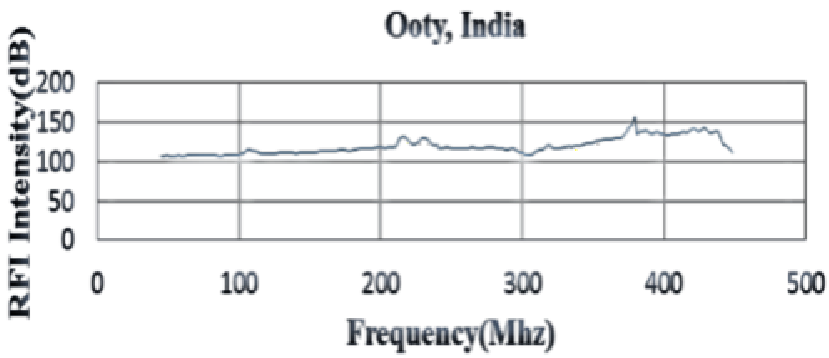

Figure 9 – RFI Profile Ooty, India July 1–31, 2017.

Table 2 – The Kurtosis Value, an Average of Radio Frequency Interference, Standard Deviation and Differences between Kurtosis and Standard Deviation at Four Sites in July 2017

Site	Kurtosis Value	Average of Radio Frequency Interference	Standard Deviation, σ	Differences between kurtosis and standard deviation
Daejeon, Korea	0.7623	121.9281	26.7984	26.0361
Banting, Malaysia	0.8523	114.7566	22.9256	22.0733
Ooty, India	1.3715	104.2515	5.4828	4.1113
Sumedang, Indonesia	64.774	103.5542	1.0578	-63.7162

Since Banting station is located near electrical substations, telecommunication substations, and satellite antennas, it has a higher RFI even though the population density is lower. RFI is also influenced by the land contour. The Banting Station was not surrounded by large trees or plants. Normally compact, practical and rather extensive forest is opaque to radio signals. The other possible factors that contribute the emission of RFI, which are temperature, weather and natural phenomenon would have explained the results in detail, combining the all of the factors will truly explain and determine the source of emission of RFI to the surrounding.

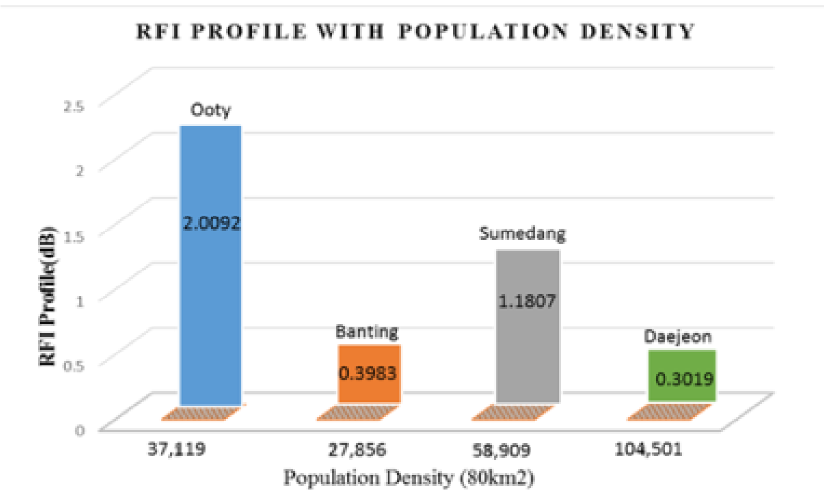

Figure 10 – Kurtosis with Human Population Density

Conclusions

In conclusion, the results that was obtained and the discussion that had made the lower kurtosis value results in higher RFI intensity. The higher population density results in higher RFI intensity. Population density in not the only factor that contributes to RFI. This was probably due to the population density of the area itself was not located exactly in the area of the stations. Other than that, other factors that contribute RFI to the surrounding such as the contour, road network and the rain effect needs to be taken in measure to have a clearer understanding of the sources of RFI and how does it affect solar burst observations. What that has proved the highest RFI will affect solar burst observation as in July has lower RFI than January and the population density is not the major factor of the emission of RFI to the surrounding that affects the solar radio observations. For future work, increase the analysis for a long period. From that, better pattern of RFI on that area can be seen. Study other parameters that contribute to RFI, such as the contour, road network and rain effects. There is a need of the study and research on RFI for better understanding of its threat imposing towards radio astronomy observation in order to achieve better results for better observation solar monitoring purposes.

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