
EXPERIMENTAL ASSESSMENT OF SPECTRUM OCCUPANCY AND TVWS AVAILABILITY IN THE UHF TELEVISION BAND (470–694) MHZ IN KANO STATE NIGERIA

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ABSTRACT

This study presents the results of a spectrum measurement campaign conducted in Kano State, Nigeria, across the UHF television band spanning 470–694 MHz. The primary objective was to determine the level of spectrum occupancy and the availability of television white spaces (TVWS) to support dynamic spectrum access in cognitive radio systems. An Agilent (Keysight) spectrum analyser was configured to sweep the television band and collect empirical data from selected urban and rural locations. The findings showed that only 21.4% of the spectrum is utilized in urban areas leaving approximately 78.6% underutilized. In rural areas, the results indicated that the entire measured spectrum 224 MHz (100%) is available and unoccupied. These findings reveal substantial inefficiency in spectrum usage and suggest significant opportunities for opportunistic access through cognitive radio technologies. The measurement results were further compared with findings from both local and international spectrum occupancy studies, which showed a consistent pattern of low utilization and significant TVWS availability across different locations. This agreement with prior studies supports the technical feasibility of deploying TVWS-based systems for broadband connectivity, Internet of Things (IoT) applications, and indoor coverage enhancement.

Keywords: Spectrum Measurement Campaign; Spectrum Occupancy; Television White Spaces; Underutilization of spectrum; Cognitive Radio

1. INTRODUCTION

Television White Space (TVWS) refers to the unused frequency spectrum in the Very High Frequency (VHF) and Ultra-High Frequency (UHF) bands originally allocated for television broadcasting services (Idowu-Bismark et al., 2025). Following the global transition from analog to digital television (DTV), the digital dividend has freed substantial spectrum capacity, creating opportunities for secondary access without interfering with primary incumbent services (Luka et al., 2023). The frequency range of interest varies by regulatory domain: in Nigeria, the Nigerian Communications Commission (NCC) has approved TVWS deployment in the 470–694 MHz band, while the European harmonized standards specify the same range for TV White Space Devices (TVWSDs), (Adefela et al., 2022; Ntlaltapa, 2013; European Telecommunications Standards Institute [ETSI], 2022).

The lower UHF band offers exceptional propagation characteristics compared to higher frequency bands such as 2.4 GHz or 5 GHz used by conventional Wi-Fi. These signals can travel longer distances, penetrate obstacles more effectively, and provide reliable non-line-of-sight (NLOS) communication (Gerolaga, 2020; Idowu-Bismark et al., 2025). As shown in table 1, TVWS provides substantially greater range than Wi-Fi, though with lower throughput, making it particularly suitable for rural broadband access and IoT applications.

Table 1: Comparative Characteristics of Wi-Fi and TVWS

Parameter	Wi-Fi	TVWS (UHF)
Range (km)	0.05 - 0.45	10 - 30
Throughput	Up to 600 Mbps	2 - 45 Mbps
Frequency	2.4 - 5 GHz	470 - 698 MHz
Non-LOS Communication	No	Yes
Environmental Sensitivity	Yes	No

Source: Adapted from (Gerolaga, 2020)

The global surge in wireless communication systems, fueled by the deployment of advanced mobile telecommunications networks and Internet-of-Things (IoT) ecosystems, has drastically increased demand for the radio frequency (RF) spectrum. Traditionally, regulatory bodies manage this finite natural resource using a static allocation framework, where specific frequency bands are exclusively licensed to designated operators or primary users (PUs). This traditional strategy, though it has helped to address the issue of interference, it has created artificial scarcity of spectrum. To overcome this challenge, researchers have led the way toward Dynamic Spectrum Access (DSA) enabled by Cognitive Radio (CR) technology. The term *Cognitive Radio* (CR) was coined by (Mitola, J., & Maguire, G. Q., 1999) at a seminal workshop on Mobile Multimedia Communications. The authors described how CR could enhance the flexibility of personal wireless services through the Radio Knowledge Representation Language (RKRL). Additionally, the International Telecommunication Union (ITU) defines a cognitive radio system (CRS) as a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies, and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained (International Telecommunication Union [ITU- R BT.2302], 2008).

CR allows unlicensed secondary users (SUs) to opportunistically access idle licensed spectrum bands, often referred to as "spectrum holes" or "white spaces," without causing harmful interference to the PUs, (Popoola, et al 2018). However, deploying CR networks requires an accurate, empirical understanding of real world spectrum usage. This has driven empirical research via spectrum measurement campaigns. Spectrum occupancy measurement is the process of determining the degree to which a specific RF band is being used by detecting and quantifying the presence of radio signals within that band over a given period. The measurement process typically involves (Popoola, et al 2018):

- I. **Sensing:** Continuously scanning the frequency band of interest using specialized equipment, such as a spectrum analyser or portable RF explorer, to monitor a range of frequencies.
- II. **Measuring:** Capturing the received signal levels across the scanned frequencies over time.
- III. **Calculating:** Computing the duty cycle, which represents the percentage of time or the fraction of total measurements that a frequency channel or band is found to be occupied.

The measurement campaigns utilize specialized hardware such as high-performance spectrum analysers, omnidirectional antennas, and energy detection algorithms to capture real-world RF occupancy data across diverse times, frequencies, and geographical spaces.

Despite numerous localized spectrum occupancy measurement studies conducted globally and various frequency bands in some states in Nigeria, which consistently indicate a significant underutilization of the radio frequency spectrum with occupancy rates often below 30%, two critical gaps necessitates further action and research.

- I. **Fragmented and Incomplete National Profile:** Existing studies are highly isolated, focusing on specific frequency bands and limited geographical locations, resulting in an incomplete understanding of the overall national spectrum utilization profile. This lack of a comprehensive, nationwide, multi-band, and multi-location dataset prevents regulatory bodies from making fully informed, national-level decisions regarding spectrum efficiency improvement and nationwide dynamic spectrum access (DSA)/Cognitive Radio (CR) deployment strategies.
- II. **High Spatiotemporal Dynamics:** While the overall trend is low occupancy, spectrum availability is highly dependent on time, location, and environment (e.g., urban vs. rural, peak vs. off-peak times). Localized, static measurements fail to capture the true potential or challenges of implementing dynamic spectrum management on a broader, interconnected scale.

Thus, the major gap is the absence of a comprehensive, unified, and contemporary understanding of the actual spectrum utilization profile across all major regions and critical frequency bands in Nigeria. This deficiency hinders the development and implementation of effective national spectrum management policies necessary to harness the significant potential of Dynamic Spectrum Access and Cognitive Radio technologies to address spectrum scarcity and improve overall efficiency, (Ajiboye et al, 2019).

The ultimate goal of this study is to fill in this gap by conducting spectrum measurement campaign in the Television band (470 – 694) MHz with the intent to identifying Television White Space (TVWS) in Kano, Kaduna state and Abuja (F.C.T) in Nigeria. The measurement campaign will be conducted in three phases. Phase 1: Kano, phase 2: Kaduna and phase 3: Abuja. In this study we are starting with phase 1 Kano. Therefore, all the result to be presented in this report will be from Kano (Lat. 11.9820, Long. 8.5147).

1.1 REVIEW OF RELATED LITERATURE

Regulatory frameworks for TVWS deployment have been established in several jurisdictions. The U.S. Federal Communications Commission (FCC) and the UK Office of Communications (Ofcom) have developed guidelines enabling TVWS device operation through geolocation databases (Idowu-Bismark et al., 2025). The European Telecommunications Standards Institute (ETSI) has published harmonized standard EN 301 598, which specifies technical characteristics for TVWSs operating in the 470–694 MHz band (Adefela et al., 2022; Ntlaltapa, 2013; European Telecommunications Standards Institute [ETSI], 2022). In Nigeria, the Nigerian Communication Commission (NCC) established a committee in 2020 to develop national TVWS guidelines, working in collaboration with the Nigerian Broadcasting Commission (NBC), (Idowu-Bismark et al., 2025).

1.2 GLOBAL SPECTRUM MEASUREMENT CAMPAIGNS

Globally, an extensive spectrum measurement campaigns have established the fundamental premise that the radio spectrum is severely underutilized. These investigations spanned multiple continents, focusing on urban and suburban environments to model temporal and spatial duty cycles. To enhance these empirical evaluations, contemporary frameworks increasingly leverage advanced paradigms, including machine learning-based spectrum occupancy prediction, to construct comprehensive, predictive models of spectral environments over time (Aygül et al., 2025).

Some of the earliest foundational measurement campaigns were conducted in the United States and Europe. Marțian (2010) highlighted a pivotal measurement campaign executed in Chicago, USA, which revealed a mean spectral occupancy of only 17.4% within the 30 MHz to 3000 MHz frequency range. This confirmed that massive blocks of allocated spectrum lay idle even in densely populated urban centers.

Similarly, in Europe, researchers focused heavily on understanding localized and event-driven spectrum dynamics. Marțian (2010) analyzed spatial and context-dependent variations, citing campaigns in Aachen, Germany, which contrasted indoor and outdoor spectral densities. They also documented intensive measurements during the 2006 FIFA World Cup in Dortmund and Kaiserslautern. These studies demonstrated a distinct interdependency between spectrum utilization and real-world human activity, showing sharp spikes in cellular bands during active match periods.

To model these variations over extended timelines, Harrold et al. (2011) conducted a long-term measurement campaign in the UK spanning five months across a 10 MHz to 5 GHz range. They emphasized that while short-term campaigns (lasting a few days) can quantify the baseline percentage of idle spectrum, long-term empirical tracking is vital to model temporal variations across working days, weekends, and holidays. This long-term modelling allows CR systems to accurately predict available white space. While, Van De Beek et al (2012) conducted a model based study in 11 countries in Europe in the band 470–790 MHz), and reported about 56% of channels are unused per location, dropping to 25% if adjacent channels are restricted.

Extensive campaigns across Asia have reinforced these global findings. Marțian (2010) evaluated a 12-weekday spectrum measurement campaign in Singapore covering a broad frequency range up to 5850 MHz, which yielded an overall average occupancy rate of just 4.54%.

In South Asia, Patil et al. (2011), conducted an outdoor spectrum measurement campaign in the suburban environment of Mumbai, India, across the 700 MHz to 2700 MHz band. The investigation reported significant low occupancy during weekdays, noting that the underutilized bands offered excellent potential for opportunistic dynamic spectrum sharing.

Furthermore, Chantaveerod et al. (2021) addressed specific limitations in general-purpose sensing by proposing a focused pass band and guard band monitoring technique for analog FM radio broadcasting in suburban environments. Their experimental model successfully identified 42 entirely unused channels, illustrating that refined empirical measurement strategies can uncover significantly more vacant spectrum than traditional wideband averaging methods.

In the Philippines, Gerolaga (2020) conducted 72-hour monitoring of the 470–698 MHz band and concluded that despite the Philippine TV broadcast being "one of the busiest users of UHF TV band," the spectrum remains significantly underutilized.

Naik, et al, (2013) conducted a nationwide geospatial study across four zones in India in the band 470–590 MHz and found that out of the 100 MHz of TVWS assigned to secondary users, only four channels (32 MHz) have been put to use.

In addition, Kurnaz et al (2016), carried out study to determine the availability of TVWS in the frequency range 470 – 790 MHz in Samsun city center, Turkey at 73 locations, using –40/–45 dB thresholds, found an average occupancy of 20.7%.

1.3 LOCAL SPECTRUM MEASUREMENT CAMPAIGNS (NIGERIA)

In Nigeria, the regulatory regime managed by the Nigerian Communications Commission (NCC) has historically operated on rigid static allocations. Over the past decade, local research groups, primarily based in Nigerian universities, have conducted tailored measurement campaigns to evaluate whether the global phenomenon of spectrum underutilization applies to the distinct socio-economic and infrastructural landscape of a developing country like Nigeria. These empirical investigations consistently point to low overall occupancy rates, confirming that massive portions of the radio spectrum remain severely underutilized across various regions.

To obtain a comprehensive baseline of Nigeria's RF profile, Popoola and Otuu (2018) conducted multi-band and multi-location spectrum measurement campaigns across five major Nigeria's metropolises within the 80 MHz to 2200 MHz frequency range. The quantitative results revealed that the actual overall spectral occupancy in Nigeria was less than 10.00%. The study demonstrated that allocated bands vary randomly in time, frequency, and space, proving that wideband spectrum utilization is consistently low and suggesting an optimistic future for the deployment of DSA and CR frameworks across the country.

Several regional studies have broken down these metrics by analysing localized variations in specific bands, primarily focusing on the Very High Frequency (VHF), Ultra High Frequency (UHF), and FM broadcasting bands. For instance, Ajiboye et al. (2019) conducted a 24-hour outdoor spectrum occupancy survey in the centre of the Minna metropolis, Niger State, targeting the VHF (30–300 MHz) band. The study discovered heavy underutilization; the Aeronautical Navigation band exhibited the highest occupancy at 39.83%, the FM broadcasting band stood at 12.90%, while Aeronautical Mobile operations and TV Broadcasting languished at 4.73% and 0.09% occupancy, respectively. This profile highlights the stark availability of underutilized local frequencies available for secondary deployment.

Luka et al. (2023) implemented a comprehensive web application using the Flask framework with an SQLite database engine. The Okumura-Hata path loss model was employed for protection contour calculations. The database covers 21 local government areas in Adamawa State and 20 in Bauchi State. Validation was performed using RTL-SDR devices configured as spectrum analyzers, which detected 70% of channels indicated as vacant by the database.

Alawode et al. (2024) conducted a localized 48-hour campaign targeting the active FM band (88–108 MHz) across four designated locations in the Osogbo metropolis using energy detection methods. While certain urban channels at university campus hubs experienced peak duty cycles as high as 99.48% due to active local transmissions, the broader regional channels remained unevenly distributed and underutilized during off-peak hours.

Furthermore, the Akure study by Adefela et al. (2022) found that 71.05% of 38 channels in the 470–960 MHz band were unused, indicating very low spectrum occupancy rates that create substantial

opportunities for secondary access. This finding is consistent with the Covenant University study, which confirmed TVWS availability within the 470–694 MHz range specified by Nigerian regulations (Idowu-Bismark et al., 2025).

Similarly, Atimati et al, (2015), conducted a survey on the availability of TV White Spaces at FUT Owerri Eastern Nigeria in the UHF band 470–870 MHz at two sites using fixed measurements. Results of their measurement revealed that 64% of 50 channels are dormant, indicating low occupancy and opportunity for deployment of CR for rural broadband.

The above literature review confirms that spectrum underutilization is a global phenomenon, with studies in the US, Europe, and Asia showing occupancy rates often below 20-30%. This trend is echoed in Nigeria, with local measurement campaigns consistently demonstrating very low overall occupancy (often under 10%) in various bands, including VHF, UHF, and FM broadcasting. The review establishes a strong foundation for the necessity of the current TVWS study in Kano, Nigeria.

To address these gaps, the study aims to conduct a spectrum measurement campaign across Kano, Kaduna, and Abuja. However, the measurement will start with Phase 1 in Kano. The ultimate goal is to identify Television White Space (TVWS) and the actual spectrum utilization in Kano.

2. METHODOLOGY

This research aims to identify TV White Spaces (TVWS) in three states (Kano, Kaduna and Abuja) in Nigeria. The study will start by conducting empirical spectrum measurement campaign in Kano to identify free TVWS channels and also determine the actual spectrum utilization in Kano state. The method will then be replicated in the subsequent two locations (Kaduna and Abuja). The work is divided into three main phases:

- **Phase 1:** Empirical Spectrum Measurement Campaign
- **Objective:** To collect real-world data on how the 470–694 MHz TV band is actually being utilized.
- **Primary Location:** Kano, Nigeria (Lat. 11.9820, Long. 8.5147).
- **Process:** The process involve the following steps:
- **Sensing:** Use a specialized device (Spectrum analyzer connected to an antenna) to continuously scan the target frequency band.
- **Measuring:** Record the power levels of any signals detected in the environment over a set period.
- **Calculating:** Measure and collect, Signal power level Noise power level, Frequency for each channel, this identifies which channels are "free" or "occupied".
- **Phase 2:** Data Analysis and Pattern Identification
- **Objective:** To process the raw data collected in Phase 1 to understand the spectrum's availability.
- **Process:** The process involve the following steps
- **Data Processing:** Clean and organize the measured signal data.
- **Spatial Analysis:** Map the occupancy data using bar chart to see how TVWS spectrum available in Kano.
- **Statistical Analysis:** Look for patterns to collect quantitative data

2.1 MEASUREMENT LOCATIONS AND SITE SELECTION

Fixed location measurements was conducted in Kano State. The measurements were taken at different time of the day to capture the worst-case scenario of spectrum usage. Measurement locations were strategically chosen to represent a mix of urban, suburban, and rural environments within Kano. The coordinate of the locations (Latitude and Longitude) are as follows: Kano Central City Area, (Lat: 11.98200, Long: 8.51470) representing Urban area, Kura L.G.A (Lat: 11.76050, Long: 8.4226⁰), representing Sub-urban area and Gwarmai (Lat: 11.4720⁰, Long: 8.2061⁰), representing Rural area.

2.2 SPECTRUM MEASUREMENT CAMPAIGN IN THE TV BAND (470–694) MHZ

Accordingly, in line with the objective of this study, spectrum measurement campaign was conducted for 3 days in Kano State from 8th – 10th September 2025. These measurements were carried out within the Ultra High Frequency (UHF) television band (470 - 694 MHz). The map in figure 1. below depicts the locations of measurements and their coordinates (latitudes and Longitudes).

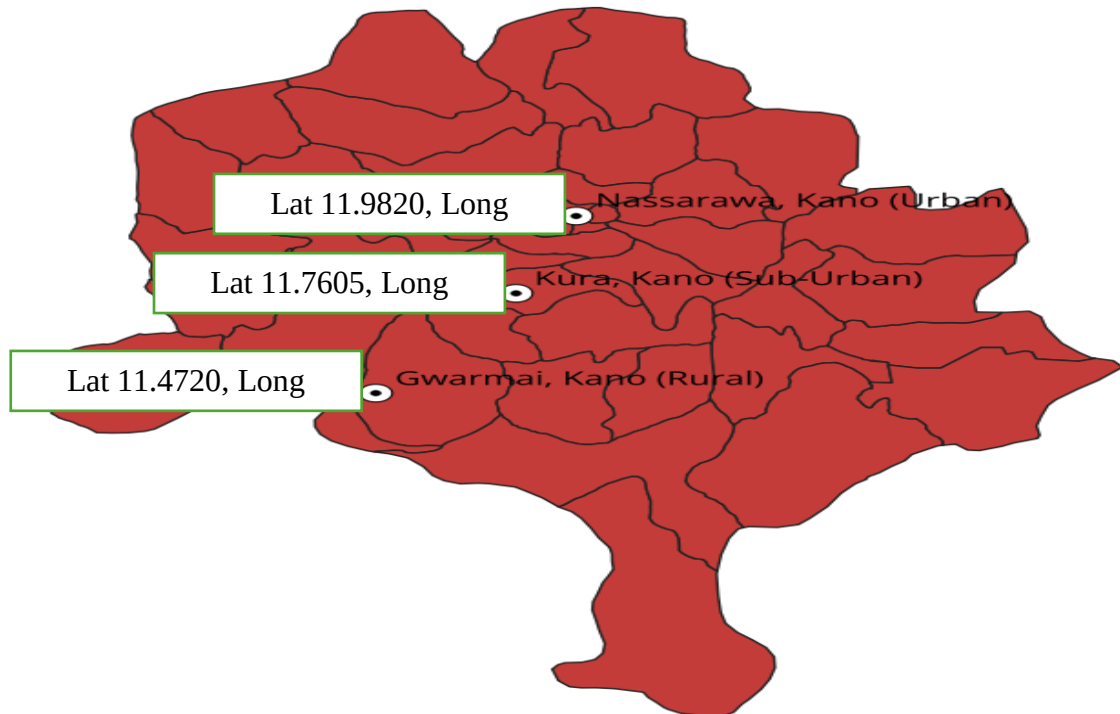


Figure 1: Map of Kano showing measurement locations in Kano

2.3 MATERIALS/INSTRUMENTATION

The following instruments were used for the measurement campaign and data collection:

- a. **Spectrum Analyzer:** Agilent (Now Keysight Technologies) Handheld Spectrum Analyzer Model No. N9344C, with a frequency range of 9 KHz to 20 GHz. This device's portability and wide frequency range made it suitable for field measurements.
- b. **Antenna:** A wide band high gain (12dB) log-periodic antenna with a frequency range of 1 MHz to 26.5 GHz. This antenna was chosen for its wideband characteristics, which allowed it to cover the entire UHF TV band without requiring multiple antennas.
- c. **Cables and Accessories:** Low-loss coaxial cables and a tripod for stable antenna placement were used.
- d. **Amplitude Accuracy:** $\pm 1.3\text{dB}$
- e. **Frequency Range:** 9 KHz to 20 GHz (fully covering the band of interest).
- f. **Frequency Accuracy:** $\pm (0.22 * \text{Span} + \text{Span} / (\text{Sweep point} - 1))$
- g. **Frequency Span:** 100Hz – 20GHz
- h. **Frequency Resolution:** 1Hz
- i. **Calibration Status:** The Spectrum Analyzer was calibrated to ISO/IEC 17025:2017 standards.
- j. **Key Settings:** Resolution Bandwidth (RBW) = 10kHz, Video Bandwidth (VBW) = 10 kHz, Sweep Time = 20 Ms.
- k. **Software:** Data was logged using the instrument's internal logging and later analyzed using PC-based software (Agilent BTA/DSA Software).
- l. **GPS Map:** Camera Lite Application, Version 1.5.8 was adopted.

2.4 MEASUREMENT PROCEDURE

The measurement campaign followed a systematic procedure to ensure data accuracy and consistency. The spectrum analyser was connected to the log-periodic antenna using coaxial cables, and was mounted at a height of approximately 3.0 meters to minimize ground reflections and interference. Resolution Bandwidth (RBW) was set at 10 kHz to resolve individual TV channels, while the Video Bandwidth (VBW) was set at 10 kHz to smooth the display trace. Attenuation loss was set at 20dB to reduce the amplitude of the incoming signal so as to protect the instrument sensitivity front-end components like (mixers) from damage and to prevent signal distortion. The detection Mode was set at Max Hold to capture the peak signal levels over a period. Finally, the spectrum analyser was configured to sweep the UHF television band from (470 – 694) MHz as shown in figure 3 and figure 4 below. Measurements were taken at each location for a duration of 60 minutes per session at multiple location to capture potential intermittent transmissions. The measurements were repeated for three days and average values of the signal was calculated and recorded. The resulting spectrum traces, showing signal strength (in dBm) versus frequency, were saved for subsequent analysis. The instrument setup is as presented in figures 2 and 3.

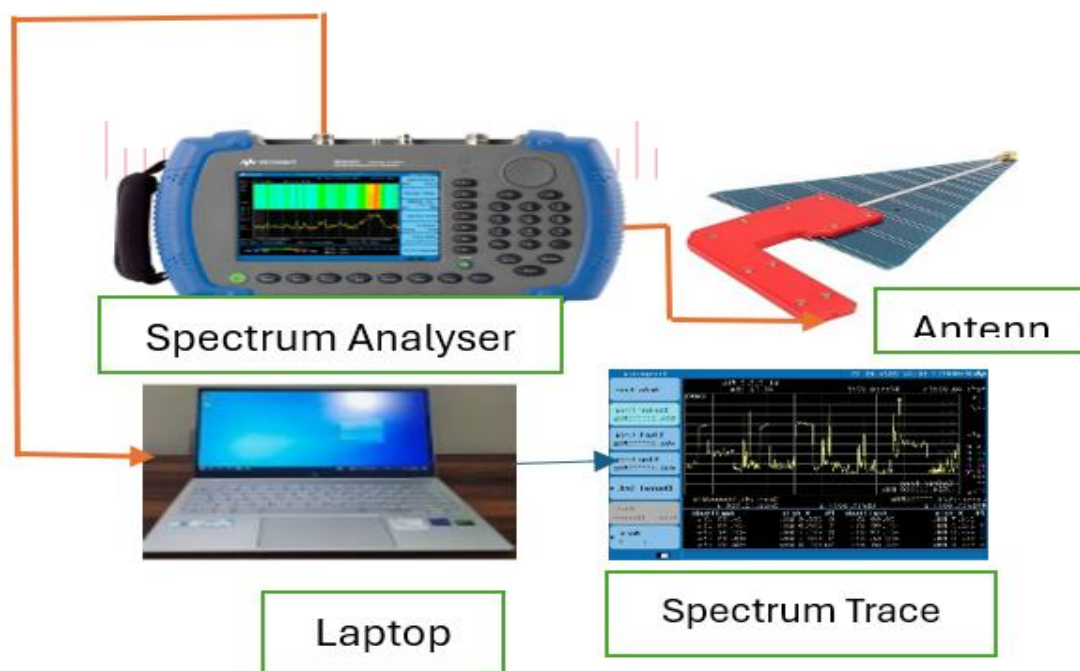


Figure 2: Spectrum Analyser connection diagram



Figure 3: Showing the Spectrum Analyser measurement set-up

3. RESULT AND DISCUSSION

In this section the result of spectrum measurement campaign, Spectrum trace, and raw data collected is presented

3.1 DATA COLLECTION

Primary data (empirical) was collected from primary source, directly from the TV antenna using the Spectrum Analyser as the instrument for data capturing. The data collected includes Received Signal Power Level (RSSI), Noise floor power level, Bandwidth, and Occupancy time and occupancy status (channel occupied active or free).

To systematically assess UHF spectrum utilization, the frequency band 470–694 MHz was divided into standard 8 MHz television channels bandwidth (Channel 21–48) resulting to 28 channels in line with the international telecommunication union (ITU) Standard.

The spectrum trace for Kano urban area (Nasarawa), bar chart of the plot of signal power level against channel number, (showing both active and free channels), bar chart of the plot of occupancy status against channel number (showing active channel labelled = 1 and free channels labelled = 0) are presented in figure 4, figure 5 and figure 6, while table 2 shows raw data collected.

Active channels

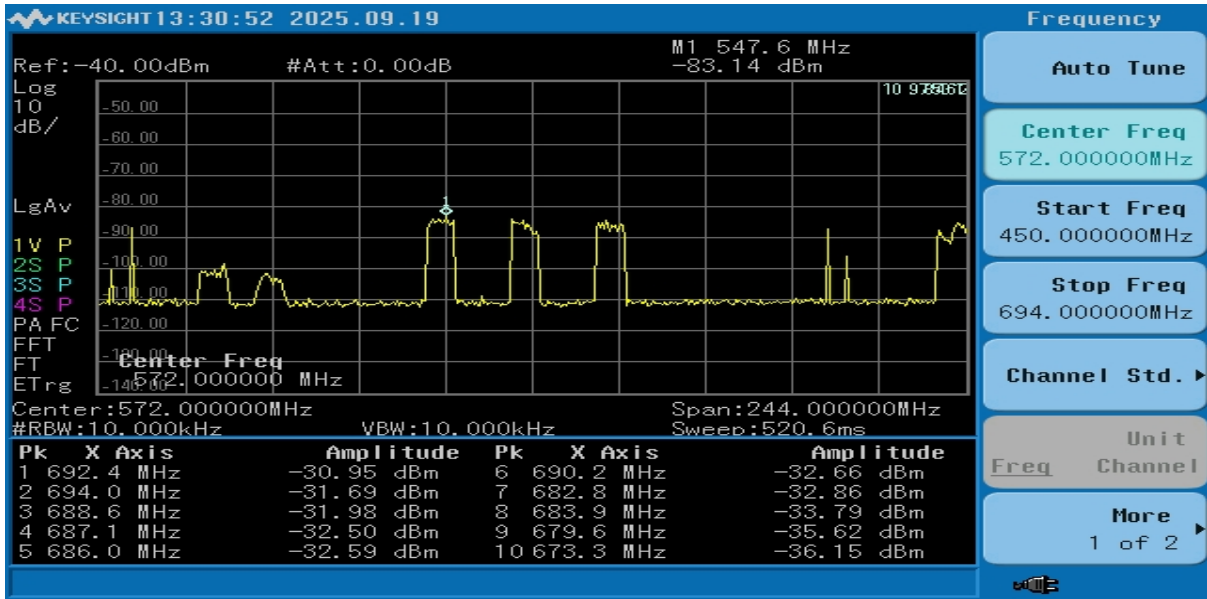


Figure 4: Spectrum Trace Nasarawa GRA, Kano City

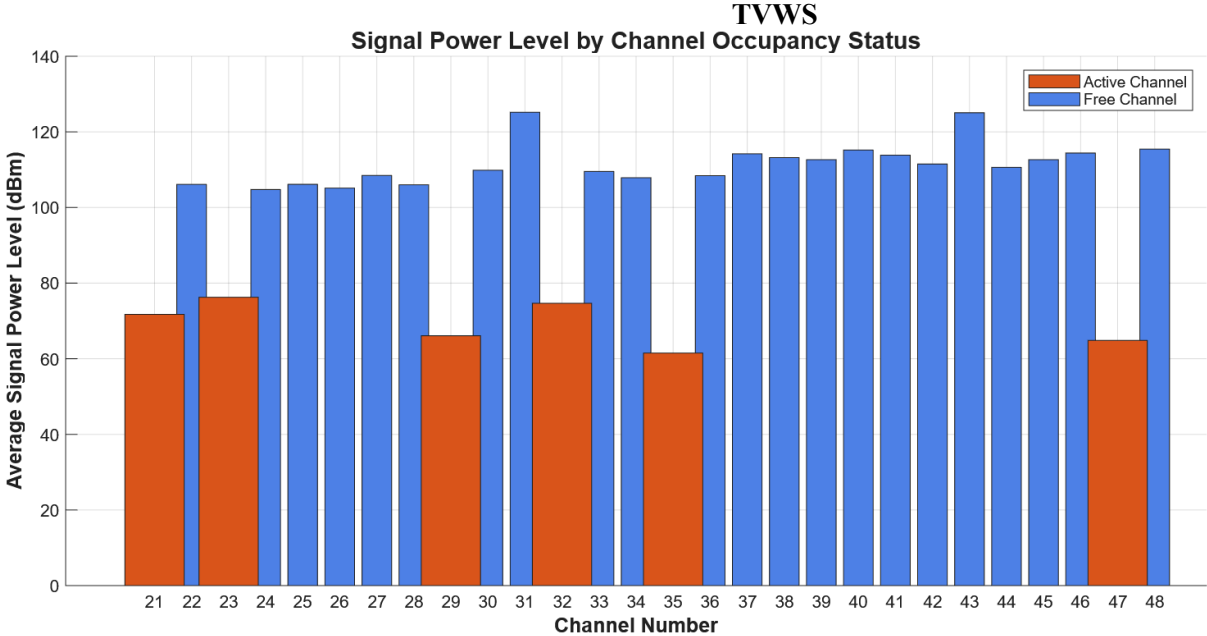


Figure 5: Bar chart plot of signal power level against channel number

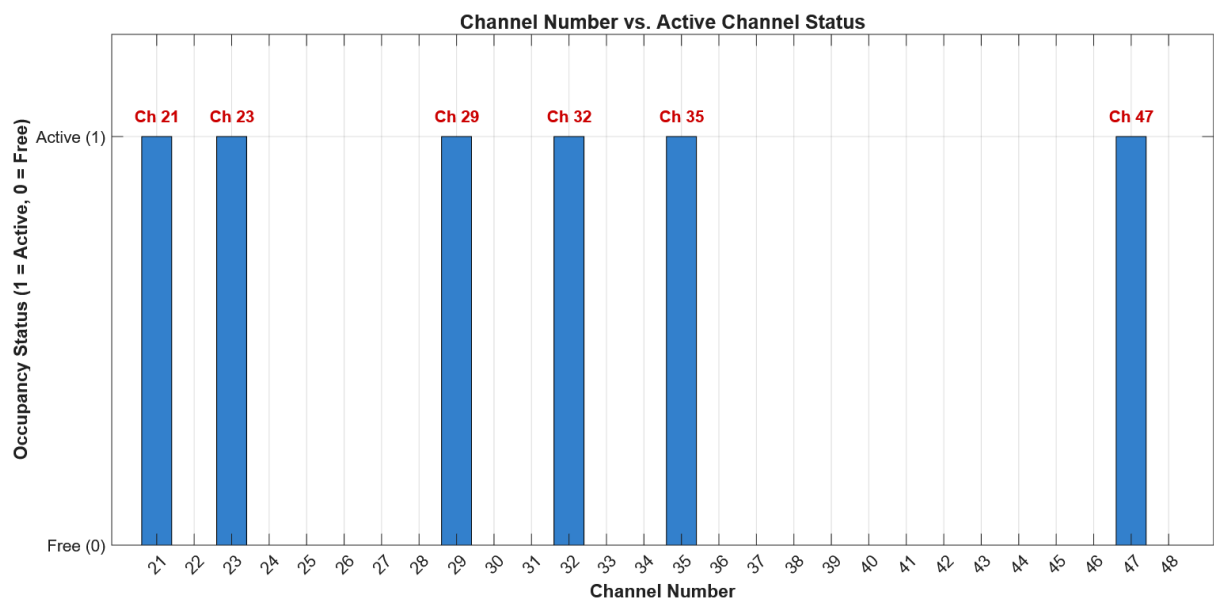


Figure 6: Bar chart plot of occupancy status against channel number

Table 2: Raw data, spectrum occupancy in Nasarawa, Kano (Urban area), Kura L.G.A (Sub-Urban Area (470–694 MHz))

EXPERIMENTAL ASSESSMENT OF SPECTRUM OCCUPANCY AND TVWS AVAILABILITY IN THE
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Channel No.	Latitude and Longitude	Start Freq. (MHz)	Centre Freq. (MHz)	End Freq. (MHz)	Signal Power Level (dBm) @ Time t = 0 Min	Signal power Level (dBm)@Time t = 60 Min	Average Signal Power Level (dBm)	Occupancy Status
21	11.9820 ⁰ -8.5147 ⁰	470	474	478	-73.25	-70.23	-71.74	Occupied active
22	11.9820 ⁰ -8.5147 ⁰	478	482	486	-111.01	-101.21	-106.11	Free
23	11.9820 ⁰ -8.5147 ⁰	486	490	494	-75.21	-77.31	-76.26	Occupied active
24	11.9820 ⁰ -8.5147 ⁰	494	498	502	-97.26	-112.21	-104.74	Free
25	11.9820 ⁰ -8.5147 ⁰	502	506	510	-97.08	-115.18	-106.13	Free
26	11.9820 ⁰ -8.5147 ⁰	510	514	518	-100.93	-109.33	-105.13	Free
27	11.9820 ⁰ -8.5147 ⁰	518	522	526	-102.50	-114.44	-108.47	Free
28	11.9820 ⁰ -8.5147 ⁰	526	530	534	-103.75	-108.25	-106.00	Free
29	11.9820 ⁰ -8.5147 ⁰	534	538	542	-66.98	-65.18	-66.08	Occupied active
30	11.9820 ⁰ -8.5147 ⁰	542	546	550	-107.51	-112.21	-109.86	Free
31	11.9820 ⁰ -8.5147 ⁰	550	554	558	-109.04	-141.34	-125.19	Free
32	11.9820 ⁰ -8.5147 ⁰	558	562	566	-73.67	-75.68	-74.67	Occupied active
33	11.9820 ⁰ -8.5147 ⁰	566	570	574	-108.54	-110.55	-109.54	Free
34	11.9820 ⁰ -8.5147 ⁰	574	578	582	-102.54	-113.23	-107.88	Free
35	11.9820 ⁰ -8.5147 ⁰	582	586	590	-62.85	-60.15	-61.50	Occupied active
36	11.9820 ⁰ -8.5147 ⁰	590	594	598	-105.61	-111.21	-108.41	Free
37	11.9820 ⁰ -8.5147 ⁰	598	602	606	-110.20	-118.20	-114.20	Free
38	11.9820 ⁰ -8.5147 ⁰	606	610	614	-111.30	-115.10	-113.20	Free
39	11.9820 ⁰ -8.5147 ⁰	614	618	622	-111.20	-114.11	-112.65	Free
40	11.9820 ⁰ -8.5147 ⁰	622	626	630	-114.20	-116.21	-115.20	Free
41	11.9820 ⁰ -8.5147 ⁰	630	634	638	-115.30	-112.40	-113.85	Free
42	11.9820 ⁰ -8.5147 ⁰	638	642	646	-114.00	-109.00	-111.50	Free
43	11.9820 ⁰ -8.5147 ⁰	646	650	654	-115.01	-135.11	-125.06	Free

Channel No.	Latitude and Longitude	Start Freq. (MHz)	Centre Freq. (MHz)	End Freq. (MHz)	Signal Power Level (dBm) @ Time t = 0 Min	Signal power Level (dBm)@Time t = 60 Min	Average Signal Power Level (dBm)	Occupancy Status
44	11.9820 ⁰ -8.5147 ⁰	654	658	662	-110.02	-111.22	-110.62	Free
45	11.9820 ⁰ -8.5147 ⁰	662	666	670	-113.20	-112.10	-112.65	Free
46	11.9820 ⁰ -8.5147 ⁰	670	674	678	-115.30	-113.50	-114.40	Free
47	11.9820 ⁰ -8.5147 ⁰	678	682	686	-66.35	-63.33	-64.84	Occupied active
48	11.9820 ⁰ -8.5147 ⁰	686	690	694	-115.70	-115.20	-115.45	Free

Similarly, the spectrum trace for suburban area Kura L.G.A, bar chart of the plot of signal power level against channel number, (showing both active and free channels), bar chart of the plot of occupancy status against channel number (showing active channel labelled = 1 and free channels labelled = 0) are presented in figure 7, figure 8 and figure 9, while table 3 shows raw data collected.

Active channels

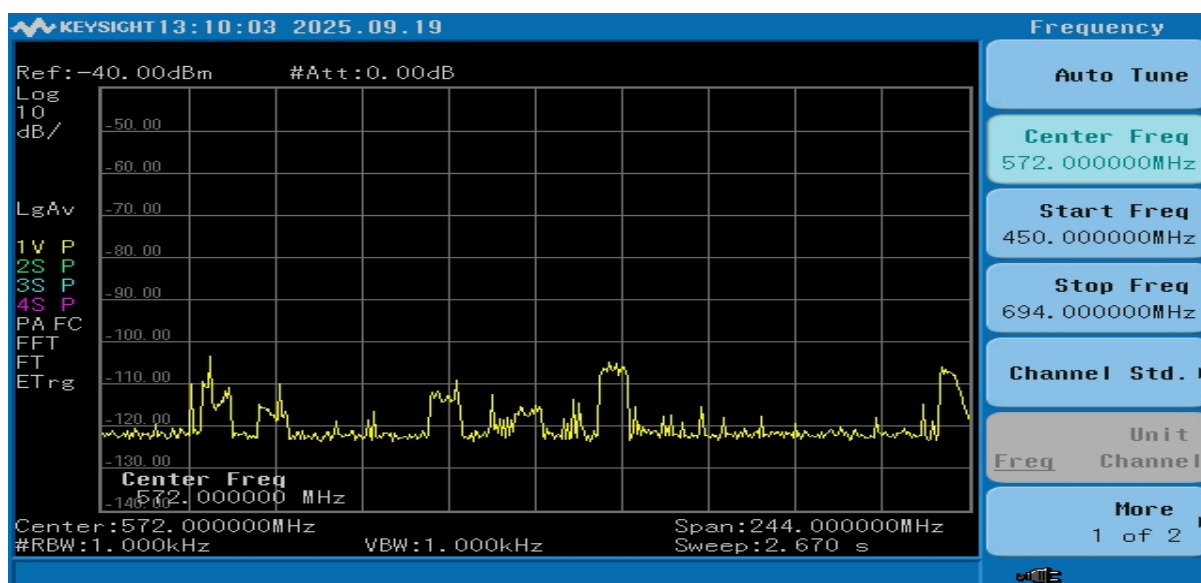


Figure 7: Spectrum Trace Kura LGA, Sub-Urban area, Kano

TVWSs

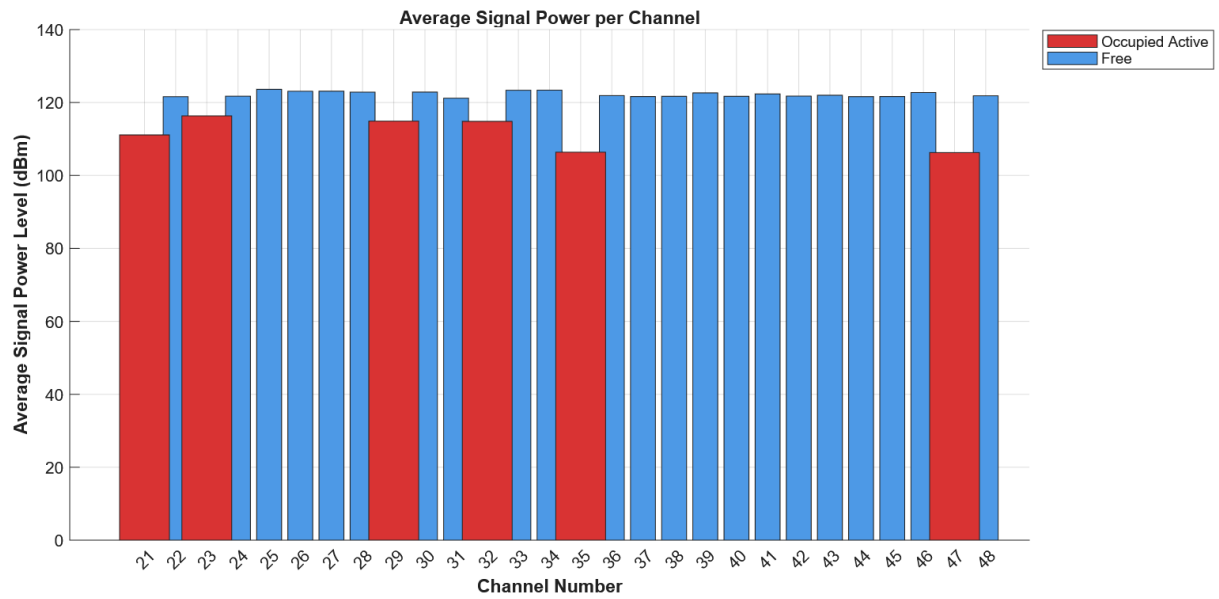


Figure 8: bar chart plot of signal power level against channel number

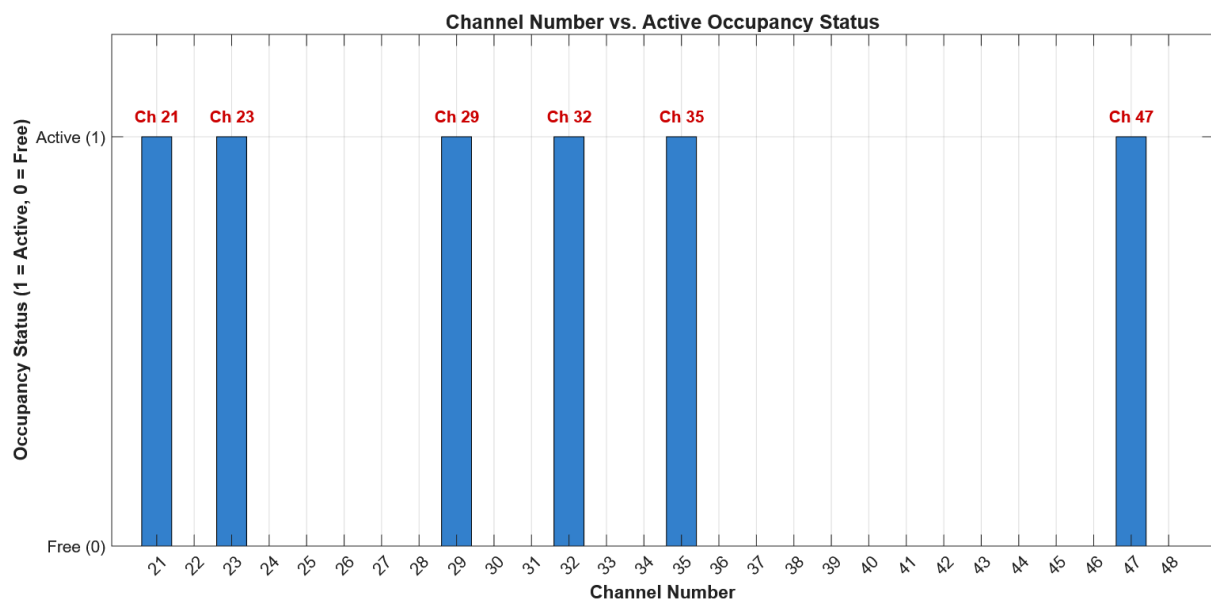


Figure 9: Bar chart plot of occupancy status against channel number

Table 3: Raw data, Spectrum Occupancy in Kura L.G.A, Sub-Urban area, (Lat: 11.76050⁰, Long: 8.4226⁰) (470–694 MH)

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21	11.7605 ⁰ -8.4226 ⁰	470	474	478	-110.00	-112.23	-111.12	Occupied active
22	11.7605 ⁰ -8.4226 ⁰	478	482	486	-121.01	-122.21	-121.61	Free
23	11.7605 ⁰ -8.4226 ⁰	486	490	494	-115.40	-117.31	-116.35	Occupied active
24	11.7605 ⁰ -8.4226 ⁰	494	498	502	-122.26	-121.22	-121.74	Free
25	11.7605 ⁰ -8.4226 ⁰	502	506	510	-123.08	-122.18	-123.63	Free
26	11.7605 ⁰ -8.4226 ⁰	510	514	518	-122.50	-123.70	-123.10	Free
27	11.7605 ⁰ -8.4226 ⁰	518	522	526	-122.79	-123.44	-123.11	Free
28	11.7605 ⁰ -8.4226 ⁰	526	530	534	-122.64	-123.07	-122.85	Free
29	11.7605 ⁰ -8.4226 ⁰	534	538	542	-114.22	-115.58	-114.90	Occupied active
30	11.7605 ⁰ -8.4226 ⁰	542	546	550	-122.43	-123.32	-122.87	Free
31	11.7605 ⁰ -8.4226 ⁰	550	554	558	-121.04	-121.34	-121.19	Free
32	11.7605 ⁰ -8.4226 ⁰	558	562	566	-113.43	-116.26	-114.84	Occupied active
33	11.7605 ⁰ -8.4226 ⁰	566	570	574	-122.93	-123.79	-123.36	Free
34	11.7605 ⁰ -8.4226 ⁰	574	578	582	-123.55	-121.23	-123.39	Free
35	11.7605 ⁰ -8.4226 ⁰	582	586	590	-105.32	-107.45	-106.38	Occupied active
36	11.7605 ⁰ -8.4226 ⁰	590	594	598	-122.61	-121.21	-121.91	Free
37	11.7605 ⁰ -8.4226 ⁰	598	602	606	-122.10	-121.20	-121.65	Free
38	11.7605 ⁰ -8.4226 ⁰	606	610	614	-121.30	-122.10	-121.70	Free
39	11.7605 ⁰ -8.4226 ⁰	614	618	622	-123.20	-122.11	-122.65	Free
40	11.7605 ⁰ -8.4226 ⁰	622	626	630	-121.20	-122.21	-121.70	Free
41	11.7605 ⁰ -8.4226 ⁰	630	634	638	-123.30	-121.40	-122.35	Free
42	11.7605 ⁰ -8.4226 ⁰	638	642	646	-122.00	-121.52	-121.76	Free
43	11.7605 ⁰ -8.4226 ⁰	646	650	654	-121.01	-123.00	-122.00	Free

Channel No.	Latitude and Longitude	Start Freq. (MHz)	Centre Freq. (MHz)	End Freq. (MHz)	Signal Power Level (dBm) @ Time t = 0 Min	Signal power Level (dBm)@Time t = 60 Min	Average Signal Power Level (dBm)	Occupancy Status
44	11.7605 ⁰ -8.4226 ⁰	654	658	662	-121.02	-122.22	-121.62	Free
45	11.7605 ⁰ -8.4226 ⁰	662	666	670	-122.20	-121.10	-121.65	Free
46	11.7605 ⁰ -8.4226 ⁰	670	674	678	-123.01	-122.50	-122.75	Free
47	11.7605 ⁰ -8.4226 ⁰	678	682	686	-105.30	-107.25	-106.27	Occupied active
48	11.7605 ⁰ -8.4226 ⁰	686	690	694	-122.70	-121.20	-121.85	Free

While, Figure 10 present spectrum trace from Gwarmai, Rural Area (Lat: 11.4720⁰, Long: 8.2061⁰) a distance of 75Km away from Kano city, with no visible spectrum occupancy in the 470–694 MHz spectrum band; making the entire 224MHz (100%) spectrum bandwidth available and free. All the 28 channels are unoccupied.

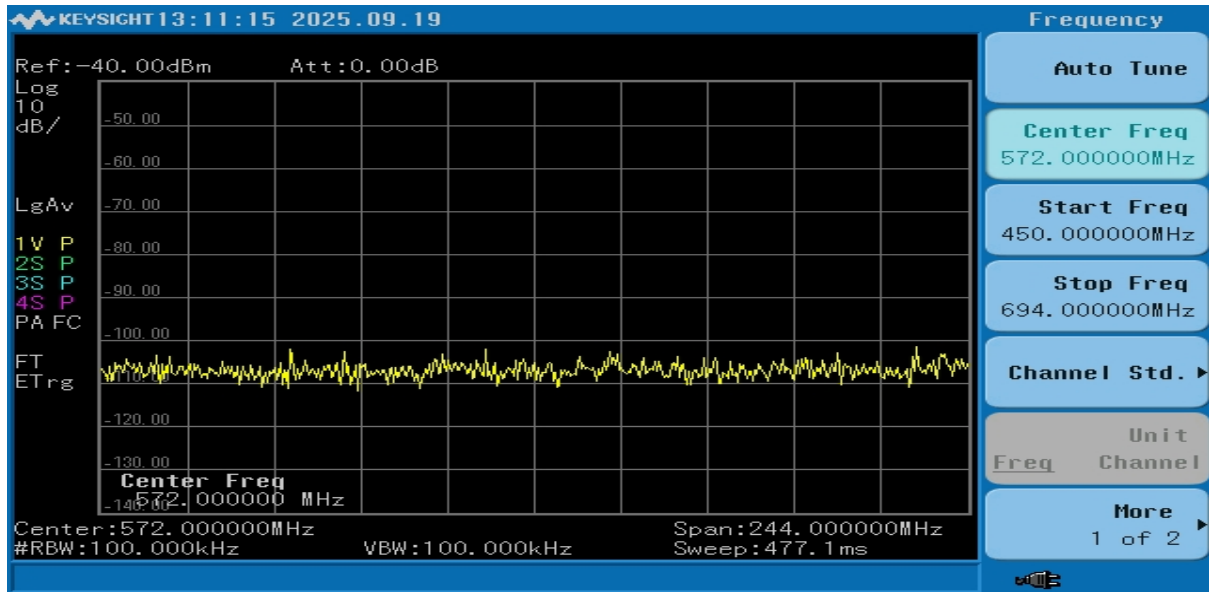


Figure 10: Spectrum Trace, Gwarmai Rural Area, Kano

TVWSs 224 MHz

3.2 Calculation of Spectrum Occupancy Rate for Kano State.

The spectrum occupancy rate for Kano location was calculated as:

$$\text{Occupancy Rate (\%)} = \frac{\text{Number of Occupied channels}}{\text{Total Number of channels}} * 100 \quad (1)$$

$$\text{Occupancy Rate (\%)} = \frac{6}{28} * 100 = 21.4 \%$$

$$\text{Occupancy Rate (\%)} = 21.4 \%$$

3.3 Statistical Analysis of TVWS Signal Power Levels for the Active channels

This is to enable calculation of Mean, standard deviation and standard error of the signal power level as well as for the noise floor

Mean can be calculated using the formula:

$$\bar{\mu} = \frac{\sum_{i=1}^n x_i}{n} \quad (2)$$

Where:

x_i = each signal level

n = total number of samples

In this case $n = 6$ signal levels as $x_1, x_2, \dots, x_6$

The mean $\bar{\mu}$ is given by

$$\bar{\mu} = \frac{\sum_{i=1}^6 x_i}{6} = \frac{415.09}{6} = -69.18 \text{ dBm} \quad (3)$$

$$\bar{\mu} = -69.18 \text{ dB}$$

Standard deviation (S) calculated as:

$$= \sqrt{\frac{\sum_{i=1}^6 (x_i - \bar{x})^2}{n - 1}} \quad (4)$$

$$\text{Variance} = \frac{174.2480}{5} = 34.8496 \text{ dB}$$

$$\sigma = \sqrt{34.8496} = 5.9034 \text{ dB}$$

Standard error (SE) calculated as:

$$SE = \frac{S}{\sqrt{n}} \quad (5)$$

$$SE = \frac{5.9034}{\sqrt{6}} = \frac{5.9034}{\sqrt{2.4495}} = 2.4100 \text{ dB}$$

Table 4 provides summary of metrics (Threshold)

Metrics	Value
Mean signal power level	-69.18 dB
Standard Deviation	5.9034 dB
Standard Error	2.2100 dB

3.4 Statistical Analysis of TVWS Noise Power Levels for the Unoccupied channels

Calculation of Mean

Mean can be calculated using the formula:

$$\bar{\mu} = \frac{\sum_{i=1}^n x_i}{n} \quad (7)$$

Where:

x_i = each signal level

n = total number of samples

In this case $n = 22$ signal levels as $x_1, x_2, \dots, x_{22}$

The mean $\bar{\mu}$ is given by

$$\bar{\mu} = \frac{\sum_{i=1}^{22} x_i}{22} = \frac{2460.64}{22} = -111.84 \text{ dBm}$$

Standard deviation (S) calculated as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}} \quad (8)$$

$$\text{Variance} = \frac{641.7956}{21} = 30.5617 =$$

$$\sigma = \sqrt{30.5617} = 5.5283 \text{ dB}$$

Standard error (SE) calculated as:

$$SE = \frac{S}{\sqrt{n}} \quad (9)$$

$$SE = \frac{5.5283}{\sqrt{22}} = 1.1786 \text{ dB}$$

Table 5: provides summary of metrics (Threshold)

Metrics	Value
Mean noise floor power level	-111.84 dB
Standard Deviation	5.5283 dB
Standard Error	1.1786 dB

Table 5 below present all the critical data collected from Kano state which includes, the mean values, standard deviation and standard error for both the signal power level and Noise power levels. These thresholds will be used for development of algorithm for spectrum sensing in cognatic radios.

Table 6: Summary of critical data collected from Kano state

Description	Metrics
Bandwidth per Channel	8 (MHz)
Number of occupied Channels	6
Spectrum Occupancy rate	21.4 (%)
Number of un-occupied Channels	22
Total Bandwidths Available	224 (MHz) 100(%)
Bandwidth in Active usage	48 (MHz)
Percentage of usage	21.4(%)
Unoccupied Bandwidth	176 (MHz)
Percentage of bandwidth free	78.6 (%)
Available Spectrum in Rural Areas	224 (MHz) 100%
Mean ($\bar{x}$) Signal power Active Channel	-69.18 dB
Standard Deviation	5.9034 dB
Standard Error	2.4100 dB
Mean ($\bar{x}$) Signal power Unoccupied Channel	-111.84 dBm
Standard Deviation	5.5283dB
Standard Error	1.1786 dB
TV Transmitter power (Pt)	30 Kw
Transmit Antenna gain (Gt)	12 dB
Transmit Antenna Hight (Ht)	30 m
Received Antenna gain (Gr) dB	12 dB
Received Antenna Hight (Hr) in meters	3.0 m

3.5 DISCUSSION

To start with, it is important to note that, the total spectrum within the span of the UHF TV band (470 – 694) MHz is 224 MHz. Each TV channel occupies bandwidth of 8MHz with a guard band or inter-channel spacing of 8MHz in line with ITU, UHF TV channelization arrangement (ITU- R BT.2302) giving rise to 28 channels from channel 21– 48 as shown in table 2 above.

The data collected from Kano State shows the spectrum utilization status clearly with channel active labelled =1, and channels that are free labelled = 0, as presented in bar charts of figures 5 and 6 while figure 4 depicts the spectrum trace. The results obtained indicates that 6 channels are occupied active with spectrum occupancy rate of 21.4%, and spectrum utilization of 48MHz. These channels are (Channels 21, 23, 29, 32, 35, and 47). While the remaining 22 channels are free, making available 176 MHz spectrum of spectrum bandwidth representing (78.6%). Measurement result from Kura L.G.A suburban area 40Km away from Kano showed the same trend as in Kano city, except that, the signal amplitudes are attenuated due to environmental factor (Patt loss and fading). The spectrum trace, bar chart of the plot of signal power level against channel number, bar chart of the plot of occupancy status against channel number and raw data collected from Kura are presented in figures 8 and 9 and table 3 respectively.

Conversely, the result obtained from Gwarmai a rural area, 75Km away from Kano shows no trace of TV signal. Meaning, there is no active primary user of the spectrum, therefore spectrum utilization is zero, and all the spectrum 224MHz (100%) is available and free. This result also revealed large, portion of spectrum, which are ideal for high-throughput applications. The quantity of spectra identified are wide and sufficient to support modern broadband technologies most especially cognitive radios. The spectrum trace is presented in figure 10 above.

Global evidence consistently demonstrates that the 470-694 MHz band is significantly underutilized across diverse geographical contexts. This underutilization ranges from approximately 80% in Nigeria's studies to even higher figures in some international campaigns. The consistency of these findings across different regulatory domains, measurement methodologies, and geographical settings strongly supports the technical viability of TVWS deployment.

4. CONCLUSION

In conclusion this report has presented the outcome of literature review on global and local spectrum measurement campaigns and the spectrum utilization measurements results conducted in Kano State, Nigeria. The aim of the experimental measurement is to identify the availability of TVWS. Measurement campaigns across the globe, from the US and Europe to Asia and the Philippines, consistently shows that the radio frequency spectrum is severely underutilized, with average occupancy rates often falling below 20-30%. Local studies in Nigeria, across various states and frequency bands (including VHF, UHF, and FM radio), confirm that this global trend of underutilization applies equally to Nigeria. The results obtained from Kano State indicates six active channels (Channels 21, 23, 29, 32, 35, and 47) with a spectrum utilization of 48 MHz (21.4%), while 176 MHz (78.6%) remains unoccupied. A measurement conducted in the Kura Local Government Area (L.G.A.) suburban region showed a trend consistent with that observed in Kano city; however, the signal amplitudes are attenuated due to distance (40 km) and environmental factors.

Conversely, in the rural area of Gwarmai, situated 75 km from Kano, no discernible signal was detected. The absence of signal indicates a complete lack of active spectrum users, thereby resulting in a zero-spectrum utilization rate, with the entirety of the 224 MHz spectrum remaining available for deployment; clearly demonstrating that vast portion of allocated spectrum remain unused for significant periods. This unused capacity is known as "white space." Therefore, this result strongly validates the need for moving away from the inefficient static spectrum allocation model to dynamic Spectrum Access (DSA) to unlock the vast potential of this unused spectrum.

4.1 PROPOSED FUTURE RESEARCH DIRECTION

Spectrum measurement campaign has confirmed the existence of significant TVWS in Kano in the UHF TV band, with higher availability in rural areas. To leverage these opportunities the following are proposed for future research:

- I. The results of various spectrum utilization measurements conducted across Nigerian states, point to the availability unoccupied TVWS, therefore, a nationwide measurement campaign should be conducted to develop a comprehensive TVWS database.
- II. Artificial Intelligence Algorithm or technics should be developed for coordination and management of the TVWS database to allow interference free access of the spectrum by Cognatic Radio users.

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4.3 AUTHOR CONTRIBUTIONS:

All authors contributed to the study conception and design. Material preparation, data collection & analysis and draft of the first manuscript was done by performed by Yahaya Hamisu Abubakar. Dr. Mathew Ehikhamenle reviewed and corrected manuscript. All authors read and approved the final manuscript.

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