OPEN-SOURCE AND CLOUD-BASED SOLUTIONS FOR EFFICIENT HFSWR SITE PLANNING

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Abstract:

The capability to detect targets beyond the horizon is one of the High Frequency Surface Wave Radar's (HFSWR) key advantages, which are primarily used for detecting vessels at distances exceeding 350 km. Compared to microwave radars, which typically have detection ranges of up to 40 km, HFSWRs offer significantly greater coverage. This paper specifically focuses on planning the coverage area of these radars using the proposed solution and open-source software tools. The proposed software tool should streamline marketing presentations, site planning, and site surveys by enabling fast and efficient coverage planning, the selection of HFSWR locations, coverage areas plotting, and the visualisation of antennas/containers, directly on Google Earth (GE). GE is a freely available desktop and mobile application which enables preliminary site visualization where HFSWR is planned. We also identified readily available, widely adopted, and free applications (open-source) that provide excellent results with minimal programming effort. Although the scripting frameworks of licenced software tools share structural similarities, the functional workflow development often demands significant time to identify suitable functions and write new code, but they are cost-effective (Google Sheets, LibreOffice Calc etc.), free and widely accessible, with no licensing costs. Cross-platform flexibility and cloud-based mode of operation are of particular importance, due to the possibility of calculating coverage area using only mobile devices, which is especially important in practice. The rapid visualization enables us to adjust input parameters and redraw multiple times until we achieve an optimal solution for each HFSWR location, as well as comprehensive coverage across multiple locations.

Keywords:

HFSWR, OTHR, Radar Location Planning, Antenna Positioning, Antenna Arrays.

INTRODUCTION

Radars are commonly used to detect remote objects using electromagnetic waves. However, High Frequency Surface Wave Radars (HFSWRs) differ significantly from conventional radars. Unlike conventional radars, HFSWR is neither mounted on towers nor compact enough to fit in vehicles or aircraft. Additionally, a direct line of sight between the radar and the target is not required for target detection. This capability to detect targets beyond the horizon is one of HFSWR's key advantages.

As the name suggests, HFSWR operates in the HF band (3–30 MHz). In this frequency band, a surface wave component forms between the electromagnetic wave and the sea surface.

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This surface wave follows the Earth's curvature, enabling reflections from targets far beyond the line of sight. Given the long wavelengths (10–100 m) in the HF band, large reflective surfaces are required. Consequently, HFSWR is primarily used for detecting vessels beyond the horizon at distances exceeding 350 kilometres. Compared to microwave radars, which typically have ranges of up to 40 km, HFSWR offers significantly greater coverage. The hardware basis of HFSWRs, as well as data on the antenna arrays used in such systems, can be found in [1] [2] [3] [4].

The primary market for HFSWR systems includes agencies responsible for a country's Exclusive Economic Zone (EEZ). Preventing illegal fishing, drug smuggling, illegal immigration, theft of crude oil, terrorism and support for rescue missions can return investment in such a kind of investment very fast. Unlike satellite or aerial surveillance, HFSWRs provide continuous, cost-effective monitoring. Many authors deal with HFSWR system design and radar signal processing, as presented in [5] [6]. They also describe how these radars actually work in practice, what their coverage areas are, system parameters, and generally what kind of signal processing leads to good results when it comes to tracking of targets, or ships in this case. In order to be able to simulate the coverage area in general, it is very important to have a good knowledge of all parts of these systems.

HFSWR allows the surveillance of wide zones at large distances. Well-planned coverage actually means that we can detect targets in a large spatial sector with no or very few blind spots, especially when it comes to a radar network, where it is necessary to use multiple radars to cover a large length of coastline. The next step relates to signal processing, which should result in the detection of all targets of interest in a spatial sector. In recent years, high-resolution primary signal processing has been of particular interest, due to its numerous advantages over classical signal processing [7] [8] [9].

HFSWR system design and performance analysis require a numerical tool capable of representing complex environments to model wave propagation in realistic conditions. Many authors deal with modelling of HFSWRs, as presented in [10] [11] [12] [13]. These papers actually form the basis for the development of the coverage area simulator presented in this paper.

The proposed software tool should streamline marketing presentations, site planning, and site surveys by enabling the visualisation of antennas/containers and coverage zone, directly on Google Earth (GE). They are cost-effective, such as Google Sheets and LibreOffice Calc, free and widely accessible, with no licensing costs. Cross-platform flexibility and cloud-based mode of operation are of particular importance, due to the possibility of calculating coverage area using only mobile devices.

In practice, after such a simulation, where the position of all elements of the HFSWR system can be quickly determined, the actual design of such a system follows, and finally the implementation of algorithms for primary signal processing, as presented in [14] [15] [16].

The paper is organized as follows. In Section 2, the main principles of HFSWR site planning are presented. In Section 3, we present open-source and cloud-based software tools for efficient HFSWR site planning. In Section 4, the simulation results, based on an open-source solution for HFSWR coverage, are shown, while in Section 5 we make some conclusions.

2. HFSWR SITE PLANNING FUNDAMENTALS

Planning the coverage area is the first step in designing such systems. Frequency Modulated Continuous Wave (FMCW) is commonly employed in HFSWR systems. To mitigate challenges such as Bragg scattering and ionospheric interference, a dual-frequency operation is advantageous. Therefore, two antenna arrays are utilized on both the Rx and Tx sides. In practice, the receiver (Rx) area typically spans approximately 500 meters along the coastline and extends up to 100 meters inland, while the transmitter (Tx) area dimensions are roughly 100×100 meters. These dimensions depend on the operational frequencies. Typical HFSWR system architecture is shown in Figure 1.

A linear monopole antenna array provides 120° azimuth coverage, with an optimal spacing of 0.45*λ between antenna elements (where λ is the wavelength). In practice, an array of 32 monopole antennas achieves sufficient sensitivity for weak signals and high angular resolution. However, this configuration requires an extended coastal area at low elevation. The azimuth coverage aligns with the coastline geometry, ensuring the monitored area encompasses the country's EEZ.

To ensure effective coupling between transmitting/receiving antennas and the water surface, antennas must be installed near water at low elevations. Due to the extremely weak reflected signals, the receiving array requires a long antenna configuration. Tx power is crucial for long-range detection, requiring sufficient physical separation between the Tx and Rx arrays to prevent Rx saturation caused by its own signal.

The Tx array must be directional, focusing energy toward the coverage area while minimizing radiation toward the Rx array.

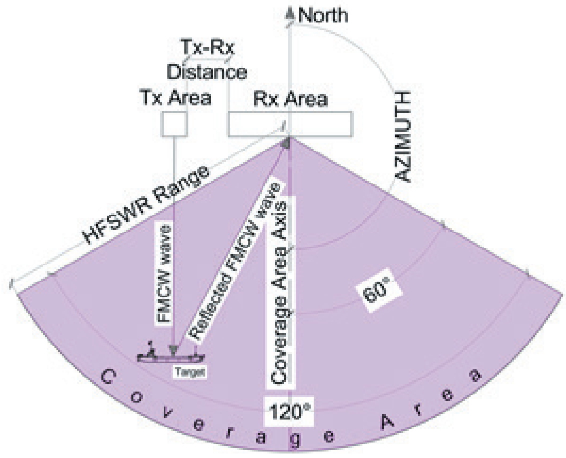
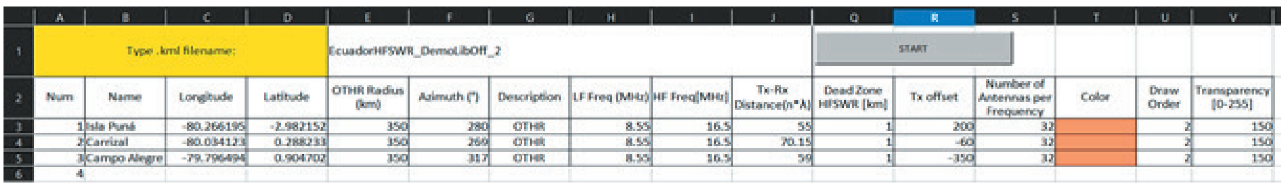
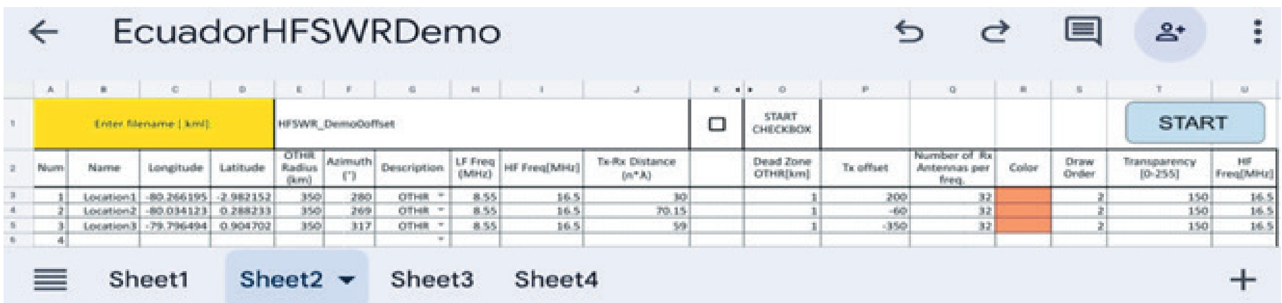


Figure 1. Typical HFSWR system architecture



Type .kml filename:				EcuadorHFSWR_DemoLibOff_2						START					
Num	Name	Longitude	Latitude	OTHR Radius (km)	Azimuth (°)	Description	LF Freq (MHz)	HF Freq[MHz]	Tx-Rx Distance(n*A)	Dead Zone HFSWR [km]	Tx offset	Number of Antennas per Frequency	Color	Draw Order	Transparency [0-255]
1	Isla Puná	-80.266195	-2.982152	350	280	OTHR	8.55	16.5	55	1	200	32		2	150
2	Carrizal	-80.034123	0.288233	350	269	OTHR	8.55	16.5	70.15	1	-60	32		2	150
3	Campo Alegre	-79.796494	0.904702	350	317	OTHR	8.55	16.5	59	1	-350	32		2	150
4															

Figure 2. LibreOffice input sheet



Enter filename [.kml]:				HFSWR_DemoOoffset							START CHECKBOX						START
Num	Name	Longitude	Latitude	OTHR Radius (km)	Azimuth (°)	Description	LF Freq (MHz)	HF Freq[MHz]	Tx-Rx Distance (n*A)		Dead Zone OTHR[km]	Tx offset	Number of Rx Antennas per freq.	Color	Draw Order	Transparency [0-255]	HF Freq[MHz]
1	Location1	-80.266195	-2.982152	350	280	OTHR	8.55	16.5	30		1	200	32		2	150	16.5
2	Location2	-80.034123	0.288233	350	269	OTHR	8.55	16.5	70.15		1	-60	32		2	150	16.5
3	Location3	-79.796494	0.904702	350	317	OTHR	8.55	16.5	59		1	-350	32		2	150	16.5
4																	

Figure 3. Google Sheets input sheet

Planning the coverage area is very important, so it is essential to develop a software tool to do this step in the fastest way. In the next section, one such solution will be presented, with a focus on open-source solutions.

3. OPEN-SOURCE AND CLOUD-BASED SOFTWARE TOOLS FOR EFFICIENT HFSWR SITE PLANNING

The topic of this section is the introduction of a software tool for HFSWR coverage estimation. This rapid visualization allows us to adjust input parameters and redraw them multiple times until we achieve an optimal solution for each HFSWR site. Also, a comprehensive EEZ coverage across multiple locations can be shown. The generated drawing serves as both a marketing tool for potential customers and a valuable resource for preliminary site planning.

The software tool generates .kml files (a format natively supported by Google Earth). Input data processing, .kml file creation, and altitude extraction were automated using Microsoft Office Excel VBA. But in this paper, we present two open-source solutions by using LibreOffice Calc VBA and Google Sheets (for cloud-based collaboration). These platforms serve as user-friendly interfaces for data entry, reporting, and scripting (via VBA/JavaScript).

The input data sheet interface in LibreOffice Calc closely mirrors Microsoft Excel, ensuring compatibility in layout, formulas, and scripting workflows (e.g., VBA).

Microsoft Office uses VBA (Visual Basic for Applications) for scripting, while LibreOffice employs its own API-based Basic code (LibreOffice Basic). Though both languages share a similar syntax, their object models and methods differ significantly, as shown in Listing 1 and Listing 2.

Notably, VBA scripting is not supported in browser-based editions. So, Desktop users can initiate the script via a dedicated START button or a checkbox in the Google Sheets interface, as presented in Figure 2 and Figure 3. The structure of input sheets is shown in these figures.

START is a control button which can start the script from Sheet2. The script generates a .kml file that automatically opens in Google Earth within seconds and enables the coverage area visualisation and antenna/container positions. The associated spreadsheets output the antenna coordinates (latitude, longitude) and altitudes as well. The generated .kml file is automatically saved in the same directory as the source spreadsheet file from which the script is executed. Table 1 shows all necessary input parameters and their detailed description. By using the LF array central position, antenna array angle, and inter-antenna distance, all antenna positions are determined. KML files outlining the EEZ of individual countries are also available online. By integrating these EEZ boundaries into custom .kml file, it is possible to enhance the visualization, enabling a clearer assessment of HFSWR coverage.

Table 1. Key hardware and software components of AI hearing aids

Parameter	Description
Name	Location name
Latitude and longitude	Array centre coordinates of the LF antenna array
Range (km)	Maximum coverage distance
Azimuth (degrees)	The orientation of the coverage area axis related to the north
Description	This section is reserved for future sensor type selection, such as the integration of microwave (MW) radars or cameras into the same script framework.
HF and LF Freq (MHz)	In this context, "LF" refers to a lower frequency within the HF frequency range, while "HF" denotes a higher frequency relative to another reference frequency
Tx-Rx distance	The separation between the Tx and Rx arrays is defined as a multiple of the lower frequency (LF) wavelength (λ).
Dead zone OTHR [km]	IT refers to the circular area near the radar system where targets cannot be detected. This occurs because the distance between the target and the radar must be significantly greater than both the operational wavelength and the Tx-Rx distance.
Tx offset	The Tx Offset quantifies the misalignment between the Rx and Tx arrays, defined as the horizontal distance of the Tx array from the Rx array's central axis (ideally minimized to zero).
Number of Rx antennas per Frequency	The number of receiving antennas allocated to each frequency band is typically between 16 and 32
Colour	The coverage area of the HFSWR is represented as a polygon. Users can customize the fill colour for each coverage area by selecting the desired fill colour in the corresponding cell. This feature enhances clarity when analysing overlapping zones or presenting results to stakeholders.
Draw order	Layering definition for overlapping polygons
Transparency	Opacity settings of the HFSWR coverage area polygon.

```
' Input Lat1 and Lon1 [decimal degrees] are starting coordinates, dist - distance between starting and
calculating coordinates [km],
' Azimuth - calculating from starting toward calculating coordinates [deg]
' Output: Lat2 and Lon2
Sub LatLonDist(ByVal Lat1 As Double, ByVal Lon1 As Double, ByVal dist As Double, ByVal Azimuth As Double,
ByRef Lat2 As Double, ByRef Lon2 As Double)

Dim Pi As Double
    Pi = 3.14159265358979
    r = 6378.1 ' km - radius of the Earth

    Lat2 = WorksheetFunction.Asin(Sin(Lat1 * Pi / 180) * Cos(dist / r) + Cos(Lat1 * Pi / 180) * Sin(dist
/  r) * Cos(Azimuth * Pi / 180)) * 180 / Pi

    Lon2 = Lon1 + WorksheetFunction.Atan2(Cos(dist / r) - Sin(Lat1 * Pi / 180) * Sin(Lat2 * Pi / 180),
Sin(Azimuth * Pi / 180) * Sin(dist / r) * Cos(Lat1 * Pi / 180)) * 180 / Pi

End Sub
```

Listing 1. An example of a program written in VBA Script (LatLonDist function)

```
function LatLonDist(lat1, lon1, dist, azimuth) {
  var pi = Math.PI;
  var r = 6378.1; // km - radius of Earth

  var lat1Rad = lat1 * pi / 180;
  var lon1Rad = lon1 * pi / 180;
  var azRad = azimuth * pi / 180;

  var lat2Rad = Math.asin(Math.sin(lat1Rad) * Math.cos(dist / r) + Math.cos(lat1Rad) * Math.sin(dist / r)
* Math.cos(azRad));
  var lon2Rad = lon1Rad + Math.atan2(Math.sin(azRad) * Math.sin(dist / r) * Math.cos(lat1Rad), Math.
cos(dist / r) - Math.sin(lat1Rad) * Math.sin(lat2Rad));

  return [lat2Rad * 180 / pi, lon2Rad * 180 / pi];
}
```

Listing 2. An example of a program written in JavaScript (LatLonDist function)

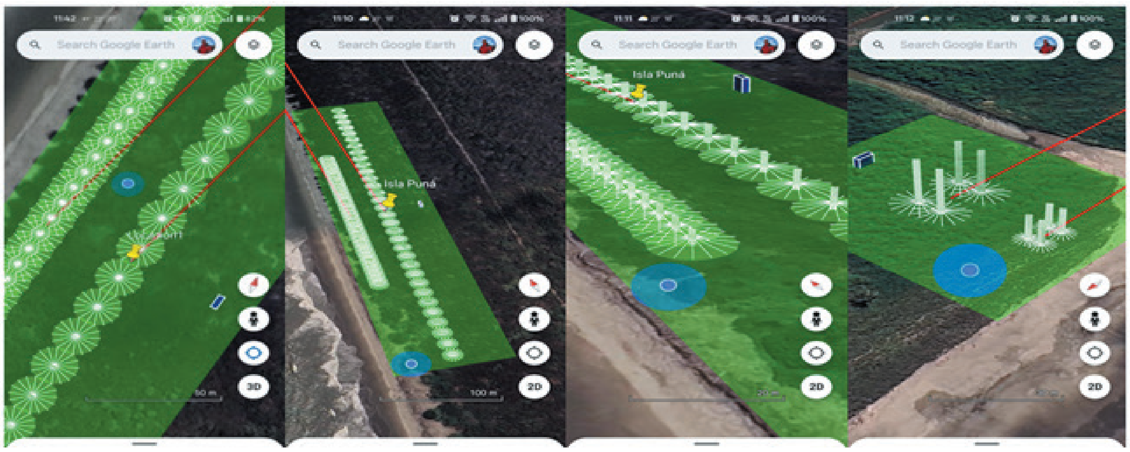


Figure 4. Rx antenna array (first 3 parts) and Tx antenna array (last part) which are displayed on a cell phone

4. SIMULATION RESULTS

The simulation results are generated for an arbitrarily chosen location in Ecuador, where complete coverage of the seashore is required. For this purpose, the coverage will first be shown by using a single radar, and then by using a radar network.

In case of using Google Sheets, the .kmz file will be saved automatically to Google Drive for immediate access to Google Earth. In cases where Google Earth fails to load the .kml file directly from Google Drive on mobile devices, the file must first be downloaded to the device's local storage and opened manually.

The script comprises four core functions. The primary function, *HFSWR_position()*, is initiated by a START button. During its execution, it calls two helper functions—*LatLonDist()* and *GetAltitudeD()*—as needed. Additionally, the onEditTrigger(e) function monitors user interactions, and automatically launches the main process when a designated checkbox is activated. The *GetAltitudeD()* function retrieves altitude data for a known antenna location via the Bing Maps API and stores this information in the corresponding cell of Sheet 3. Note that this function will need to be updated in the future, as Microsoft has announced the retirement of the Bing Maps API. Therefore, the migration to Azure Maps is recommended for continued functionality. The *LatLonDist()* function calculates and returns latitude and longitude values.

Figure 4 shows Tx and Rx antenna positions which are displayed on a cell phone by reading output .kmz file from Google Drive. The user's real-time position is displayed as a blue marker on Google Earth. This feature aids in verifying antenna alignment, optimizing their placement, or ensuring safety protocols during site inspections.

The distance between the LF Rx array and the HF Rx array is equal to λ_{LF}, and the bearing is the azimuth. Using this information, we compute the central point of the HF Rx array and subsequently determine all HF Rx antenna positions. The container location with electrical equipment is also calculated to maintain a safe distance.

Ideally, the centre of the Tx antenna array should be aligned with the corresponding Rx array axis. All calculated antenna positions are stored in Sheet4 and they are categorized by location name and antenna array number. For the antenna positions, we illustrate lines representing antenna monopoles and radials. The height of each antenna is determined as follows: $Ha=\lambda/8+1.5\text{m}$, where $\lambda/8$ is the monopole height, and 1.5m is the bracket height. The Tx area is calculated by using the same Lat/Lon formula, with the Tx-Rx distance provided in the input sheet (Sheet 2). Tx antennas are arranged in a rectangular configuration with dimensions of $\lambda/2$ and $\lambda/4$, where $\lambda/2$ is parallel to the shoreline and the Rx array line of the corresponding frequency. Users can adjust parameters and regenerate site layouts within seconds. For example, if an antenna array's proximity to water risks flooding, its latitude and longitude can be updated directly in the spreadsheet.

The simulated coverage area by one HFSWR (cell phone preview) and corresponding antenna positions are shown in Figure 5, while Table 2 shows the corresponding altitudes for first 12 Rx antennas for 3 different HFSWR locations. The main goal is to cover the entire sea coast, which is impossible with just one radar.

For on-site visits, the .kml file can be downloaded onto a mobile phone, providing real-time orientation. During a site survey, engineers can access precise information about the locations of antennas and containers in their vicinity. If the designer identifies necessary changes during the site survey, a Google Sheets script is available for final adjustments. The updated coordinates can then be forwarded to local surveyors to identify property owners and facilitate ownership agreements between the system user and property owners. Figure 6 shows the simulation of coverage of the entire sea coast by using a radar network.

Position Name	Antenna Description	Latitude	Longitude
Isla Puná	LF Rx 1	-2.98432	-80.2665772
Isla Puná	LF Rx 2	-2.98418	-80.2665526
Isla Puná	LF Rx 3	-2.98404	-80.2665279
Isla Puná	LF Rx 4	-2.9839	-80.2665032
Isla Puná	LF Rx 5	-2.98376	-80.2664786
Isla Puná	LF Rx 6	-2.98362	-80.2664539
Isla Puná	LF Rx 7	-2.98348	-80.2664293
Isla Puná	LF Rx 8	-2.98334	-80.2664046
Isla Puná	LF Rx 9	-2.9832	-80.2663799
Isla Puná	LF Rx 10	-2.98306	-80.2663553
Isla Puná	LF Rx 11	-2.98292	-80.2663306
Isla Puná	LF Rx 12	-2.98278	-80.266306
Isla Puná	LF Rx 13	-2.98264	-80.2662813
Isla Puná	LF Rx 14	-2.9825	-80.2662566
Isla Puná	LF Rx 15	-2.98236	-80.266232
Isla Puná	LF Rx 16	-2.98222	-80.2662073
Isla Puná	LF Rx 17	-2.98208	-80.2661827
Isla Puná	LF Rx 18	-2.98194	-80.266158
Isla Puná	LF Rx 19	-2.9818	-80.2661334
Isla Puná	LF Rx 20	-2.98166	-80.2661087
Isla Puná	LF Rx 21	-2.98152	-80.266084
Isla Puná	LF Rx 22	-2.98138	-80.2660594
Isla Puná	LF Rx 23	-2.98124	-80.2660347
Isla Puná	LF Rx 24	-2.9811	-80.2660101
Isla Puná	LF Rx 25	-2.98096	-80.2659854

Figure 5. The simulated coverage area by one HFSWR (left), and corresponding antenna positions (right)

Table 2. The corresponding altitudes for first 12 Rx antennas

Locations/Sites	LFRx1	LFRx2	LFRx3	LFRx4	LFRx5	LFRx6	LFRx7	LFRx8	LFRx9	LFRx10	LFRx11	LFRx12
Isla Puná	1	1	1	1	1	1	1	1	1	1	1	1
Carrizal	6	6	6	6	6	6	6	6	6	6	6	6
Campo Alegre	9	9	9	10	10	10	10	10	10	10	11	11

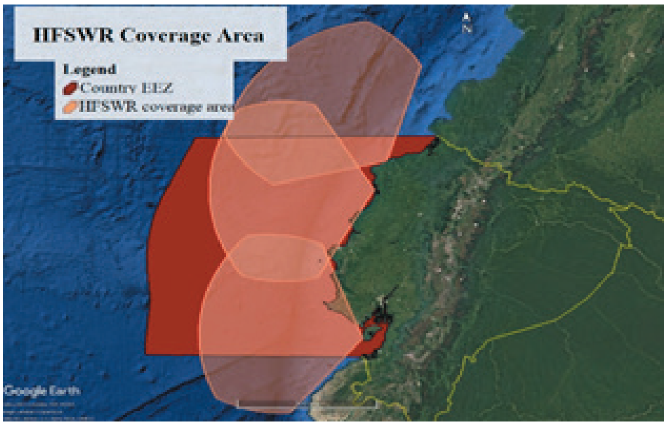


Figure 6. The coverage of the entire sea coast by using a radar network

5. CONCLUSION

In this paper, we proposed the open source and cloud-based software solution for HFSWR site planning that enables fast and efficient coverage planning, coverage areas plotting and the visualisation of hardware elements (antennas/containers), directly on Google Earth. Of particular value is the ability to display the coverage area of a multiple radar network, making it possible to easily simulate coverage of the entire sea coast, which is impossible to cover with just one radar. The key advantages of this solution include cost efficiency and cross-platform flexibility. We use Google Sheets and LibreOffice Calc which are widely accessible, with no licensing costs. These platforms serve as user-friendly interfaces for data entry, reporting, and scripting (via VBA/JavaScript). Another advantage is rapid iteration, because users can adjust parameters and regenerate site layouts within seconds. The proposed software tool shows the entire site in Google Earth, ensuring immediate validation of the required coverage area. Of particular importance is the application on mobile devices, especially during site surveys. Related to the main drawbacks, although macro-based workflows pose security risks in general, they are acceptable here due to internal file-sharing practices and special purposes. Also, LibreOffice, comparable to Microsoft Excel, has a smaller support community and fewer specialized resources, but JavaScript has extensive developer support and enables real-time scripting on mobile devices.

6. ACKNOWLEDGEMENTS

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