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Contribution of SAR Radar Imagery in the Detection of Suspicious Vessels in the Ivorian EEZ

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Abstract

The present work proposed a method for match SAR and AIS data to detect vessels carrying out suspicious activity in the Ivorian EEZ. Two superposition methods, detected AIS and SAR data, based on point-to-point association on the one hand and point-to-line on the other hand, were used to detect suspicious vessels in Ivorian marine waters. The results showed that most vessels detected in the Ivorian EEZ do not declare their positions to avoid being spotted. These funds are likely to practice illegal, undeclared and unregulated fishing (INN fishing). This clandestine activity is very recurrent in Ivorian waters. This is illustrated by the number of suspicious vessels detected by SAR radar imagery which is greater compared to declared or authorized vessels.

Keywords

INN Fishing, CFAR Algorithm, AIS, Sentinel-1A, Ivory Coast

1. Introduction

Safety and security at sea are today worrying problems for those involved in fishing and for our governments. Like the Exclusive Economic Zones (EEZ) of West African countries, due to their potential in fisheries resources, that of Côte d'Ivoire attracts numerous vessels and is subject to all forms of maritime activities; overfishing, maritime traffic, illegal fishing, etc. The United Nations Food and Agriculture Organization (FAO) has highlighted the need to manage marine resources so that the rate of harvest is commensurate with their capacity to self-renew [1] [2]. This is why improving maritime domain knowledge and the sustainable use of oceans, seas and marine resources has gained importance [3]. This requires monitoring tools that can provide observations on fishing net activity [4] [5]. Thus, the strengthening of maritime surveillance must be done in this area, particularly in the ship detection system [6]. Today fishing activities can be monitored by several systems which can be broadly classified as cooperative (AIS system) and non-cooperative (radar system). But given the limitations presented by the Automatic Identification System (AIS) data in ship surveillance, the non-cooperative system such as satellite-based synthetic aperture radar (SAR) is the most suitable because it allows the detection of ships over wide bands without being seriously affected by weather conditions and day-night cycles [7] [8] [9] [10]. However, this system lacks regular and global coverage of the oceans [11]. Given their distinct limitations, the synergistic exploitation of the two aforementioned data (AIS-SAR) represents an opportunity to effectively monitor fishing activities [12] [13] and detect abnormal activities [14]. So it is true that vessel monitoring through the integration of SAR and AIS has attracted a lot of attention [15] [16]. This study, initiated by CURAT (University Center for Research and Application in Remote Sensing) and financed by the Fund for Science, Technology and Innovation (FONSTI), fits into this context by proposing a method for match SAR and AIS data to detect vessels carrying out suspicious activity in the Ivorian EEZ. The Ivorian Exclusive Economic Zone (EEZ) is an integral part of the entire marine ecosystem of the Gulf of Guinea located in West Africa and is between 1˚0' and 5˚5' North latitude and 3˚30' and 7˚5' West longitude. It is bounded to the east by the Cap des Trois Pointes on the Ghanaian border and the Cap des Palmes on the Liberian border, bordering the 520 km long Ivorian coastline. **Figure 1** below shows the location of the Ivorian EEZ.

2. Materials and Methods

2.1. Data

2.1.1. SAR Data

The SAR data used in this study relate to the Sentinel-1A synthetic aperture radar. Sentinel-1A (S1A) is a mission of the European Space Agency ESA and was launched on April 3, 2014. It operates in C-band and it is the IW mode which is the main mode of operation of Sentinel-1 which has been used. This mode allows systematic monitoring of large land and coastal areas with a ground resolution of 5 m × 20 m and a temporal resolution of 6 to 12 days. The data was uploaded to the Copernicus website at: https://scihub.copernicus.eu/dhus/#/home. Total coverage of the entire Ivorian EEZ required seven Sentinel-1 scenes. The downloaded data covers the months of January, June and September 2020 and totals approximately 27 scenes.

2.1.2. AIS Data

The data was provided by the Directorate of Aquaculture and Fisheries of Côte d'Ivoire (DAP) via its fisheries monitoring service. The temporal and spatial

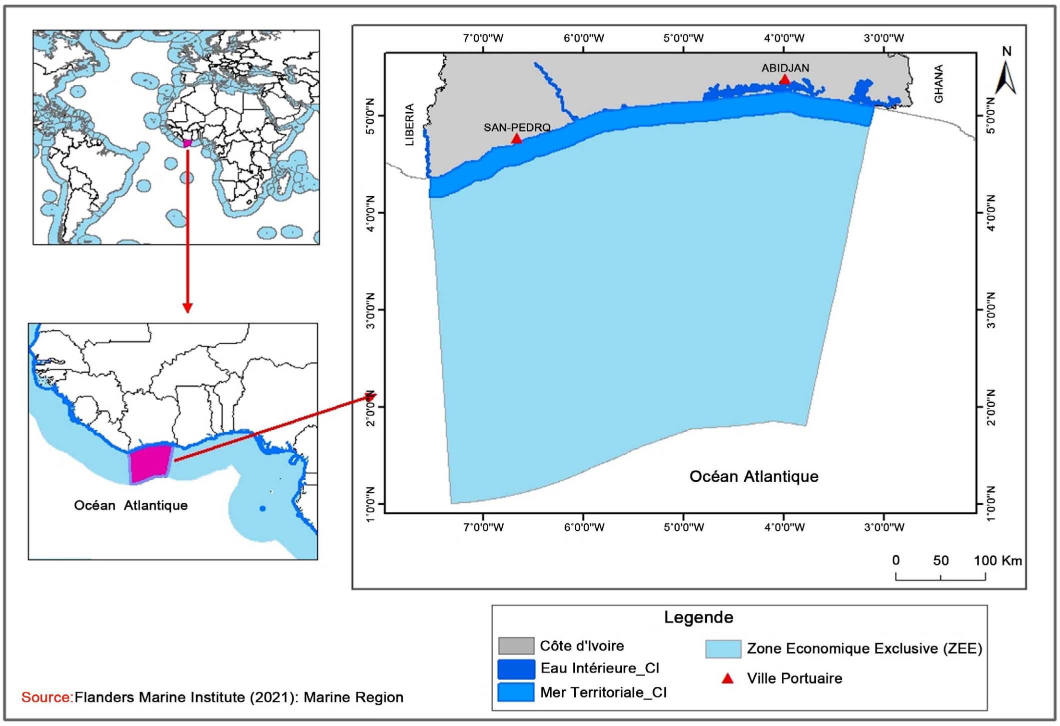

Figure 1. Location of the Ivorian Exclusive Economic Zone (EEZ).

resolution of AIS data is modeled on that of Sentinel-1A satellite imagery. Indeed, the data are those for the year 2020 and cover the months of January, June and September and are distributed across the entire Ivorian EEZ. All AIS data were also acquired between 6 p.m. and 7 p.m. The information contained in AIS data is the vessel identification number (MMSI), its geographic position, position time and timestamp received.

2.2. Methods

Detection of unauthorized vessels undergoes a rigorous process in Sentinel-1A (S1A) image processing. This process requires, first, the preprocessing and processing of Sentinel-1 SAR images and AIS data to then map suspicious vessels operating in Ivorian marine waters.

2.2.1. Sentinel-1A Image Preprocessing

Preprocessing is an essential step in the processing of all types of satellite imagery (optical, radar). Preprocessing Sentinel-1A SAR images will help reduce interference in the form of speckle noise caused by the impact of the backscatter signal process and geometric distortions due to microwave propagation [17]. Figure 2 presents a summary of the preprocessing process followed.

1) Thermal noise correction

It is a radiometric correction which makes it possible to reduce the effects of noise between the sub-beams of the acquisitions, by normalizing the backscattered signal over the entire area of the scene and by minimizing the discontinuities in the signal of the modes of transmission multibeam acquisitions like IW.

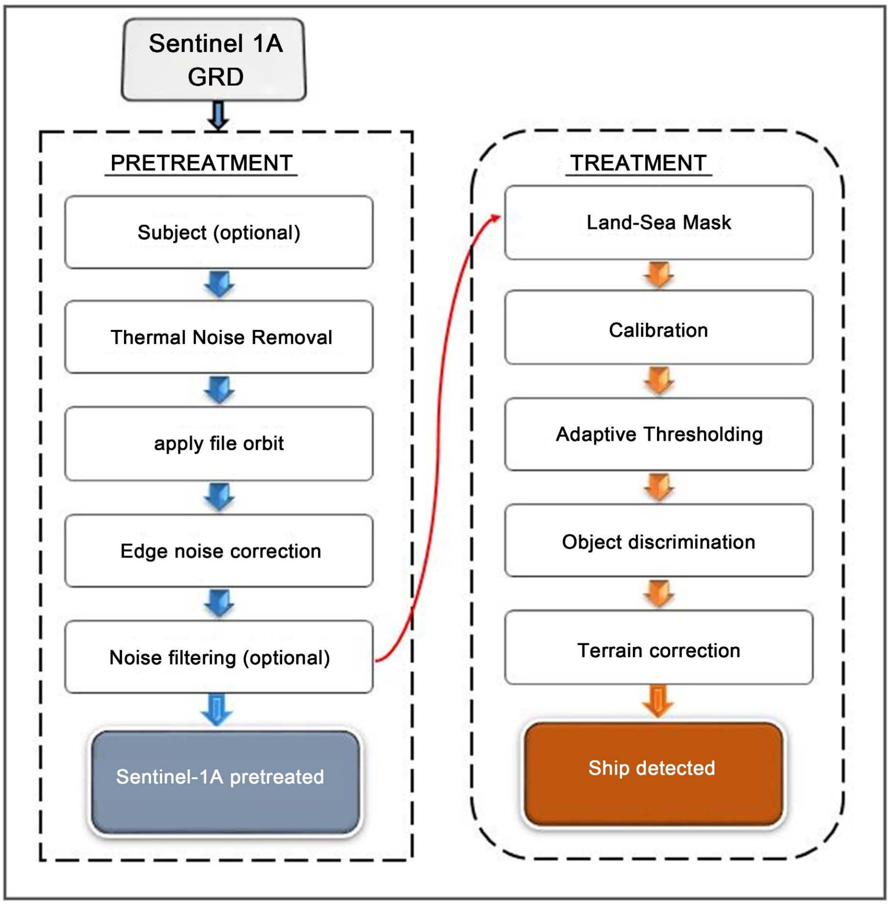

Figure 2. Schematic summary of the methodology used for vessel detection.

2) Correct satellite location

Since the location on the orbit during acquisition provided by default in the meta-data file is generally not precise, it is important to correct the location of the satellite.

3) Edge noise correction

The edge noise correction algorithm integrated into SNAP will remove low-level noise and invalid data at the edges of Sentinel-1 scenes.

4) Noise filtering

The purpose of this noise filtering operation is to remove or reduce the effects of speckle noise and increase the readability of the image. For this purpose, there are numerous filter tests in order to find the best compromise between noise filtering and preservation of the radiometric quality of the signal. Thus, the LEE filter with a window size 3 × 3 was used in this study [18].

2.2.2. Treatment

The processing stage will make it possible to detect ships in the SAR images. The oceanic objection detection operator integrates four main processing stages: land-sea masking, calibration, the adaptive threshold and the object discrimination or identification phase.

1) Land-Sea Masking

Our study area is essentially composed of the oceanic area (for most of the images) but also certain images of the coastline straddling land and sea. In order to avoid detecting false targets outside the study area, the land-sea mask was used to mask the land area.

2) Calibration

In reality, the raw images of SAR data are amplitude images and we cannot exploit them quantitatively. To this end, it is necessary to replace or transform the amplitude image with a calibrated product (sigma_0) for quantitative use of SAR products. Calibration is therefore necessary so that the pixel values truly represent the radar backscatter from the reflecting surface [19].

3) Adaptive threshold or pre-selection of objects

The core of the most common ship detection process is based on the Constant False Alarm Rate (CFAR) algorithm developed by Veridian ERIM in which marine echoes are modeled according to an appropriate statistical distribution and then a threshold is calculated based on a desired Probability of False Alarm (PFA). Thus, this detection algorithm is a local process that allows locating regions of light image samples that are statistically different from the surrounding ocean clutter [20]. The CFAR detection algorithm is automatic type and is implemented in SNAP's ocean object detection tool for rapid vessel detection. The algorithm is applied in a moving window and the user is supposed to define the parameters of the moving window: the target window corresponds to one or more pixels to test (local window size for a signal box supposed to contain the ship); the guard window prevents contamination of the background values by the target pixels (buffer window size which contains the signal window) and a background window size which contains the buffer window (also the signal window signal) [20].

The approach to calculating the CFAR detection form used in this study is based on that used by [20] [21] [22]. According to this approach, for each pixel to test a new threshold, the value is calculated based on the statistical characteristics of its local background. For this purpose, if the pixel value is above the threshold, the pixel is classified as a target pixel (then a ship is detected). However, if the pixel value is below the threshold, no vessel is detected as in Equation (1).

$$Xt \geq T = \text{Target};\ Xt < T \leftrightarrow \text{none Target} \tag{1}$$

With Xt the pixel tested and T a given threshold. Furthermore, the probability of false alarm (PFA) was given by the following formula:

$$PFA = 1 - \int_{-\infty}^{T} f\left(x\right)\mathrm{d}x = \int_{T}^{\infty} f\left(x\right)\mathrm{d}x \tag{2}$$

$$\int_{T}^{\infty} f\left(x\right)\mathrm{d}x < PFA = \text{Cible} \tag{3}$$

where $f(x)$ is the probability function of ocean clutter and x is the range of possible pixel values. In addition, the decision criterion is expressed under the formula below, if the Gaussian distribution is assumed to be constant for the oceanic clutter:

$$xt > \mu b + \sigma b = \text{Target (the target window is a single pixel) or,} \quad (4)$$

$$\mu t > \mu b + \sigma b = \text{Target (the target window contains several pixels)} \quad (5)$$

where xt is the target pixel value; μt is the average value of the target window; μb is the background mean and σb is the background standard deviation.

The next step is the discrimination of ocean objects.

4) Object discrimination

This phase is the last in the ocean object detection process. It allows you to filter fake targets based on minimum and maximum size limit criteria. A target with a dimension less than the minimum size threshold is eliminated and a target with a dimension greater than the maximum size threshold is also eliminated.

The minimum and maximum sizes determined in this study, for vessel detection, are 20 m and 600 m respectively. The minimum size of 20 was chosen because in Ivory Coast the boats of artisanal fishermen of the Fanti type with motor have a length ranging from 5 m to 18 m or even 20 m [23]. The size of 600 m was chosen in order to have a wide range in the detection of very large vessels such as tankers and cargo ships which can reach up to 500 m.

5) Geometric terrain correction

Geometric correction makes it possible to orthorectify the image in order to clean it of distortion effects, georeference the image to project it into a geographic terrestrial reference frame (WGS). This last processing operation will thus make it possible to reproject the image in the right direction, assign it a projection and correct the effects linked to the terrain [17].

2.2.3. AIS Data Processing

In order to have quality AIS data that is easily manipulated, we have preprocessed it and cleaned it of bias. To do this, we proceeded as follows:

Grouping of data from the same month in order to have a single csv file constituting all the AIS of the month.

Quality control of AIS data in order to remove duplicate position signals from the database

Importing data into a GIS (QGIS) by converting it into Shapefile (.shp) form to facilitate processing.

2.2.4. Mapping of Suspicious Vessels (INN Fishing)

In order to map declared and suspected vessels, we compared the AIS/S1A data using the overlay technique. Thus, we adopted two methods inspired by those used by [6] [24] and [25] proposing two types of associations based on minimum distance criteria between AIS and SAR positions.

- **Point-to-point method**

The data association method consists of a time and position matching step [26]. At this level, we did a spatial analysis using a buffer zone (200 m) based on a distance criterion to match the SAR vessels detected from AIS positions; this is the nearest neighbor matching system. SAR data within the buffer radius are considered reported vessels. On the other hand, those which are far from the AIS buffer zone will be qualified as suspicious vessels which have not declared their positions.

- **Point-to-line method**

It is a method based on the identification of the ship's route. The idea is to reconstruct the route or trajectory of the vessel by transforming the AIS position points likely to belong to the same vessel into a line. To do this, the data (points) were converted to AIS online. Thus, the route traveled by the ship is reconstructed. Subsequently, we created a 50 m buffer around the lines created and superimposed the SAR data on it. By clipping (extracting) the buffer from the SAR data, if there is a SAR data item that is in the buffer zone of a ship's route, then it is considered to be the same ship and is qualified as a declared vessel. However, SAR data that is outside of a vessel's route buffer will be considered suspicious vessels. Figure 3 below illustrates the method of mapping suspicious vessels.

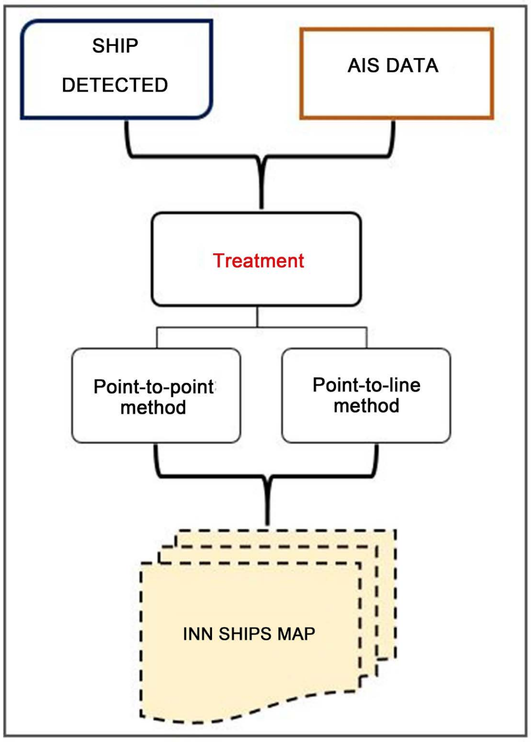

Figure 3. Schematic diagram of the matching between SAR and AIS data for suspect ship mapping.

3. Results and Discussion

3.1. Results

3.1.1. AIS Overlay—Sentinel-1A Radar (S1A)

There Figure 4 below represents the overlay between AIS data and vessels detected by sentinel-1A radar satellite imagery for the months of January, June and September 2020. On this map, the purple dots represent fishing vessels detected by sentinel satellite imagery -1A and blue dots are recorded vessel AIS positions. Indeed, there are 343 AIS vessel positions recorded and 237 vessel positions detected by S1A radar satellite imagery for the month of January. For the month of June, there are 544 AIS positions recorded and 203 vessel positions detected by S1A radar satellite imagery. As for the month of September, 426 AIS positions and 490 ship positions were recorded detected by S1A radar satellite imagery (**Table 1**). The crossing of these two types of data will make it possible to know among the data detected by the S1A satellite those which are superimposed on the AIS data we will say that they are correlated or declared and those which are not we will say that they are not declared or illicit. This process was possible thanks to the 200 m buffer that was applied.

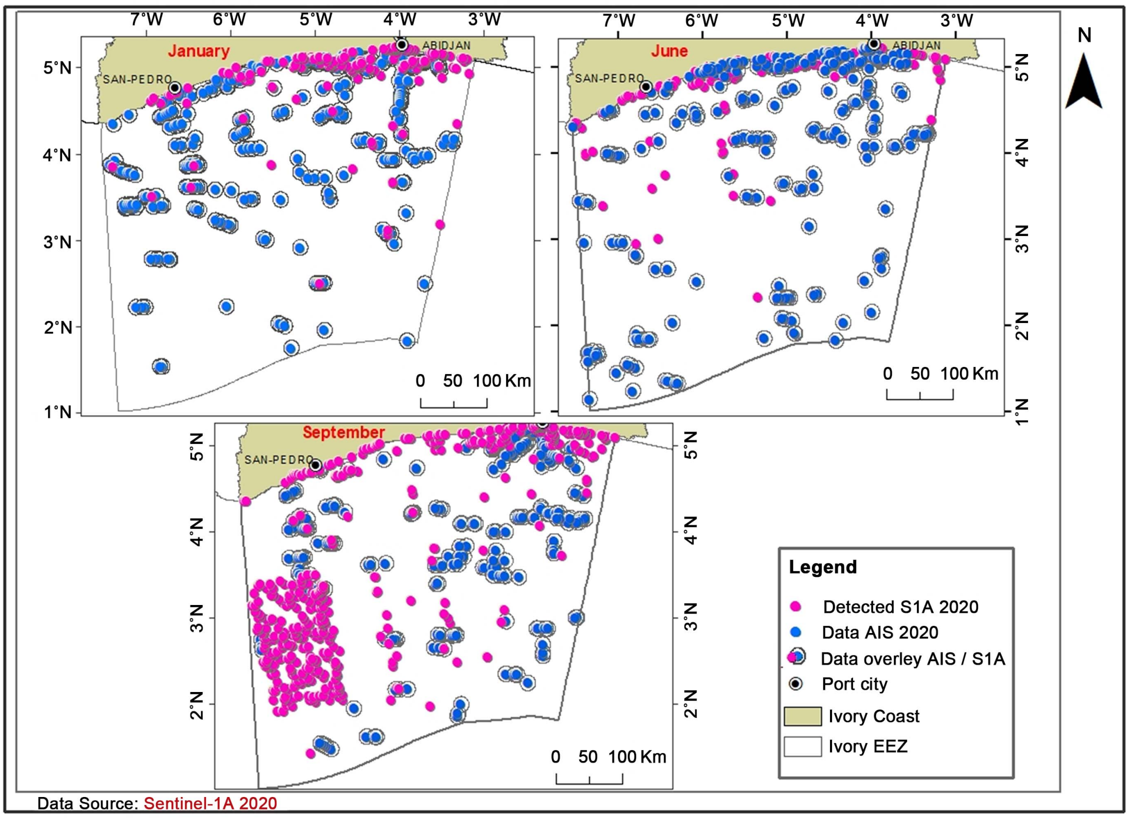

Figure 4. Map of the mapping of SAR and AIS data for the months of January, June and September 2020.

Table 1. Number of AIS data recorded and number of vessels detected by S1A for the months of January, June and September 2020.

		AIS positions recorded	Ship positions detected by S1A
Month	January	343	237
	June	544	203
	September	426	490

3.1.2. Mapping of Suspicious Vessels

The mapping of the areas of operation of suspicious vessels for the months of January, June and September 2020 is shown by **Figure 5**. Among the vessels detected by the radar imagery, those that correlated with the AIS data are represented by the red dots. These are called authorized or declared vessels because they have been registered and given their AIS position. On the other hand, vessels detected by radar imagery which did not correlate with AIS data are represented by black dots. The latter are classified as suspicious vessels because they have not declared or given their AIS position. As a result, they are likely to practice illegal, undeclared and unregulated fishing (INN fishing). We note that the number of suspicious vessels detected by radar imagery is much more compared to those declared (**Figure 6**). For example, in January 2020, 203 suspicious vessels or 85.65% were detected by Sentinel-1A radar imagery compared to 34 declared vessels or 14.35% recorded by the AIS (**Table 2** and **Figure 6**). Spatial analysis of the different maps from January, June and September 2020 shows that the majority of declared vessels are located on the coasts. The spatial distribution of suspicious vessels detected is such that most of them are located (many visible) in the South-West on the Liberian border, on the central coasts within the maritime zones of Jacqueville, in the East near the Ghanaian borders and on the high seas. Also, most of the vessels detected in Ivorian marine waters do not declare their positions so as not to be spotted and thus practice INN fishing. The

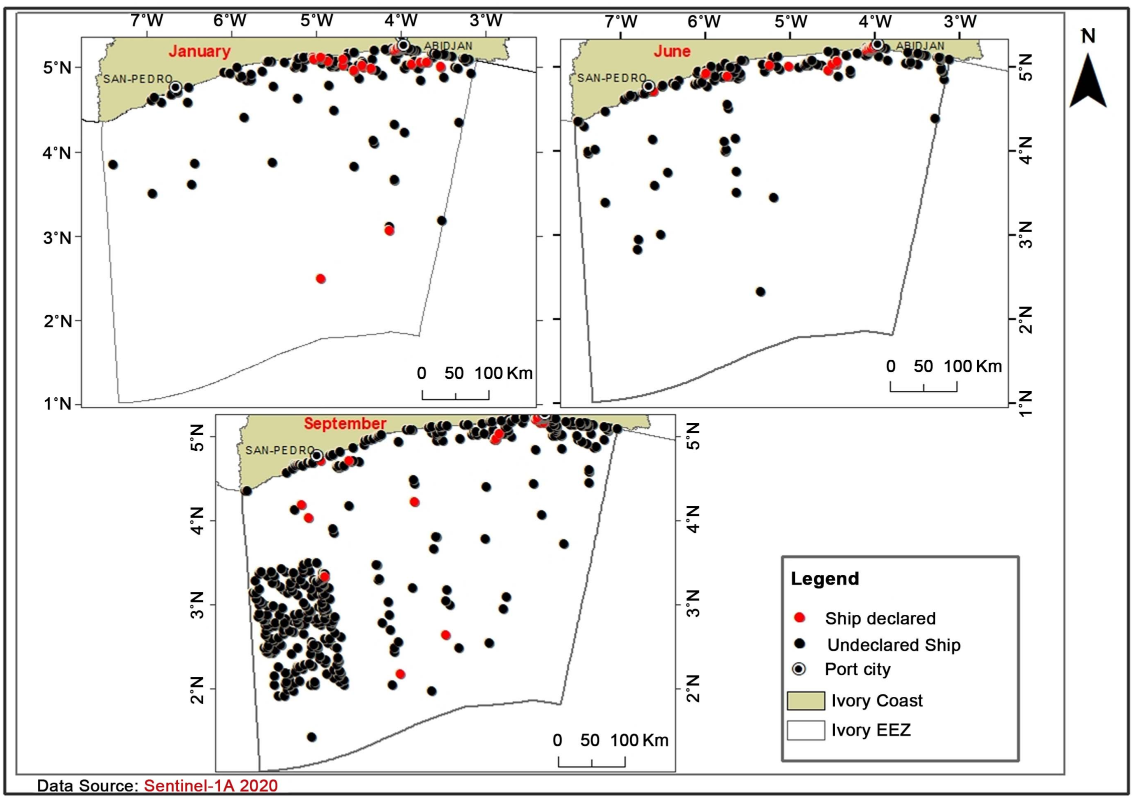

Figure 5. Map of the detection of vessels carrying out suspicious activities in the Ivorian EEZ for the months of January, June and September 2020.

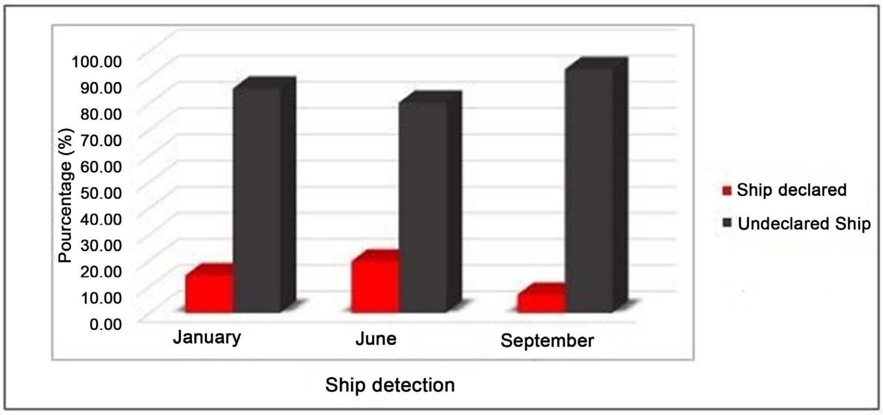

Figure 6. Difference in proportion between declared vessels and suspect vessels for the months of January, June and September 20.

Table 2. Number of authorized and unauthorized vessels for the months of January, June and September 2020.

		Ships reported (correlated)	Suspicious vessels
Month	January	34	203
	June	40	163
	September	34	456

month of September 2020 is the most characterized by strong INN fishing activities, especially on the high seas. These vessels will fish clandestinely on the high seas at the risk of their lives, ignoring safety conditions and thus exposing themselves to accidents at sea, etc. This phenomenon causes the Ivory Coast to lose shortfalls in fishery products and does not allow the regeneration of species.

3.2. Discussions

This study managed to effectively map the declared vessels which activate their transponder to give their AIS positions and the vessels which do not do so, thus qualifying them as suspects [26]. From our results, it appears that most of the vessels detected in Ivorian marine waters do not declare their positions so as not to be spotted and thus practice IUU fishing. This clandestine and illicit activity is so important in Ivorian waters that the number of suspicious vessels detected by radar imagery is much higher than the declared vessels. Our results corroborate those of [27], in his study on the surveillance of the Ivorian EEZ using a Sentinel-1A SAR imagery scene in the Abidjan marine zones to detect vessels which activate their AIS transponder and those which do not. It concluded that of all vessels detected by SAR imagery, 25% were detected by AIS data considered declared vessels while 75% were not detected qualifying them as suspect vessels. Our results are also in the same direction as [18] who in his study on the Java Sea of Indonesia using Sentinel-1 imagery in the detection of fishing vessels showed that of all vessels detected, 7.06% were detected by AIS and 92.94% were not. However, the high number of suspicious vessels detected compared to vessels reported could be an intentional act or not. This joins [28] who claim that vessels not being identified by AIS data are a result of the lack of AIS devices on fishing vessels. However, possible position errors could occur between the actual passage of the SAR radar and the transmitted AIS signal. This discrepancy could affect the correct superposition of SAR and AIS data. Also, the lack of information on a reliable database of oil and gas platforms in the Ivorian EEZ in order to extract them in SAR targets as false alarms have certainly been considered as vessels. All of these aspects constitute limitations in this study.

4. Conclusion

Surveillance of vessels in the Ivorian Exclusive Economic Zone was essentially based on the AIS system. The contribution of SAR Sentinel-1 synthetic aperture radar satellite imagery strengthens and makes ship detection more effective because the SAR is not affected by atmospheric or weather conditions and can operate day and night. Vessel detection was possible using the Constant False Alarm Rate (CFAR) algorithm. The CFAR algorithm provided by the SNAP software and automatic type allowed us to quickly detect ships. The combination of AIS and SAR Sentinel-1 data made it possible to detect that most vessels operating in the EEZ do not declare their positions. They are thus suspected of practicing illegal, undeclared and unregulated fishing (INN fishing). The month of September 2020 was the most characterized by strong INN fishing activities, especially on the high seas. Our results also showed that the spatial distribution of suspicious vessels detected is such that most of them are located in the South-West, on the Liberian border, on the central coasts within the maritime zones of Jacqueville, in the East near the Ghanaian borders and on the high seas.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] FAO (2011) Aperçu mondial des ressources halieutiques marines. Examen de l'état des ressources halieutiques marines mondiales. Division des pêches de la FAO, Rome.

[2] FAO (2020) Commission générale des pêches pour la Méditerranée. L'état des pêches en Méditerranée et en mer Noire 2020. FAO, Rome.

[3] Nations Unies (2015) Transformer notre monde: l'Agenda 2030 pour le développement durable; Résolution adoptée par l'Assemblée générale. Rapport technique, Nations Unies, New York.

[4] Kanjir, U., Greidanus, H. and Ostir, K. (2018) Détection et classification des navires à partir d'images optiques spatiales: Une étude de la littérature. *Télédétection Environ*, **207**, 1-26.

[5] Kourti, N., Shepherd, I., Greidanus, H., Alvarez, M., Aresu, E., Bauna, T., Chesworth, J., Lemoine, G. and Schwartz, G. (2005) Intégration de la télédétection dans le contrôle des pêches. Poisson. *Fisheries Management and Ecology*, **12**, 295-307.

[6] Galdelli, A., Mancini, A., Ferrá, C. and Tassetti, A.N. (2020) Integrating AIS and SAR to Monitor Fisheries: A Pilot Study in the Adriatic Sea. *Proceedings of the* 2020 *IMEKO TC*-19 *International Workshop on Metrology for the Sea*, Naples, 5-7 October 2020, 39-44.

[7] Grover, A., Kumar, S. and Kumar, A. (2018) Ship Detection Using Sentinel-1 SAR Data. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **IV-5**, 317-324. https://doi.org/10.5194/isprs-annals-IV-5-317-2018

[8] Santamaria, C., Stasolla, M., Fernandez, Arguedas, V., Argentieri, P., Alvarez, M. and Greidanus, H. (2015) Surveillance Maritime Sentinel-1. Rapport Technique, Union Européenne, Luxembourg.

[9] Santamaria, C., Alvarez, M., Greidanus, H., Syrris, V., Soille, P. and Argentieri, P. (2017) Traitement de masse des images Sentinel-1 pour la surveillance maritime. *Télésens*, **9**, Article No. 678. https://doi.org/10.3390/rs9070678

[10] Tanveer, H., Balz, T. and Mohamdi, B. (2019) Utilisation de l'approche du réseau neuronal convolutif (CNN) pour la détection des navires dans l'imagerie SAR Sentinel-1. *Actes de la* 6*e Conférence Asie-Pacifique sur le radar à synthèse d'ouverture* (*APSAR*), Xiamen, 26-29 November 2019.

[11] Lemoine, G., Chesworth, J., Schwartz-Juste, G., Kourti, N. and Shepherd, I. (2004) Détection de navires en temps quasi réel à l'aide d'images SAR spatiales à l'appui des opérations de surveillance et de contrôle des pêches. *Actes du IGARSS* 2004-*IEEE International Geoscience and Remote Sensing Symposium*, Anchorage, 20-24 September 2004, 4825-4828.

[12] Graziano, M.D., Renga, A. and Moccia, A. (2019) Intégration des données du système d'identification automatique (AIS) et des images radar à synthèse d'ouverture (SAR) à canal unique par estimation de la vitesse des navires basée sur le SAR pour la connaissance de la situation maritime. *Télésens*, **11**, Article No. 2196. https://doi.org/10.3390/rs11192196

[13] Snapir, B., Waine, T. and Biermann, L. (2019) Classification des navires maritimes pour surveiller les pêcheries avec SAR: Démonstration en mer du Nord. *Télésens*, **11**, Article No. 53. https://doi.org/10.3390/rs11030353

[14] Ferlansyah, N. and Suharjito, S. (2020) Une revue systématique de la littérature sur les méthodes de détection du comportement des anomalies des navires basées sur le système d'identification automatique (AIS) et une autre fusion de capteurs. *Advances in Sciences, Technology and Engineering Systems Journal*, **5**, 287-292.

[15] Brusch, S., Lehner, S., Fritz, T., Soccorsi, M., Soloviev, A. and Schie, B. (2011) Surveillance des navires avec TerraSAR-X. *Transactions IEEE Sur la Géoscience et la Télédétection*, **49**, 1092-1101.

[16] Yang, C. and Kim, T. (2012) Intégration du SAR et de l'AIS pour la détection et l'identification des navires. Détection et surveillance des océans, Actes de la SPIE No. 8372, 1-6.

[17] Bioresita, F., Pribadi, C.B. and Firdaus, H.S. (2018) Ship Detection in Madura Strait and Lamong Gulf Using Sentinel-1 SAR Data. *Physical Sciences and Engineering*, **1**, 13-23. https://doi.org/10.29037/digitalpress.11224

[18] Sarah Putri, F., Gaol, J.L. and Kushardono, D. (2020) Fishing-Vessel Detection Using Synthetic Aperture Radar (SAR) Sentinel-1 (Case Study: JAVA Sea). *International Journal of Remote Sensing and Earth Sciences*, **16**, 131-142. https://doi.org/10.30536/j.ijreses.2019.v16.a3235

[19] Serco Italia, S.P.A. (2018) Ship Detection with Sentinel-1—Gulf of Trieste (Version 1.3). https://ruscopernicus.eu/portal/theruslibrary/learn-by-yourself/

[20] Wackerman, C.C., Friedman, K.S., Pichel, W.G., Clemente-Colon, P. and Li, X. (2001) Automatic Detection of Ships in RADARSAT-1 SAR Imagery. *Canadian Journal of Remote Sensing*, **27**, 568-577. https://doi.org/10.1080/07038992.2001.10854896

[21] Crisp, D.J. (2004) The State-of-the-Art in Ship Detection in Synthetic Aperture Radar Imagery. Australian Government, Department of Defence, Edinburgh.

[22] Friedman, K.S., Wackerman, C., Funk, F., Rowell, K., Pichel, W.G., Clemente-Colón, P. and Li, X. (2000) Validation of an Automatic Vessel Detection Algorithm Using *In-Situ* Positions. *Proceedings IGARSS* 2000, Honolulu, 24-28 July 2000, 2071-2073.

[23] Koffie-Bikpo, C.Y. (2010) La pêche maritime en Côte-d'Ivoire face à la piraterie halieutique. *Cahiers d'Outre-Mer*, **63**, 321-346. https://doi.org/10.4000/com.6032

[24] Zhao, Z., Ji, K.F., Xing, X.W. and Zou, H.X. (2014) Effective Association of SAR and AIS Data Using Non-Rigid Point Pattern Matching. *IOP Conference Series*: *Earth and Environmental Science*, **17**, Article ID: 012258. https://doi.org/10.1088/1755-1315/17/1/012258

[25] Pelich, R., Longepe, N., Mercier, G., Hajduch, G. and Garello, R. (2015) Performance Evaluation of Sentinel-1 Data in SAR Ship Detection. *IEEE International Geoscience and Remote Sensing Symposium* (*IGARSS*), Milan, 26-31 July 2015, 2103-2106. https://doi.org/10.1109/IGARSS.2015.7326217

[26] Grasso, R., Mirra, S., Baldacci, A., Horstmann, J., Coffin, M. and Jarvis, M. (2009) Performance Assessment of a Mathematical Morphology Ship Detection Algorithm for SAR Images through Comparison with AIS Data. 9*th International Conference on Intelligent Systems Design and Applications*, Pisa, 30 November-2 December 2009, 602-607. https://doi.org/10.1109/ISDA.2009.99

[27] Zamblé, G.R. (2020) Surveillance de la Zone Economique exclusive (ZEE) de la Côte d'Ivoire par la détection des navires: Apport de l'imagerie radar à synthèse d'ouverture (RSO) Sentinel-1A. Mémoire Master 2, Université Félix Houphouet-Boigny, Cocody, 65.

[28] Muhammad, A.H., Paroka, D., Rahman, S. and Syarifuddin (2018) Tingkat Kelayakan Operasional Kapal Perikanan 30 GT Pada Perairan Sulawesi (Studi Kasus KM INKA Mina 957) The Operational Feasibility Level of 30 GT Fishing Vessel in Sulawesi Waters (Case Study of KM INKA MINA 957). *Marine Fisheries*, **9**, 117-125. https://doi.org/10.29244/jmf.9.1.1-9