Σχολή Οικονομίας και Τεχνολογίας

Πρόγραμμα Μεταπτυχιακών Σπουδών

Οικονομία, Άμυνα και Ασφάλεια

Διπλωματική Εργασία

Εντοπισμός και Αντιμετώπιση των Παγκόσμιων Παράνομων Ροών Πετρελαίου

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Τρίπολη, Σεπτέμβριος 2022

Acknowledgments

Words cannot express my gratitude to my professor Thomas Alexopoulos for his invaluable patience and feedback. Additionally, this endeavor would not have been possible without the generous support from my brother-in-law Stephen Hagberg, who financed my studies.

I am also grateful to my childhood friend Antonis Fytopoulos for his late-night feedback sessions, and moral support. Thanks should also go to Dr. Dimitra Kalaitzi, for her editing help.

Lastly, I would be remiss in not mentioning my family, especially my wife Eleonora and my children, and my mother Sofia. Their belief in me has kept my spirits and motivation high during this process. I would also like to thank my dearly beloved sister Dimitra, for all the positive motivation and emotional support during my studies, and the completion of this work.

Abstract

Despite maritime piracy is a major concern to international trade, there is no comprehensive study that considers the causing factors, spatio-temporal patters and association rules of pirates' behaviour that influence the choice of attack areas that can be used as a decision support tool to enhance security in the most vulnerable areas. To solve this issue and contribute further on the literature, we apply multiple methods namely AHP, and spatio-temporal analysis by using data from the National Geospatial-Intelligence Agency. It is observed that territorial waters are preferable areas; thus, pirates prefer to attack the ships close to the coastline. Moreover, pirates in certain areas are influenced by the activity and the information from other pirates, which can be used as tool from the authorities e.g. derive information from pirates that have been arrested.

Keywords

Maritime piracy; AHP; spatio-temporal data analysis; Time-varying Granger causality; oil tankers

JEL: C33, K32, K42

Περίληψη

Παρά το γεγονός ότι η θαλάσσια πειρατεία αποτελεί μείζον μέλημα για το διεθνές εμπόριο, δεν υπάρχει καμία ολοκληρωμένη μελέτη που να εξετάζει τους παράγοντες που προκαλούν, τα χωροχρονικά μοτίβα και τους κανόνες συσχέτισης της συμπεριφοράς των πειρατών που επηρεάζουν την επιλογή των περιοχών επίθεσης που μπορούν να χρησιμοποιηθούν ως εργαλείο υποστήριξης αποφάσεων ενίσχυση της ασφάλειας στις πιο ευάλωτες περιοχές. Για να λύσουμε αυτό το ζήτημα και να συνεισφέρουμε περαιτέρω στη βιβλιογραφία, εφαρμόζουμε πολλαπλές μεθόδους, όπως την AHP (Analytical Hierarchy Process) μέθοδο και χωροχρονική ανάλυση χρησιμοποιώντας δεδομένα από την Εθνική Υπηρεσία Γεωχωρικών Πληροφοριών. Παρατηρείται ότι τα χωρικά ύδατα είναι προτιμότερες περιοχές. Έτσι, οι πειρατές προτιμούν να επιτίθενται στα πλοία κοντά στην ακτογραμμή. Επιπλέον, οι πειρατές σε ορισμένες περιοχές επηρεάζονται από τη δραστηριότητα και τις πληροφορίες άλλων πειρατών, οι οποίες μπορούν να χρησιμοποιηθούν ως εργαλείο από τις αρχές.

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1. Introduction

Global transportation and particularly sea transportation of crude oil plays an important role in global oil industry supply chain management. However, maritime transportation can be dangerous e.g., piracy, natural disasters, vessel collisions (Lim et al., 2018). Maritime piracy is a pressing global issue and can be defined as "an act of boarding or attempting to board any ship with the apparent intent to commit theft or any other crime and with the apparent intent or capability to use force in the furtherance of that act" (International Maritime Bureau, 2009, cited in Hassan and Hasan, 2017). Despite that the number of worldwide maritime piracy incidents per year declined, it continues to be a threat impacting significantly companies dealing with the production and distribution of oil and leading to several social and political impacts.

195 maritime piracy attacks reported in 2021, and the Gulf of Guinea has been indicated as the world's most dangerous shipping route (IMB, 2021). One of the most casual factors is the opportunity i.e. favourable geophysical attributes and laws against maritime piracy (Murphy, 2007) For example, the high unemployment rates, inadequate law enforcement, unregulated oil market capacity, corruptible officials, enable pirates in the Gulf of Guinea to move stolen products back onto legitimate markets (European Union, 2020). This area is a transit point in the illicit trade of oil out of Africa that costs annually African countries around $524 on counter-piracy efforts (Stable Seas, 2021). Similarly, the Southern Gulf of Mexico has recently received attention as four attacks reported in a span of 11 days in April 2020. The maritime piracy in the Gulf of Mexico and Caribbean can be attributed to a number of factors such as the Covid-19 pandemic, lack of the necessary resources and capabilities to adequately detect and respond to these attacks (Drake, 2021). It is supported that this region will continue to be a hotspot in the future, but more will also emerge. For example, Russia's war in Ukraine that caused the rising of crude oil prices might lead to piracy attacks on tankers in Asia (Concepcion, 2021). All these incidents lead to severe risks in terms of safety, delays and increasing cost (e.g. the insurance cost of oil tankers is rising, cost of the wide range of interventions, such as naval patrols cost of re-routing); currently worldwide is a loss of nearly $ 25 billion per year (Fan et al., 2022).

Despite the importance of maritime piracy and the rise of the incidents in 2020, it is worth noting that there is not much research in the specific area and there are a few outdated studies concerned with patterns of maritime attacks (Marchione and Johnson, 2013; Townsley and Oliveira, 2015). Moreover, most of the papers focus only on a particular area to trace the evolution of maritime piracy e.g., Nigeria (Otto, 2014) and lacked a holistic view of maritime piracy. Last but not least, despite that a few studies identified the maritime piracy prone areas they do not explore the characteristics of the piracy within these vulnerable areas. Therefore, global-based studies that provide a complete overview of maritime accidents, identified hotspot accident areas, and explored in-depth characteristics of accidents within the identified areas need further study. The aim of this paper is to analyse maritime piracy via attempting to address the following research questions (RQs):

RQ1: Where are the hotspots of maritime piracy?
RQ2: What are the main causes of maritime piracy?
RQ3: Are there any patterns and dependencies in the timing and location of incidents of maritime piracy?

This study, therefore, aims to explore the issue of maritime piracy (attempted and completed attacks) with a particular focus on oil tankers rather than vessels carrying other products. This type of commodity is desirable for pirates as it has high value and they can easily sell it on the black market and the ship itself is also valuable (Robitaille et al., 2020).

A hybrid three-phased method applied to answer the above RQs of the study. First, an Analytic hierarchy process (AHP) used in this paper developed by Saaty in 1977 which is an effective decision-making tool used in complex situations (Pereira and Bamel, 2022) in order to set priorities by developing a weighted multi-criteria model and identify the prominent factors of maritime piracy. This model is based on the developed geodatabase that contains all relevant layers and the influenced factors, the so-called maritime piracy-related criteria (i.e., zone, security, time, distance) according to their importance; thus, it defines the weightage each factor has in relation to risk of pirate attacks.

The results of this study can be used to facilitate the determination of areas most prone to maritime piracy. In addition, kernel density estimation (KDE) applied to estimate the concentration of maritime piracy incidents at each sample location and identify and predict where piracy is most likely to take place. Apart from spatial hotspot identification, in this study the temporal component of piracy events is considered in order to explore whether dynamic causal realtionships exist. Last but not least a joint spatial and temporal analysis is introduced to shed light to underlying common pirate networks or persons.

The recognition of 'hot spots' in terms of time and space concentrations will enable the deployment of resources to prevent the generation of piracy attacks. Moreover, the identification and explanation of emerging piracy patterns enables more effective planning of functional environment in order to minimise the vulnerability of certain locations to marine piracy. The paper begins by examining the existing research findings and methodologies applied to explore maritime piracy. Then Section 3 discusses the methods employed by the present study to address the above RQs. Next, in Section 4, 5, 6 the results are presented and discussed. The paper concludes with Section 7 that entails the conclusions, limitations of the study and opportunities for further research.

2. Literature review

Between 2015-2020 most piracy attacks emerged in bulk carriers in March, April, and May in 2015 in Southeast Asian waters (Ece and Kurt, 2021). A recent study also highlighted that pirate attacks on ships are more prone to Southeast Asian and African waters (Nwokedi et al., 2022). Maritime piracy impacts the whole supply chain, and several companies demand assurance of security by identifying the factors that make these ships vulnerable to piracy. There are various root causes of piracy which makes it a multidimensional phenomenon, and each cause are not stand-alone but are interconnected with one another. There are macro level determinants (e.g. political, economic stability, socioeconomic conditions, geographic location, moral values) and micro level determinants (e.g., vessel type, size, and voyage) of marine piracy (Jin et al., 2019). Mathematical and agent-based models have been used to explore spatial and temporal patterns of maritime pirate attacks. For example, Jiang and Lu (2020) developed a probability prediction model based on a Bayesian Network (BN) to investigate the causal factors of piracy in Southeast Asia and found that the main factors are the environment, ship's features and anti-piracy measures. Özdemir and Güneroğlu (2017) applied fuzzy AHP and fuzzy TOPSIS methods and identified the major causing factor of piracy namely economic insufficiency and as less significant factor the geographic location of the canals and straits.

Jakob et al. (2010) proposed a spatially explicit agent-based to help the visualisation, anticipation and prevention of preventing pirate attacks. Vos Fellman et al. (2015) applied the social network analysis and visualized the maritime attacks by region, and its characteristics. Townsley and Oliveira (2015) utilised the rational choice theory and optimal foraging theory to explore space-time patterns of maritime piracy in Africa and confirmed that pirate activity clusters in space and time. Marchione et al. (2014) developed an agent-based model by focusing on the Gulf of Aden to investigate the geometry of shipping routes, seasonal variation of attacks, and show if the attacks differ by vessel type and state of registration, an approach that followed also by Mejia et al. (2009) who applied econometric analysis.

Tešić (2020) proposed a qualitative approach of computation-with-words approach to track maritime objects and identify attacks and decide on the countermeasures. Jin et al. (2019) classified piracy risk into macro-level and micro-level analyses and employed binary logistic regression model and found that small vessels and open registry vessels are more prone to be targeted by pirates. Desai and Shambaugh (2021) identified a pattern between the fish volumes caught using destructive and high-bycatch methods and piracy by conducting a geographically disaggregated analysis. Ofosu-Boateng (2017) focused particularly on oil maritime piracy. This study developed three models (Ordinal Logistic Regression, Bayesian Network Predictor, and Series Hazard Models) to forecast piracy attacks the next fifteen years in the Gulf of Guinea. Balogun (2018) applied the spectrum-based theory of enterprise, and Porter's value chain to discuss oil theft, illicit business and petro-piracy in the Gulf of Guinea.

Moreover, several studies focused on the implications of maritime piracy. For example, Fu et al. (2010) developed a simulation model to explain the financial implications (e.g., increased cost of insurance, increased costs associated with ships being forced to take alternate routes) on the global shipping industry. Some studies that particularly concentrated on Somali piracy found piracy led to increased shipping cost and decreased trade volumes (Besley et al., 2015; Burlando et al., 2015). Similar outcomes observed by the study of Bensassi (2012) who supported that hijacking is linked with decrease in exports and Shepard and Pratson (2020) who supported that higher pirate attack rate is associated with a 7.5-vessel reduction in tanker traffic. Other studies highlighted that piracy prone waters led decision makers to increase the voyage length in order to avoid high-piracy areas (Dinwoodie et al., 2013; Vespe et al., 2015). Last but not least, a few studies also highlight the impacts on seafrarer's wellbeing and the associated human cost (Abila and Tang, 2014; Seyle et al., 2018).

Apart from recognising the oil theft causing factors and its impacts, studies also discussed some of the countermeasures. Romsom (2022) discussed the need of smart technology, processes and transnational collaboration that promote and align economic and policy regimes which is in line with other studies (e.g., Osinowo, 2015). Bouejal et al. (2014) implemented a Bayesian network that considers different characteristics e.g., potential target, environmental constraints to identify appropriate countermeasures. Another study applied a Fuzzy AHP and found that international convention and policy, defense strategies when sailing, hardware and software, security plan, response ability, and communication facilities are the main elements that need to be considered to minimise piracy attacks (Tseng et al., 2021). Studies also suggested that anti-piracy operations, regulations and policies as well as coordination at domestic, regional, and international level enable the minimisation and control of piratical activities (Ahmad, 2020). There is a need to reconsider and improve the legal system for maritime piracy by strengthening the universal jurisdiction (Jin and Techera, 2021). Last but not least, Hasan and Hasan (2017) focused on the Gulf of Guinea and supported the need of exploration of piracy-prone zones, the knowledge of the particular ship types, the economic support particularly of youthful population and information-sharing are some of the strategies that can be utilised to combat piracy.

Most of the above studies focused on specific geographical areas (e.g., de Montclos, 2012; Nwalozie, 2020) thus they do not focus on the issue of marine piracy in a holistic way. Moreover, there are a few studies that rigorously explore in a quantitative way the causes of maritime piracy (Danzell et al., 2021). Previously published studies on the subject have been mostly restricted to show the patterns and the existence concentrations of marine piracy without investigating in detail the determinants of their presence. In this sense, to the best of our knowledge, this study is unique and explores marine piracy concentration thus enriching the extant literature on marine piracy by investigating clusters and causes of marine -piracy.

3. Data and empirical methodologies

3.1. Data description

This paper uses data from the National Geospatial-Intelligence Agency (NGIE, 2022). This database registers all the hostile acts worldwide against ships and mariners. We selected attacks only against fossil fuel transportation, i.e., oil, LNG, oil products, etc., from 2000 until 2022. In total, there are 2145 observations. Each entry has details regarding the date, the location (coordinates and naval area), the attacker, the victim, and a description from which we extracted further information about the success of the hostile act or not and if it took place underway or in position. The data have been used on a daily or a monthly frequency, depending on followed methodology. The Illicit oil flows are not officially recorded in that level of detail appropriate for systematic analysis. To overcome this, we select to use, as a proxy variable, all the hostile acts against tankers as they result directly or implicitly in supply disruptions of legitimate oil transportations in favor of illicit oil flows (Hatipoglu et al., 2022). In most cases, delaying fossil fuel transportation was the mildest repercussion, reaching total oil loss in the worst-case scenario.

3.2. AHP methodology

AHP is a widely used multi-criteria analysis method that considers both quantitative and qualitative criteria and helps users make better decisions (Saaty, 2008). This method has been applied in various fields e.g. decision theory, conflict resolution, neuroscience (Vargas, 1990). The method is essentially a framework in which a problem can be solved based on three principles: decomposition, comparative judgments and composition (Saaty, 1983). AHP uses the Eigenvalue approach to the pair-wise comparisons and allows the user to develop a numeric scale in order to measure the qualitative or quantitative performance of criteria (Vaidya & Kumar, 2006). Table 1 shows the fundamental scale developed by Saaty. This scale explains the way that the criteria will be ranked from 1 to 9 and their interpretation. It should be underlined, that the ranking of the criteria is at the discretion of the user, according to the general objective (focus of the problem).

Table 1 The fundamental scale of relevant importance among criteria (Saaty, 1987)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	The activities contribute equally to the objective described from the author
3	Moderate importance of one over another	Experience and judgment favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and it is dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
reciprocals	If activity i has one of the above numbers assigned to It when compared with activity j, then j has reciprocal value when compared with i	

AHP will be applied in this study to predict the behavior of the pirates/smugglers, which attack the ship or the tankers, carrying oil and then transport those ships to the endpoint. The final destination, would be a warehouse or a safe port, in which the smugglers can offload the stolen oil and make the transaction with the buyer. The focus of this research is to identify the areas that the pirates will perform most of their attacks in order to help prosecution authorities enhance the degree of security in these specific areas. We have identified four criteria which pirates will take into account before the attack – during their decision-making process-, i.e. these criteria will influence their behavior before attacking a ship. Those criteria are the following: 1) Security (if the sea is secure for the smugglers or not – existence of prosecuting authorities), 2) Time (the time that the smugglers need for the operations), 3) Topography/ area (wind, weather, underwater obstacles etc.), and 4) Fuel consumption.

According to the previous explanation, Table 2 shows the criteria with respect to the overall focus. Therefore, for example, as in Table 2 indicated topography criterion is of “essential or strong importance” over the time criterion (based on the numerical scale presented in Table 1).

Table 2 Pairwise comparisons of the criteria

FOCUS	Security	Time	Topography	Fuel Consumption
Security	1	8	4	7
Time	1/8	1	1/5	1/2
Topography	1/4	5	1	1
Fuel Consumption	1/7	2	1	1

Apart from the aforementioned criteria, we will also discuss the three areas that pirates/smugglers may prefer to perform their attack. Based on the previous criteria and the application of the AHP method, the alternative area achieving the highest score will be the most preferable that is chosen from the pirates/smugglers. The three alternatives areas in our case are the following: 1) Port areas, congested channels and checkpoints that the ship will pass-through. 2) Territorial waters up to 12 nautical miles from the coastal baseline (without the port), 3) International waters which are located more than 12 nautical miles away from the costal baseline (Hastings, 2009).

A few assumptions made towards our analysis, particualry in this AHP application we indicatively assume that the smugglers attack and seize the whole ship or the oil that is being transferred. Finally, some specific assumptions will be highlighted for the four criteria below:

1) Security: It is more secure for the smugglers to seize ships in territorial waters than in international watersand more secure to seize in international waters than in ports. Herein, we assume that it is much more dangerous for the pirates to attack in the ports, since the base of the port authorities is located there. In addition, in territorial waters the ships move slower than in international waters and it is easier for the smugglers to board on it, minimizing the danger of engagement, as they also have a lower-level of security than that in the international waters (Murphy, 2007).

2) **Time**: It is more time consuming to seize ships in international waters, than in territorial waters and ports. The endpoints (e.g. warehouses etc.) that are needed to transfer the oil are on the land. (Hastings, 2009)

3) Topography: Regarding the wind, weather, underwater obstacles etc., it is better for smugglers to attack in the ports or territorial waters than in deep sea. Many incidents take place in or near narrow, congested channels that serve as chokepoints for world commerce, such as the Bab al-Mandab at the southern tip of the Red Sea, and the Phillips and Singapore Straits at the southern terminus of the Strait of Malacca in Southeast Asia. In such places, ships must slow down to navigate through shallow waters and underwater obstacles, as well as avoid other ships, leaving them open to attack by land-based pirates (Murphy, 2007)

4) Fuel consumption: It is cheaper to attack ships near ports than in territorial or international waters, because the end point is on land.

3.3. Spatial, temporal, and spatiotemporal analyses

Following Waller and Gotway (2004), we first explore the existence of spatial point patterns in our data set *N* of 2145 point observations. Towards that direction, we employ the estimates of probability density function *p(s)*, using non-parametric kernel estimators in their intensity function *λ(s)*, as follows:

$$\widehat{p(s_g)} = \frac{\hat{\lambda}(s_g)}{\sum_{j=1}^{G} \hat{\lambda}(s_j)} \qquad (1)$$

$$\hat{\lambda}(s_g) = \frac{C}{A_g} \sum_{i-1}^{n} K({}^{d_{ig}}/_{h_g}).\, y_i \qquad (2)$$

where *K (.)* is the weight applied to the number of events y_i located at our data point s_i based on the quartic kernel function, s_g is the grid point derived from a grid we have generated to cover the area of interest, d_{id} is the Euclidean distance between our data point and the grid point, and h_g is the kernel's smoothing factor, i.e., its radius. A_g is the area over which the kernel function is evaluated at grid point s_g, and *C* is a proportionality constant.

Continuing spatial pattern exploration, we employ a K-means clustering of our events. We use the default Euclidean distance as a similarity measure and partition our events into ten sets to minimize the within-cluster variance. We selected this number of clusters after visualizing our events on the world map. We notice that all events are mainly located in three areas: on the west coast of Africa off Nigeria and Cameron (AREA I), between the east coast of Africa and West India (AREA II), and the broader region of Indonesia (AREA III). Considering some apparent congregating of events in the area east of Africa, a total number of ten clusters is a good selection for our analysis.

The following research question we attempt to answer is if pirates, e.g., from $AREA_{i,}$ are affected by the activity of the pirates from $AREA_{j}$, or in other words if information concerning the attacks from one area is traveling to the rest areas, triggering a sequence of attacks or events there. To examine this, we carefully select standard and time-varying Granger causality tests based on the features of our data and employ them in a pair-wise mode in the three time series with events corresponding to the three areas described above. We first run the usual descriptive statistics and the empirical CDFs of these three-time series of events and then employ a set of unit roots tests to assess the order of their integration, which is a prerequisite for the next step of our temporal analysis. For robustness, we use the tests of Dickey, Fuller with GLS detrending (DF-GLS,), of Phillips-Perron (PP), of Kwiatkowski, Phillips, Schmidt, and Shin (KPSS), of Ng and Perron (NP), and of Hylleberg, Engle, Granger, and Yoo ( ). For the tests DF, PP, NP, and HEGY, the null hypothesis is non-stationarity; for the KPSS, the null hypothesis is that of stationarity. Depending on the stationarity results of our time series, we apply, in pairs, either the classic Granger causality test (Granger, 1969 and 1988) or the Toda-Yamamoto test (1995) as follows.

$$y_t = \hat{\beta} + \widehat{A_1} y_{t-1} + \cdots + \widehat{A_p} y_{t-p} + \underbrace{\ldots . + \widehat{A_p} y_{t-p-d} +}_{only\ for\ T-Y\ tests} + \widehat{\varepsilon_t}$$

where $y_t, \beta\ and\ \varepsilon_t$ are n-dimensional column vectors and A_k is an *n×n matrix* of parameters for lag *k*. In our case, given the pair-wise mode, n equals to two; thus, the former equation can be written in matrix notation, using the standard bivariate VAR(m), as follows:

$$y_t = \Pi x_t + \varepsilon_t$$

where $$y_t = [y_{1t}\ \ y_{2t}]'$$

$$x_t = \left[1\, y'_{t-1}\ \ y'_{t-2} \ldots y'_{t-k}\right]'$$

$$\Pi_{2X(2m+1)} = [\Phi_0 \, \Phi_1 \, \cdots \Phi_m]$$

$$\Phi_0 = \left[\, \varphi_0^{(1)} \; \varphi_0^{(2)} \right]' \quad \& \quad \Phi_\kappa = \begin{bmatrix} \varphi_{1\kappa}^{(1)} & \varphi_{2\kappa}^{(1)} \\ \varphi_{1\kappa}^{(2)} & \varphi_{2\kappa}^{(2)} \end{bmatrix} \, for \; k = 1, \ldots, m$$

The null hypothesis of no Granger causality from variable $y_i \; to \; y_j$ is then H_0: $R_{i \to j} \, . vec(\Pi)$, where $R_{i \to j}$ is the coefficient restriction matrix and $vec(\Pi)$ is the row vectorization of Π. The model notation for Toda-Yamamoto is the same but for m, which is replaced by m'=m+d, with d standing for the additional lags for the maximum order of integration.

Although these causality tests are attractive because they do not need guidance from economic theory or for the use of simple reduced-form VAR models, and in the case of the Toda-Yamamoto test, for its basis on standard asymptotic distribution regardless of the size of integration and cointegrating properties, still they face issues regarding structural stability (Thoma, 1994; Swanson, 1998; Psaradakis, et al., 2005). To overcome this, we apply time-varying Granger causality tests with three recursive testing algorithms, namely the forward expanding (FE) window, the rolling (RO) window, and the recursive evolving (RE) window (Phillips et al.,2015; Shi et al., 2108; shi et al. 2020). If we consider a sample of T+1 observations $\{y_0, y_1, \ldots, y_T\}$, a number w, satisfying 0 <w< 1, and $T_w = integer(T \cdot w)$ then the time-varying Wald statistic, $WS_{w1,w}$ is computed over the subsample $\{y_{T_{w1}}, \ldots, y_{T_w}\}$. In the FE algorithm, a series of Wald-test statistics $WS_{w1,w}$ are estimated, with w_1=0 and $w \in [w_{min}, 1]$, in the RO algorithm, the statistic is being estimated in a rolling window of constant size, running all the samples, and in the RE algorithm, we obtain test statistics for any subsample having the size $T_{w_{min}}$ or larger in a repeated procedure, providing a common end point of all the subsamples. All the obtained values of the Wald-Test statistic are compared with the 90th and 95th percentiles of bootstrap statistics explained in the works of Shi, Hurn, and Phillips (2020) and Shi, Philips, and Hurn (2018).

An additional research question we try to answer in this paper is if the pirates from an area have underlying relationships, or are known with the other pirates of the same location, or are there multiple different networks within an area that operate independently. The question is of high importance. If pirates belong to or use, more or less, the same networks and people, then it would be more efficient to control these areas first since capturing one pirate in this area could bring another to light with fewer resources, effort, and time. To do so, we follow Tobler's concept of spatial autocorrelation, which in Tobler's words, says that "*Everything is related to everything else, but near things are more related than distant things*" (Tobler, 1970). We use the global indice of spatial autocorrelation of Moran's *I* (Boots and Tiefelsdorf, 2000) . By definition this index cannot give a straightforward answer to our research question. We first include the time dimension in it and use as a variable of interest the, as we call it, "time-neighboring" value with other events. This value is no other than the average time interval between the $event_{t-1}$ and $event_{t,}$ and $event_t$ and $event_{t+1,}$. Low values suggest events close in dates, while the opposite is true for high values. Said that, and based on the interpretation of Moran's I index, we can make the following hypothesis:

Null Hypothesis, H_o: Time neighboring has no spatial pattern (spatial randomness)

Alternative Hypothesis, H_a (with Z-score > 0): High and Low values of Time-neighboring are more spatially clustered than would be expected with spatial randomness

Alternative Hypothesis, H_a (with Z-score < 0): High and Low values of Time-neighboring are more spatially dispersed than would be expected with spatial randomness

Our research question could be addressed in the case of significant p-values with positive z-score. In this case, among others, we could infer that there are events clustered with low values of time-neighboring, or in other words, we have events close enough in time and space that might be attributed to having common or even the same networks or persons.

4. Results and discussion

4.1. AHP findings

AHP method applied by creating 4 tables, each for every abovementioned criterion with a view to finding the best alternative that satisfies the criteria (Saaty, 1987). In this context, for example according to the security criterion, if the smugglers think to attack near ports - where the degree of security is very high - they will try to avoid it, while the opposite is true, for territorial waters. Therefore, a higher score will be given to the area of the territorial waters than the ports, under the security criterion. In the same way, we repeat the procedure for the other three criteria (i.e. Time, Topography and Fuel Consumption). The results - indicatively- for security criterion are presented in Table 3.

Table 3 Pairwise comparisons of alternatives with respect to Security criterion

SECURITY	Ports	Territorial	International
Ports	1	1/7	1/3
Territorial	7	1	5
International	3	1/5	1

According to table 2, we obtain for the vector of relative weights:

(Security, Topography, Time, Fuel Consumption) = (0.643, 0.056, 0.179, 0,122)

with a CI= 0.054<0.10, which is accepted according to the literature (Saaty, 1987).

Then, we repeat the same procedure after solving for the principal eigenvector for the other alternatives, based on the rest of the criteria. We can realize that under security criterion, the smugglers will think probably to attack in territorial waters and not in international waters or near ports. As we mentioned above, there is enhanced security near the ports due to port authorities which is deterring smugglers to attack the ships. The overall weights occurring for the three alternatives strategies under the criterion “Security” are the following:

(Ports, Territorial, International) = (0.081, 0.731, 0.188).

Consecutively, the local derived scales for the three other criteria are the following:

(Ports, Territorial, International) = (0.727, 0.200, 0.073).

(Ports, Territorial, International) = (0.661, 0.272, 0.067).

(Ports, Territorial, International) = (0.692, 0.231, 0.077).

Finally, based on the above information we multiply the two matrices below, in order to find the final weight for each alternative according to the AHP analysis.

$$\begin{bmatrix} 0.081 & 0.727 & 0.661 & 0.692 \\ 0.731 & 0.200 & 0.272 & 0.231 \\ 0.188 & 0.073 & 0.067 & 0.077 \end{bmatrix} X \begin{bmatrix} 0.643 \\ 0.056 \\ 0.179 \\ 0.122 \end{bmatrix} = \begin{bmatrix} 0.295 \\ 0.558 \\ 0.147 \end{bmatrix}$$

Based on the above calculations, the second alternative- the territorial waters-, is the most preferred strategy with the highest score of 0.558. Therefore, most of the times the smugglers prefer to attack in territorial waters, fewer times near ports, and rarely in international waters. This is in line with other studies (X), as there is no big effect of piracy in international waters, after analyzing real life events. Finally, it is essential to mention that the analysis with the use of AHP method is not limited to specific places or countries but takes a holistic perspective.

4.2. Spatio-temporal data analysis

On spatial pattern recognition, Figures 1 and 2 show the kernel estimates of the probability density of events for areas II and III and area I, respectively. The quartic kernel function has been used with the minimum (weighted) number of data points as the kernel bandwidth method.

Figure 1 Kernel estimates of the Probability densities of attacks in areas II and III

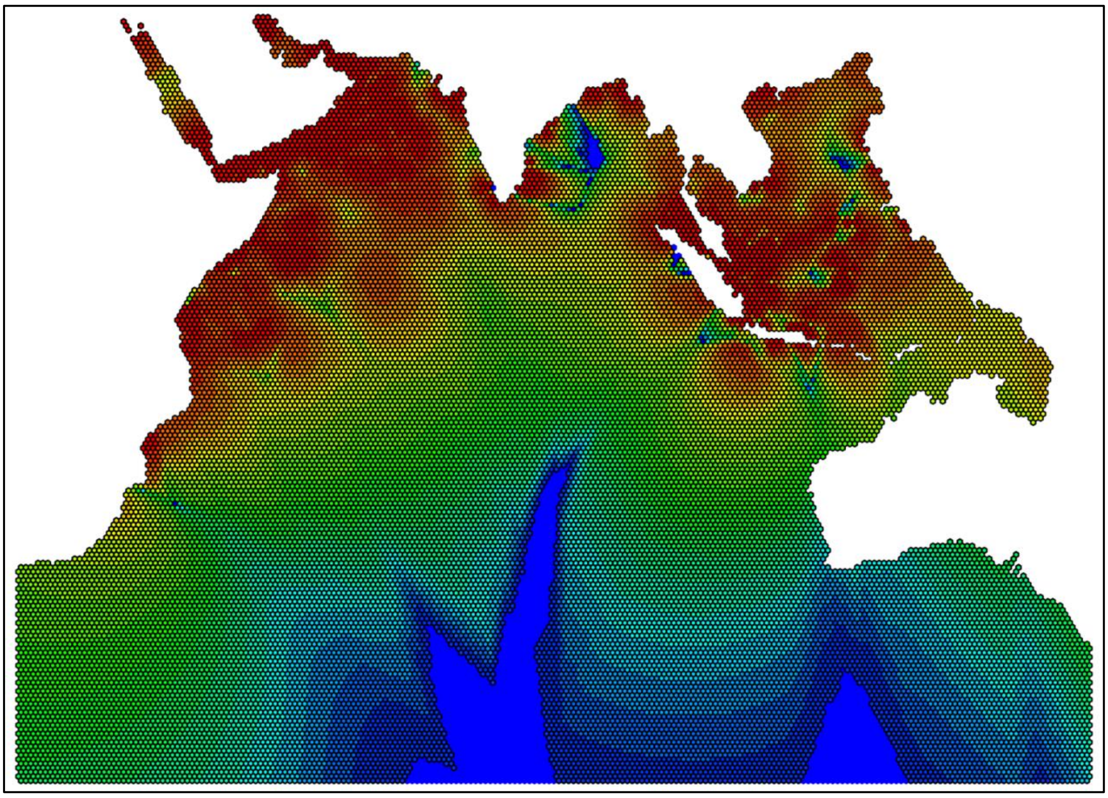
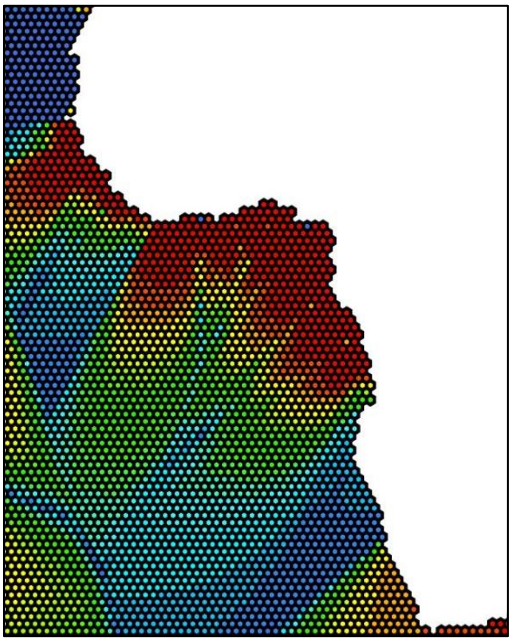
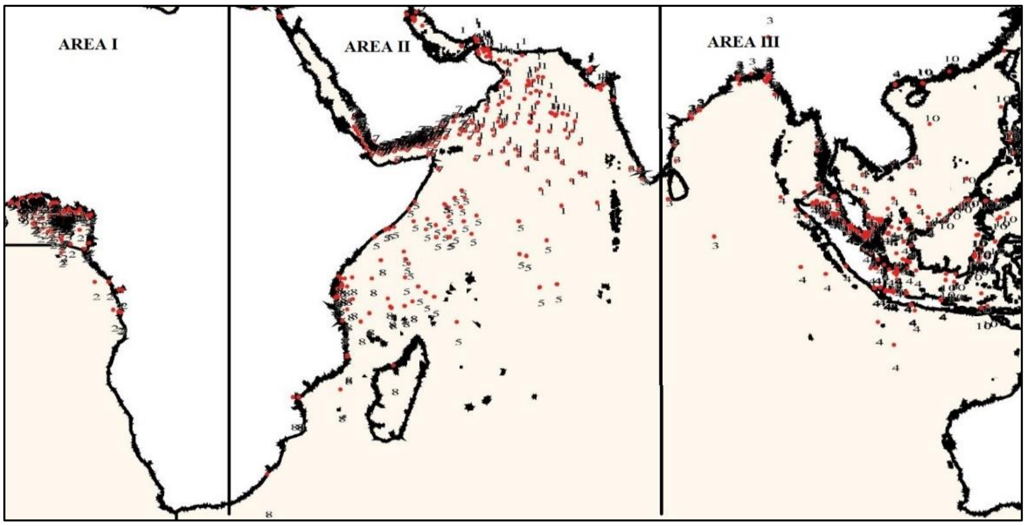


Figure 2 Kernel estimates of the Probability densities of attacks in area I



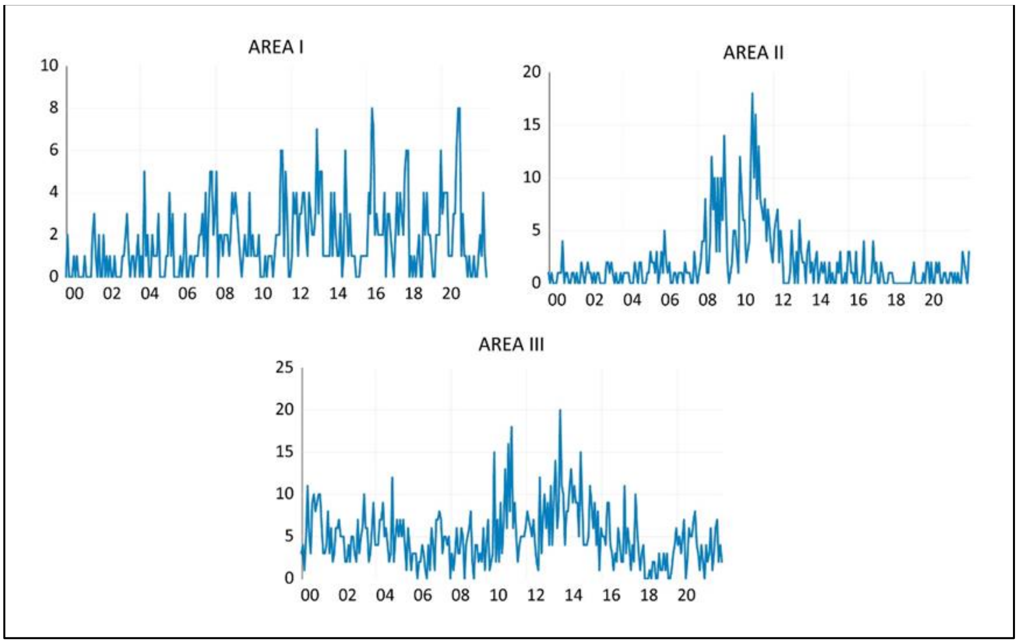
The mapped, in Figures 1 and 2, probabilities of the events suggest that pirates prefer to hit close to the coastline, except for the Arabian sea (the only open sea), where there is a high probability. Also, pirates like coasts of countries ranked low in surveillance or control from government forces, and in general, underdeveloped countries or face wars, riots, and so on. Next, in Figure 3, we see the k-means clustering of the events. Area II has the most clusters, 4 out of 10, followed by area III with three clusters, and area I with 2 clusters. Cluster 6 is on the coasts of south and central America and does not belong to any of the three areas.

Figure 3 K-means clustering of the attacks in all area



The monthly attacks on tankers, their statistics, and their empirical CDFs, are shown in figure 4, Table 1 and figure 5 respectively.

Figure 4 Monthly attacks against tankers in areas I, II and III for the period 2000-2020



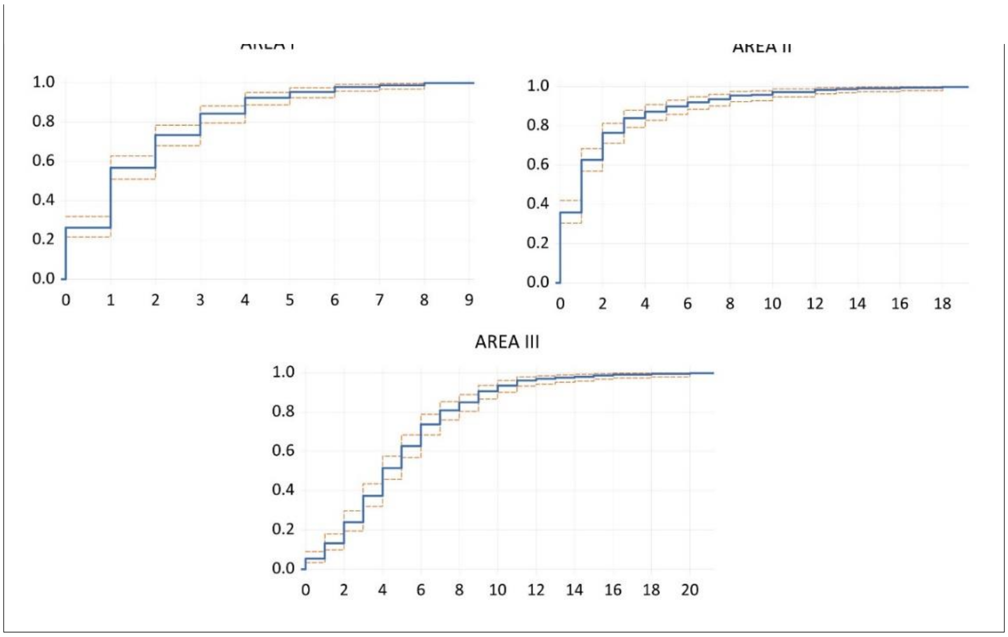
As shown in Figure 4, area II has two spikes of incidents around 2008 and 2010. Two tips also appear in area III, around 2010 and 2013, while for area I, a slightly increasing trend is recorded from 2000 until 2020.

Table 4 Maximum Wald-Statistics using the recursive algorithms of FE, RO and RE

Direction of Causality	Max Wald FE	Max Wald RO	Max Wald RE
Area I -> Area II	17.458 (6.989) [9.070]	19.171 (6.729) [8.693]	21.869 (7.521) [9.749]
Area II -> Area I	8.977 (8.083) [11.600]	21.525 (9.485) [11.545]	21.525 (9.485) [11.600]
Area I -> Area III	4.391 (6.558) [8.466]	19.778 (8.501) [9.346]	24.395 (8.770) [9.607]
Area III -> Area I	5.217 (8.633) [9.805]	12.061 (8.523) [9.864]	13.783 (8.876) [10.595]
Area II -> Area III	19.588 (8.015) [11.256]	22.070 (7.710) [11.000]	22.070 (8.015) [11.256]
Area III -> Area II	3.840 (7.017) [8.458]	19.382 (7.350) [8.620]	21.956 (7.733) [8.620]

(a) Area I pairs use the time varying LA-VAR model of Toda-Yamamoto test.
(b) FE, RO, and RE stand for forward, rolling and recursive respectively.
(c) The 90th and 95th percentiles of the empirical distribution of the bootstrap statistics are in parentheses and brackets, respectively.

Figure 5 Empirical CDFs of the monthly attacks of areas I, II and III for the period 2000-2020



The three areas of study exhibit different similarities and dissimilarities, making a precise match among them not straightforward. For instance, areas II and III appear to be more correlated than the other pairs; on the contrary, the empirical CDFs of areas I and II are closer than of areas II and II, and so on.

The unit root test results in Table 5 answer in the negative in stationarity, except for area I, where the KPSS test reject's the null hypothesis of stationarity.

Table 5 Moran' s I global index results

AREA	*I*-stat	E(*I*)	St.dev(*I*)	Z-score	P-value
I	0.04	0.002	0.01	6.61	0.00
II	0.10	0.002	0.01	7.46	0.00
III	0.12	-0.001	0.01	27.11	0.00

(a) Variable of interest is, for all areas, time-neighboring
(b) A binary weights matrix has been created with threshold distance for neighbors the unit, 1-tail test has been used

Given the stationarity results, we implement the standard Granger causality test for areas II and III and the augmented Toda-Yamamoto test for the pairs, including area I. As shown in Table 6, the causality results suggest causality running only from area III to area I, for a significance level of 10%. No other causal relationships exist.

Table 6 Statistics and Spearman's correlation

	AREA I	AREA II	AREA III
Mean	1.73	1.96	4.94
Median	1.00	1.00	4.00
Maximum	8.00	18.0	20.00
Minimum	0.00	0.00	0.00
Std. Dev.	1.73	2.91	3.38
Skewness	1.26	2.56	1.10
Kurtosis	4.42	10.57	4.92
r_s [(a)]	AREA I	AREA II	AREA III
AREA I	1	-	-
AREA II	0.10	1	-
AREA III	0.14	0.21	1
Obs.	269	269	269

(a) Spearman's non-parametric correlation

Although the Granger causality test is a helpful tool for detecting dependencies among time series, just as with other structural stability issues, it may be fragile when different periods are examined. To address this issue, robust causality tests have been introduced, using time-varying methods and estimations (Rossi and Wang, 2019; Phillips et al., 2015, Shi et al., 2018 and 2020). In Table 7 and Figure 6 that follow, we show the time-varying Granger causality tests based on Shi et al. (2018, 2020).

The results in Table 7, for the entire sample, show that we fail to reject the null hypothesis of no causal relationship from area I to area III and vice versa and from area III to area II, when the FE recursive algorithm is used. A casual relationship exists in all other pairs of areas, regardless of the algorithm used. Nevertheless, as shown in Figure 6, these results show strong instability. In most cases, the produced series of wald-statistics exceed or fall behind the critical values depending on the time window and the recursive algorithm. Hence, if all algorithms and time windows are taken into account, causality exists only from area I to area II in the first 100 months, from area III to area II after the 200th month (based on RE algorithm), and from area I to area III before the 100th month and after the 200th month.

Figure 6 Series of Wald test statistics with FE, RO and RE recursive algorithms

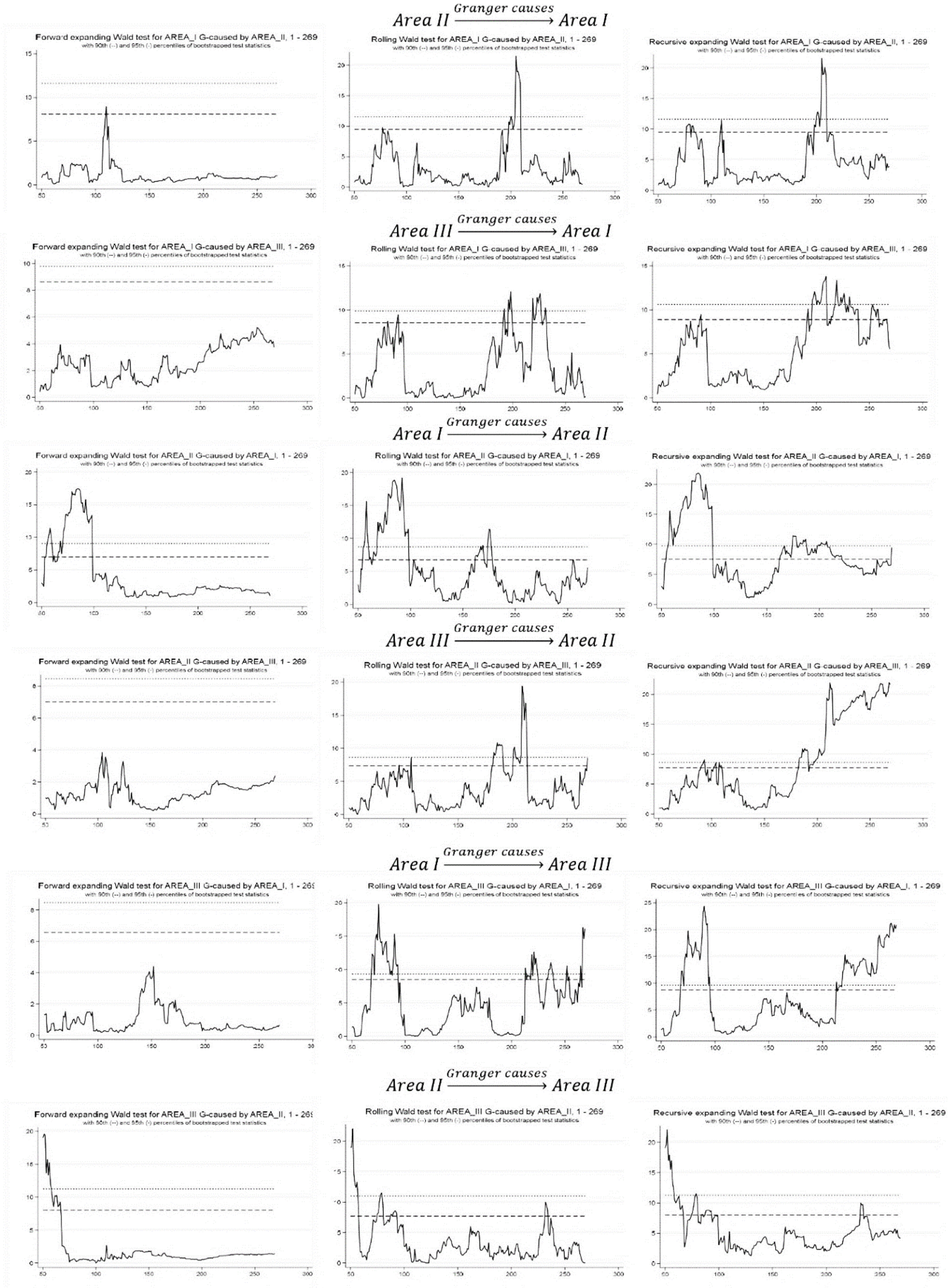


Table 7 that follows, presents the results of the global index of spatial autocorrelation, Moran's *I*, using the time-neighboring concept as the variable of interest.

Table 7 Unit roots test results

Unit roots tests	**DF-GLS test**	**PP-test**	**KPSS-test**	**NP -Test (MZ_a)**	**HEGY Seasonal test**
AREA I	-4.06***	-6.89***	0.98***	-29.47***	28.01***
AREA II	-4.53***	-5.82***	0.33	-34.72***	36.24***
AREA III	-3.68***	-5.45***	0.24	-21.20***	27.76***

(a) In HEGY seasonal test, the periodicity has been set to 12 given our monthly data, t- statistic and critical values are for all seasonal frequencies jointly, results are identical with any frequency in separate.
(b) AREA I is I(1) based on the KPSS unit root test

All areas have strong positive values of Z-scores and reject the null hypothesis of spatial randomness. In other words, it might be argued that in each of the three areas, pirates use the same or related networks or persons for their attacks since there are clusters where attacks happened to close to each other in space and time terms.

5. Conclusions

Maritime piracy is a great concern as it affects not only the vessel and cargo but also leads to delays of ships and other socioeconomic impacts. Oil tanker companies try to reroute their ships or invest in security e.g. armed guards, water cannons. Despite the urgency of mitigation practices and the need to handle systematically the piracy incidents, only a few studies have been conducted that discuss the regularities in patterns of attacks, association rules and entail a spatio-temporal analysis to support in decision making towards piracy and interventions.

In this paper, AHP method applied to explore the causing factors of piracy and which are the most highly vulnerable areas of hijacking of ships. Various factors enable these incidents such as increased volume and value of a cargo, technological advances and political instability (Min, 2011). In this study the focus was on the following criteria: zone, security, time, distance. It is found that most of the times smugglers prefer to attack ships in territorial waters rather in international waters.

Our spatiotemporal analysis suggests that there are specific clusters where most attacks occur. Pirates often prefer attacks close to the coastlines of underdeveloped countries or have no robust democracies. This is in line with the findings from the study of Desai (2021) who conducted a geographically disaggregated analysis. The challenges for combating maritime piracy derive from the lack of robust legal and institutional mechanism mostly at the domestic level (Ahmad, 2020). Also, areas I and III seem to granger cause, at least for some time intervals, area II. To rephrase it, pirates in area II are influenced by the activity and the information coming from the pirates of areas I and III, suggesting a priority to control these two areas first. In addition, in all areas, the hypothesis of shared networks and persons from pirates has been verified, encouraging authorities to derive as much information as possible from pirates that have been arrested.

Even though this study explored and answered three important questions regarding causing factors, hotspots of maritime piracy and association rules, future work may contain further analysis of policies that need to be developed and how to hanle piracy in specific geographical areas, thus how interventions against maritime piracy may differ according to regions. Moreover, future studies could evaluate the costs of maritime security of conservation initiatives.

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