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An Investigation of Maritime Accidents in Turkish Territorial Waters

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Abstract

Maritime accidents pose significant challenges to both global and regional safety, often resulting in severe environmental, economic, and human consequences. Understanding the underlying patterns and factors contributing to these accidents is crucial for developing effective safety measures and regulatory frameworks. This study presents a comprehensive analysis of 498 marine accidents that occurred in Turkish territorial waters between 2016 and 2022, examining relationships between accident types, temporal trends, accident characteristics, and vessel-specific factors. The dataset, obtained from the Directorate General of Coastal Safety, underwent rigorous data cleaning to ensure accuracy and reliability. Statistical methods, including frequency analyses, chi-square association tests, and Kruskal-Wallis H tests, were employed to investigate patterns and differences across variables such as accident season, type, region, vessel tonnage and length, and casualty numbers. Key findings revealed that hull/equipment failure was the most common accident type, with general cargo vessels and the Turkish Straits System (TSS) region experiencing the highest frequencies. Grounding accidents were more prevalent in smaller vessels (<1000 GT), while sinking accidents occurred primarily in medium-sized vessels (1000-3000 GT). The Kruskal-Wallis tests identified significant differences in casualty rates based on vessel length, with larger vessels (>200 meters) associated with higher casualty rates compared to medium-sized vessels. Accidents were most frequent during the winter season, and the TSS region exhibited the highest accident density, underscoring its critical role in maritime safety due to dense traffic and challenging navigational conditions. These findings highlight the importance of vessel type-specific safety measures and region-focused regulations, offering valuable insights for the development of effective accident prevention strategies.

Keywords: Maritime accident, statistics, accident trends, chi-square

1. Introduction

Maritime transport is a sector that carries out more than 80% of world trade and is recognized as one of the key factors of the global [1,2]. Despite facing significant challenges due to the global crises in recent years, the sector has shown remarkable resilience. Moreover, maritime trade is expected to grow by more than 2% annually between 2024 and 2028 [3]. While this highlights the economic and strategic importance of maritime transport, it also raises debates concerning its environmental impacts and sustainability. Increasing maritime trade volume can have serious consequences, such as maritime accidents, human losses, environmental destruction and economic damage [4]. Maritime accidents, especially in central areas with heavy traffic such as the Turkish Straits, are not only local, but can also negatively affect international trade and security. In this context, analyzing the causes of marine accidents and their changes over time is of critical importance for

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both improving safety standards and preventing future accidents [5]. Extensive research has explored various factors contributing to maritime accidents, including human error, vessel characteristics, environmental conditions, and operational variables, often using statistical and machine learning techniques to identify risk patterns. However, despite the increasing complexity of maritime operations and rising traffic density, studies providing a comprehensive analysis of accident patterns, particularly in high-risk regions like the Turkish territorial waters, remain limited. To establish a robust contextual basis for this study, the following section critically reviews the existing literature on maritime accident analysis, summarizing key methodologies and findings while identifying gaps that warrant further investigation into accident patterns and risk assessment.

1.1. Literature Review

There are numerous studies on marine accidents in the literature. Luo and Shin [6] conducted a comprehensive analysis of 572 articles on marine accidents, revealing a shift in research focus from maritime technology to human error and socio-economic factors. The authors emphasized the need for future research to adopt an interdisciplinary approach, incorporate multiple data sources, and apply advanced research methods to better understand the complex interactions influencing maritime safety. Fan et al. [7] proposed a novel methodology for developing maritime accident prevention strategies from a human factor's perspective, employing Bayesian Networks and the TOPSIS method within a multi-criteria decision-making framework. Their findings highlighted that the most effective strategies for reducing human error involved improving information flow, providing clear orders, and fostering a strong safety culture. Chen et al. [8] analyzed global maritime accident data from 1998 to 2018, covering 16 ship types and 13 sea regions. Using a TOPSIS model, they evaluated the significance of various accident factors, identifying foundering, stranding, and fires/explosions as the most critical contributors. Jiang et al. [9] developed a Bayesian network-based risk analysis model to assess maritime accidents along the Maritime Silk Road. Their analysis, based on accident reports, identified key risk factors such as accident type, location, ship type, speed, and vessel age. Scenario analysis revealed that hijacking posed the highest risk, while contact accidents were the least severe. Cao et al. [10] conducted a bibliometric analysis and systematic review of 491 maritime accident publications from 2000 to 2022. The study highlighted emerging research hotspots, including human factors in remote-controlled ships and accident prevention strategies for Arctic waters. It also emphasized the growing use of machine learning and big data mining techniques, offering a theoretical basis and future directions for maritime safety research. Pilatis et al. [11] performed a statistical analysis of 213 ship accidents involving collisions, groundings, and hull failures that occurred between 1990 and 2020 using IBM SPSS Statistics software. Their findings established significant correlations between accident characteristics such as ship type, ship age, damage location, and cause of the accident, with human error identified as the leading cause of marine accidents. Lan et al. [12] applied association rule mining to analyze the causes of total loss marine accidents using data from 1554 incidents recorded between 2010 and 2020. The study identified hull/machinery damage (52%) and water ingress (20.9%) as the most common causes of total losses. Additionally, vessel age exceeding 20 years and cargo condition were found to be primary indicators of accident severity and human casualties. Liu et al. [13] developed a Bayesian Network combined with advanced machine learning techniques to investigate the causes of maritime accidents in Chinese coastal waters. Their findings indicated that small general cargo ships were the riskiest vessel type, with adverse weather conditions frequently contributing to accidents. Minor accidents were more prevalent in regions with lower traffic density. Wang et al. [14] examined the injury severity outcomes of maritime accidents using a zero-inflated ordered probit regression model. They investigated factors such as accident type, ship characteristics, seafarer experience, and environmental conditions. Their analysis found that capsizing, poor sea conditions, and short rank periods significantly increased the likelihood of injury-prone accidents, while large gross tonnage and water depth were associated with more severe injuries. The study provides valuable insights for maritime safety authorities to develop strategies aimed at reducing injury severity in maritime accidents. Demirci and Gülmez [15] conducted a Human Factors Analysis and Classification System (HFACS) analysis of 30 Ro-Ro ship accidents, identifying human error as the cause in 93.27% of the cases. Unsafe actions, particularly routine violations, were the most frequently observed error types. The study emphasized the importance of compliance with established regulations and the need for proper maintenance and inspections to reduce human error.

Previous studies have provided a broad understanding of maritime accidents on a global scale, examining accident types, frequencies, and contributing factors through various analytical approaches. Building on this foundation, the present study focuses specifically on accidents occurring within the Turkish Straits System (TSS) and Turkish territorial waters. Relevant studies conducted in these regions are summarized below. Uğurlu et al. [16] analyzed 850 maritime accidents in the Turkish Straits between 2001 and 2010, identifying human error as the primary cause. Among these accidents, 89 resulted in economic losses, while 11 led to injuries or fatalities. The accidents were categorized into collisions, groundings, sinkings, fires/explosions, and machinery failures, highlighting their significant economic and safety impacts. Essiz and Dagkiran [17] evaluated accident risks in the Istanbul and Çanakkale Straits by conducting a risk analysis of ship accidents and their consequences. Their findings revealed that 153 out of 240 reported accidents over the past 13 years occurred in the Ahırkapı anchorage area, with collisions, groundings, and clashes being the most common. The authors recommended expanding or creating new anchorage areas and reducing supply operation times for transit vessels to enhance maritime safety. Korçak and Balas [18] investigated collision risks between ships navigating the İstanbul Strait and domestic ferries crossing the same route. Using simulation modeling, they identified collision hotspots and calculated collision probabilities. Their results suggested that optimized transit schedules could reduce collision risk by 7.2%, highlighting schedule management as a cost-effective mitigation measure. Yılmaz and İlhan [19] analyzed 182 maritime accidents involving Turkish-flagged vessels or incidents within the Turkish Search and Rescue Region from 2002 to 2014. Their findings indicated that 56.6% of incidents were categorized as maritime accidents, with capsizing (31.3%) and collisions (12.6%) being the most common accident types. The study also reported that vessels under 3000 GRT and 90 meters in length, particularly recreational yachts, private boats, and passenger ships, were most frequently involved. Balık et al. [20] examined traffic density, waiting times, and maritime accidents in the Istanbul and Çanakkale Straits between 2006 and 2020. They observed a gradual decrease in the number of vessels transiting the straits, while the total tonnage and vessel size, particularly in the Çanakkale Strait, increased. Additionally, the number of accidents in the Istanbul Strait showed a notable reduction over time, with an average of 7 accidents per year between 2004 and 2019. Ece [21] analyzed 857 maritime accidents in the Strait of Istanbul between 1982 and 2018 using both qualitative and quantitative statistical methods, including frequency distribution, chi-square test, Cramer's V, and regression analysis. The results identified collisions and groundings as the most common accident types, with cargo ships being the most frequently involved vessels. The study also established strong correlations between accident rates and variables such as current velocity, foggy and snowy days, wind conditions, and ship tonnage. In another study, Ece [22] further investigated maritime accidents in the Strait of Istanbul between 1994 and 2019 using similar statistical methods. Collisions were identified as the most frequent accident type (45.6%), followed by groundings and contact incidents (17.5%). The study also highlighted that cargo ships accounted for 49.8% of the accidents, while 71.5% of the vessels involved were operating without a pilot. Human error was again identified as the primary cause across all accident types. Additionally, a statistically significant relationship was found between accident type and variables such as ship type, pilot usage, and accident year. Yildiz et al. [23] examined the impact of operational conditions on marine accidents in narrow waterways, focusing on the İstanbul Strait and the Dover Strait between 2004 and 2020. They used GIS-based Kernel Density Analysis to create maritime accident density maps and conducted chi-square independence tests to explore relationships between operational factors and accident characteristics. Expert opinions validated their findings, emphasizing the influence of ship size, type, age, transit time, traffic density, and channel-specific risks on accident likelihood. The study stressed the importance of dynamic passage planning, vessel-specific risk assessments, and operational measures such as mandatory pilotage and tugboat assistance. Görçün and Burak [24] assessed maritime traffic risks in the Bosphorus between 2001 and 2010 using both qualitative and quantitative risk assessment methods. Their findings identified collisions as the most common accident type (41%), followed by groundings (22%). Navigational errors, unknown factors, and vessel-related issues were highlighted as the primary causes. The study also observed that accident risk was highest during nighttime hours and winter months, especially January and February. Bulk carriers were identified as the highest-risk vessel type, involved in 63% of accidents, while vessels under 200 meters exhibited a notably higher accident rate (69%). Arıcan [25] investigated maritime accidents in Turkish territorial waters, focusing on violations of international maritime conventions using multiple linear regression and frequency analysis. The study revealed that vessels under 500 GRT were more frequently involved in accidents occurring in Turkish territorial waters. Kamal and Çakır [26] analyzed 418 ship accidents in the İstanbul Strait between 2016 and 2021, exploring probabilistic relationships between accident types and factors such as ship size, age, type, wind speed, visibility, and current velocity. Their findings indicated that small vessels under 300 GRT were particularly prone to drift accidents, while older ships demonstrated a higher risk of machinery failures, underscoring the importance of regular maintenance.

1.2. Research Objectives and Scope

The aim of this study was to conduct an in-depth analysis of marine accidents that occurred within Turkish territorial waters, encompassing maritime zones extending up to 12 nautical miles from the baseline, in accordance with international law, between 2016 and 2022. The analysis focused on four major regions: the TSS - including the İstanbul Strait, the Çanakkale Strait, and the Marmara Sea, the Aegean Sea, the Mediterranean Sea, and the Black Sea. The dataset, which was sourced from the Directorate General of Coastal Safety, included detailed records of 498 marine accidents. To uncover patterns and relationships in the data, statistical methods such as frequency analysis, chi-square tests, and the Kruskal-Wallis H test (a non-parametric statistical procedure for comparing multiple independent groups) were applied. The analysis aimed to identify key accident characteristics, examine the influence of regional and vessel-specific factors, and assess casualty distributions across different categories.

This study was distinguished by its comprehensive focus on Turkish territorial waters and the use of robust statistical methods applied to a large dataset spanning multiple years. Unlike previous studies, which often focused on specific accident types or smaller datasets, this research provided a holistic examination of marine accidents, contributing valuable insights into regional and vessel-specific safety dynamics. The findings of this study held important implications for developing targeted safety measures and regulatory strategies to mitigate marine accidents in Turkish territorial waters.

The study was structured as follows: Section 2 detailed the dataset and methodological framework employed to analyze maritime accidents, including statistical approaches such as frequency analysis, chi-square tests, and Kruskal-Wallis H tests. Section 3 presented the results, offering an in-depth discussion of key findings related to accident patterns, vessel characteristics, and regional variations. Finally, Section 4 concluded the study by synthesizing the main insights and proposing recommendations aimed at enhancing maritime safety.

2. Materials and Methods

The data set used in this study is taken from the official records of the Directorate General of Coastal Safety and the reported accidents of bulk carriers, container ships, general cargo, passenger/RoRo, tugboat and tanker type vessels occurring in Turkish territorial waters between 2016-2022 are taken into consideration After the accident records with repetitive, incorrect or incomplete information (such as the absence of the ship name/ship's IMO registration) were removed from the raw data, it was seen that the regions where 498 accident records took place were Mediterranean, TSS, Aegean Sea and Black Sea. Different parameters were assessed in analysing these accidents: year (from 2016 to 2022) and season of the accident (spring, summer, autumn, winter), type of accident (allision/collision, fire, grounding, hull/equipment failure, man over board, sinking and others), type of vessel (bulk carrier, container ship, general cargo, passenger/RoRo, tugboat and tanker), the region in which the accident occurred (Mediterranean Sea, TSS, Aegean Sea and Black Sea), the tonnage of the vessel (<1000 GT, between 1000-3000 GT and >3000 GT), the length of the vessel (between 0-99 meters, between 100-200 meters, higher than 200 meters) and the number of casualties (dead/missing).

Various statistical methods were applied to gain insights into the marine accident dataset. First, frequency analysis, a common statistical tool for understanding the descriptive characteristics of data, was conducted using graphical representations. In addition, the chi-square test was employed to evaluate the significance of relationships between categorical parameters utilized in the study. The chi-square test, a non-parametric statistical method, assesses whether a significant relationship exists between two categorical variables [27]. Two hypotheses were tested: the null hypothesis (H_0), indicating no significant relationship, and the alternative hypothesis (H_1), indicating a significant relationship. Following a significant chi-square test result, the Bonferroni correction was applied as a post-hoc test to identify which groups exhibited significant differences. While the chi-square test examines whether an overall difference is present, post-hoc tests specifically determine between which categories these differences occur. To assess variations in casualty numbers across groups defined by vessel-specific factors (e.g., vessel type and gross tonnage) and accident region, Kruskal-Wallis H tests were conducted. This robust non-parametric method identifies significant differences in the median values of a continuous variable (e.g., casualty numbers) across more than two independent groups. Unlike One-Way ANOVA (analysis of variance), which compares means and assumes normality and homogeneity of variances, the Kruskal-Wallis H test focuses on medians and does not require these assumptions. This flexibility makes it particularly suitable for datasets with skewed distributions, heteroscedasticity, or ordinal data. While One-Way ANOVA is preferred for datasets meeting its assumptions, the Kruskal-Wallis H test is a more adaptable option for datasets that deviate from these conditions, such as the casualty data analyzed in this study. The Kruskal-Wallis H test examines two hypotheses: the null hypothesis (H_0), which posits no significant differences in casualty distributions across groups, and the alternative hypothesis (H_1), which indicates that at least one group differs significantly. A p-value below 0.05 was considered significant, prompting further post-hoc analyses. The mean rank values generated by the Kruskal-Wallis H test represent the relative rankings of casualty numbers across groups, with higher values indicating relatively greater casualty numbers. The Kruskal-Wallis H value, as the test statistic, measures the variability among groups, while its associated p-value determines the significance of observed differences. Even when the results are not significant, the mean rank values provide insights into group rankings. For significant results, pairwise comparisons (post-hoc tests) were conducted to identify which groups were responsible for the differences. These analyses offered critical insights into the influence of vessel-specific and regional factors on casualty distributions.

All statistical analyses were performed using the R programming language, with key packages such as ggplot2 for visualization, chisq.posthoc.test for post-hoc analysis, stats for statistical computations, and dplyr and tibble for data manipulation. This methodological approach ensured a rigorous and reproducible analysis of the data.

3. Results and Discussion

3.1. Frequency and chi-square Analysis

As shown in Figure 1, accidents between 2016 and 2022 occurred most frequently during the winter season (n=151, 30.3%). Furthermore, 2022 was the year with the highest frequency of accidents within the period considered in the study (n=110, 22.1%). When analyzing the distribution of accidents occurring in the winter months by year, it was observed that 28.5% (n=43) of the accidents took place in 2022, 17.9% (n=27) in 2019, 15.9% (n=24) in 2020, 13.9% (n=21) in 2021, 11.9% (n=18) in 2017, 9.3% (n=14) in 2018, and 2.6% (n=4) in 2016. Additionally, results from the chi-square test confirmed that there was a significant relationship between the year and the season, X2 (18, n=498) =55.627, p-value <0.001. This result indicated that vessel accidents were more or less frequent in certain seasons during specific years. Given the significant relationship between year and season, a series of post hoc tests were conducted. In the autumn of 2016 and the summer of 2017, it is noteworthy that ship accidents occurred more frequently (p-values <0.001) compared to other years. In other words, the frequency of vessel accidents during these years and seasons was higher than expected. Figure 2 shows the distribution of vessel types involved in accidents according to seasons. It was observed that general cargo vessels were more prominent compared to other vessel types in terms of accident frequency (n=209, 42%). Following general cargo vessels, the frequency distribution of vessel types involved in accidents was as follows, from highest to lowest: bulk carriers (n=143, 28.7%), tankers (n=67, 13.5%), container ships (n=36, 7.2%), passenger/RoRo vessels (n=33, 6.6%), and tugboats (n=10, 2%). The chi-square test, which examined whether there was a relationship between vessel types and the season in which the accidents occurred, confirmed a non-significant relationship, χ^2 (15, n=498) =18.227, p-value =0.251. This suggests that the distribution of vessel accidents is not meaningfully influenced by seasonal variations, implying other factors may be at play in determining accident frequency across different vessel types.

Figure 3 shows the frequency distribution of accident types and the vessel types involved in the accidents. The most common cause of accidents for all vessel types was hull/equipment failure (n=171, 34.3%). The frequency distribution of other accident causes was as follows: allision/collision (n=162, 32.5%), grounding (n=50, 10%), others

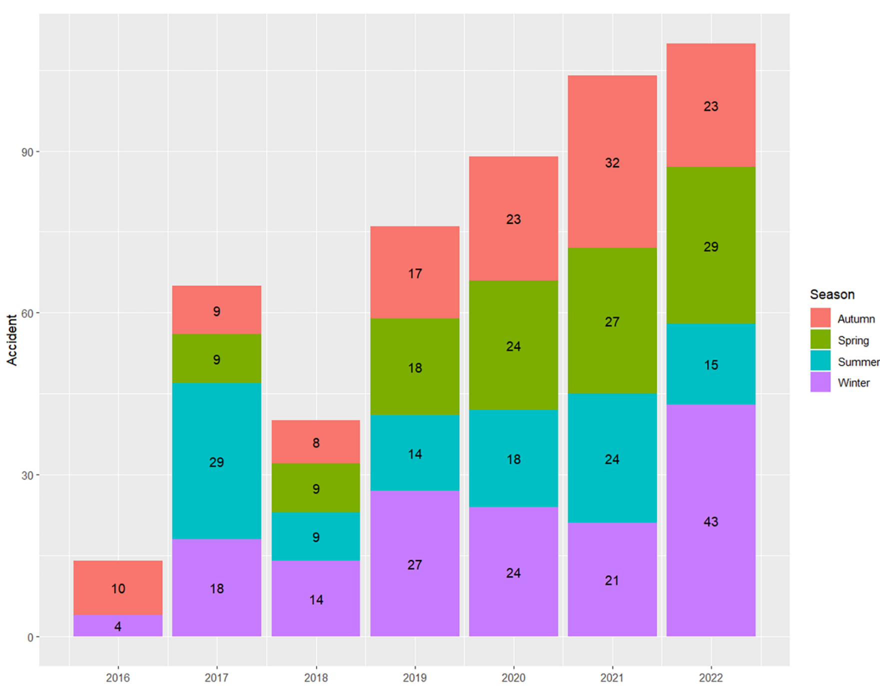

Figure 1. Distribution of accident season by years.

(n=41, 8.2%), fire (n=33, 6.6%), sinking (n=23, 4.6%), and man overboard (n=18, 3.6%). When hull/equipment accidents were examined in detail, it was found that the vessel type with the highest frequency of these accidents was the bulk carrier (n=61, 35.7%). Following bulk carriers, 32.2% (n=55) of hull/equipment accidents occurred on general cargo vessels, 15.8% (n=27) on tankers, 8.2% (n=14) on container ships, 5.3% (n=9) on passenger/RoRo vessels, and 2.9% (n=5) on tugboats. When the causes of accidents were examined separately for each vessel type, it was observed that the most common accident type for bulk carriers, container ships, tankers, and tugboats was hull/equipment failure (n=61, 42.7%; n=14, 38.9%; n=27, 40.3%; n=5, 50%, respectively). For general cargo vessels,

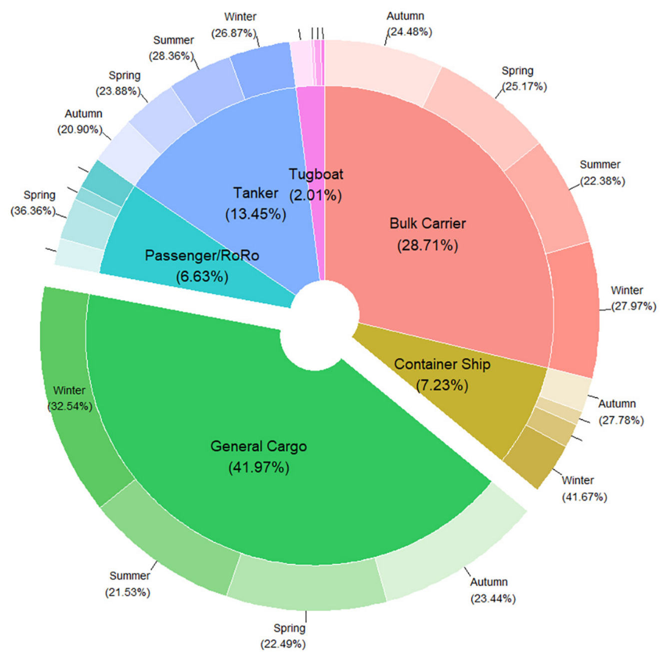

Figure 2. Distribution of the vessel types by season.

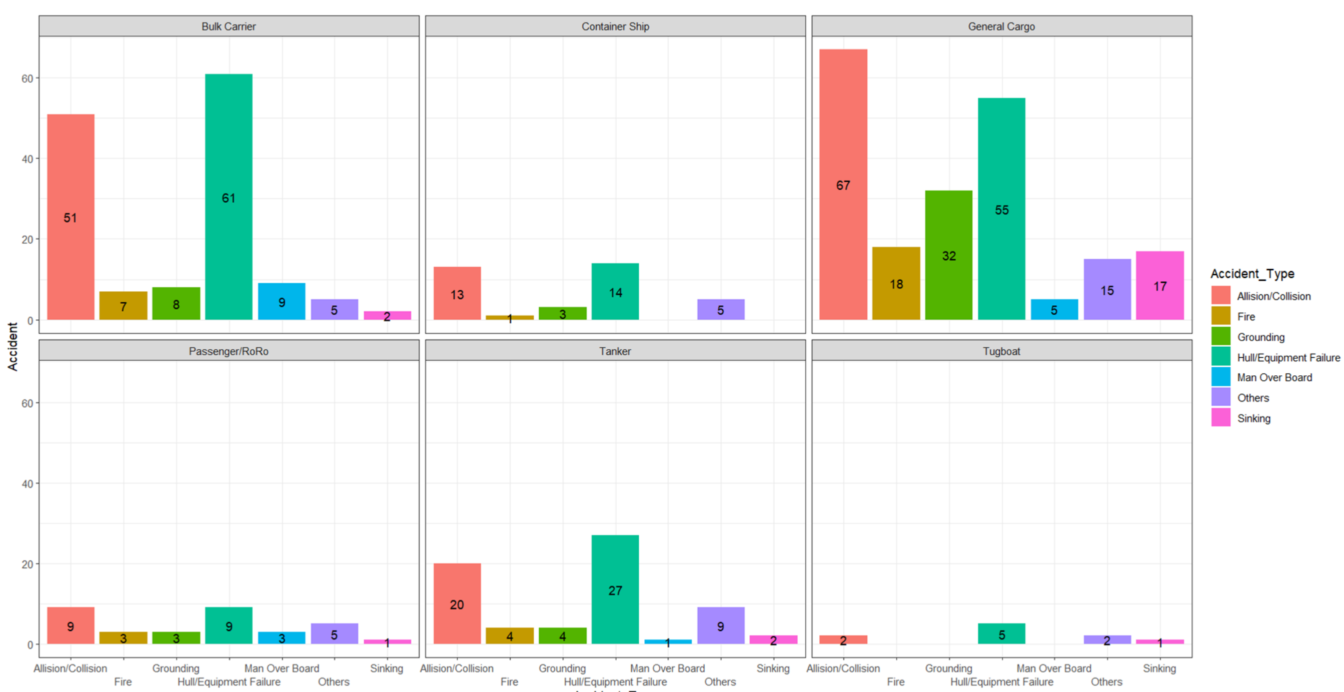

Figure 3. Distribution of the vessel types by accident type.

the most common accident type was allision/collision (n=67, 32.1%). In passenger/RoRo vessels, allision/collision and hull/equipment failure occurred with equal frequencies (n=9, 27.3%). The chi-square test results revealed a significant association between vessel type and accident type, χ^2 (30, n=498) =56.927, p-value =0.002. This finding suggests that certain accident types were more or less likely to occur in specific vessel types. However, except for general cargo vessels, post-hoc analyses for all other vessel types did not show significant differences, indicating that there were no statistically significant differences between vessel types for accident types (i.e., the differences between observed and expected frequencies were not significant). A statistically significant difference was observed for grounding-type accidents in general cargo vessels (p=0.03), indicating that grounding occurred more frequently in this vessel type compared to other types of accidents.

When examining the frequency distribution of accident types by season (Figure 4), it was observed that the winter season stands out as having the highest frequency of the most common accident type, namely hull/equipment failure, with 28.07% (n=48) of such accidents occurring in winter. Additionally, winter recorded the highest frequency of allision/collision accidents (n=49, 30.2%), grounding accidents (n=20, 40%), and other accident types (n=15, 36.6%). Conversely, the autumn season saw the highest occurrence of sinking accidents (n=10, 43.5%), while the summer season recorded the highest frequency of man-overboard accidents. Finally, fire-related accidents were most common in the spring season (n=9, 27.3%). A chi-square test was conducted to investigate whether there was a statistically significant relationship between accident types and the seasons in which they occurred. The p-value was greater than the 5% significance level, indicating that the null hypothesis (H_0), which stated that no relationship exists, could not be rejected, χ^2 (18, n=498)=20.303, p-value =0.316. In other words, the analysis showed that the season does not have a statistically significant effect on the occurrence of specific accident types. This finding was further supported by post-hoc analyses, which revealed that no individual accident type exhibited a significant association with any particular season. Therefore, the distribution of accidents by type appears consistent across different seasons, without notable seasonal influence on specific accident types.

Figure 5 illustrates the frequency distribution of vessel accident types by region. When analyzing the regions where accidents occurred, it was notable that the TSS had the highest frequency of accidents (n=362, 72.7%). In other words, 72.7% of the vessel accidents recorded between 2016 and 2022 took place in the TSS region. The Mediterranean (n=53, 10.6%), Aegean (n=49, 9.8%), and Black Sea (n=34, 6.8%) followed as the next most frequent regions for accidents. When examining hull/equipment failure, which was the most common accident type in the analyzed data set, it was observed that this type of accident occurred most frequently in the TSS (n=143, 83.6%). Hull/equipment failure was also the most common accident type in the Mediterranean region (n=13, 24.5%). In contrast, the Aegean and Black Sea regions

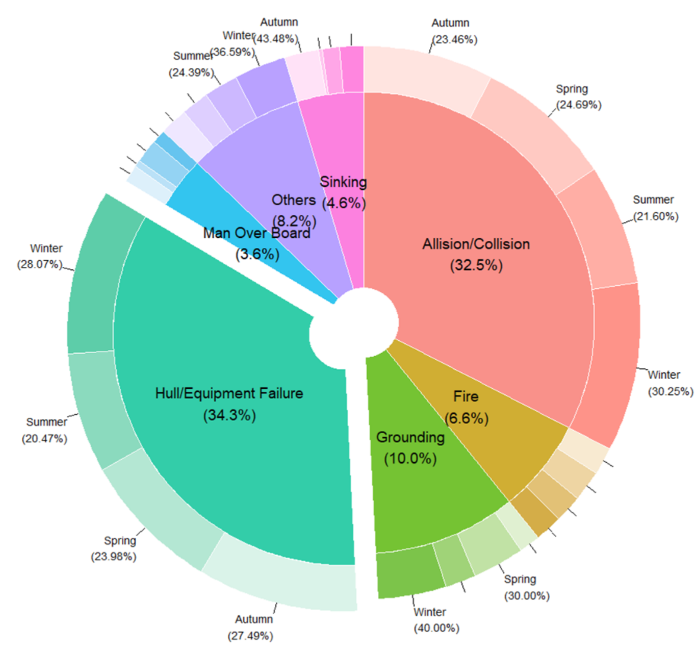

Figure 4. Distribution of the accident types by season.

showed different patterns. The Aegean region experienced the highest frequency of allision/collision accidents (n=16, 32.7%), while the most frequent accident types in the Black Sea region were allision/collision and grounding, both with equal frequency (n=7, 20.6%). Results from the chi-square test confirmed a significant relationship between accident type and region, χ^2 (18, n=498)= 64.443, p-value <0.001. This indicates that certain accident types were more or less frequent in specific regions. Post-hoc comparisons for allision/collision, grounding, man-overboard, and other accident types were not significant, showing no statistically significant differences between regions for these types of accidents (i.e., the difference between observed and expected frequencies was not statistically significant). However, there was a statistically significant difference for fire-type accidents in the TSS region compared to other regions (p-value =0.007), indicating that fire-type accidents occurred less frequently there. Additionally, sinking-type accidents were found to occur more frequently in the Black Sea Region (p-value =0.004). Hull/equipment failure accidents occurred more frequently in the TSS region (p-value =0.002), while sinking-type accidents occurred less frequently in this region compared to others (p-value =0.006).

Figure 6 illustrates the distribution of accidents of vessel types across different regions. It was observed that the TSS were the regions where the highest number of accidents occurred across all vessel types. For instance, 77.6% (n=111) of the accidents involving bulk carriers took place in this region, followed by the Mediterranean region with 11.6% (n=17). Also, the frequency of general cargo type vessels having accidents in this region was quite high compared to other regions (n=141, 67.5%). For passenger/RoRo and tugboat vessels, the TSS recorded the highest number of accidents, with the Mediterranean being the second most frequent region for these incidents. After the TSS, the Aegean Sea was the region with the second highest number of accidents for container ships and tankers (n=6, 16.7%; n=6, 9%, respectively). For general cargo vessels, on the other hand, the Black Sea was the second most frequent region (n=24, 11.5%). The chi-square test results indicated a significant relationship between vessel type and region, χ^2 (15, n=498) =27.632, p-value =0.02. This finding suggests that certain vessel types experienced accidents more or less frequently in specific regions. Post-hoc comparisons for bulk carriers, container ships, passenger/RoRo, tankers, and tugboats were not significant, leading to the conclusion that there was no statistically significant difference in accident rates between regions for these vessel types. However, a statistically significant difference (p-value =0.01) was found for general cargo type vessels in the Black Sea region, where the number of accidents observed was significantly higher than expected compared to other regions.

A new categorical variable was created based on gross tonnage, dividing vessels into three groups: those with a gross tonnage below 1000 GT, those between 1000 and 3000 GT, and those above 3000 GT. Subsequent analyses were performed using this classification. As shown in Figure 7, the dataset comprised 9.8% (n=49) vessels with a gross

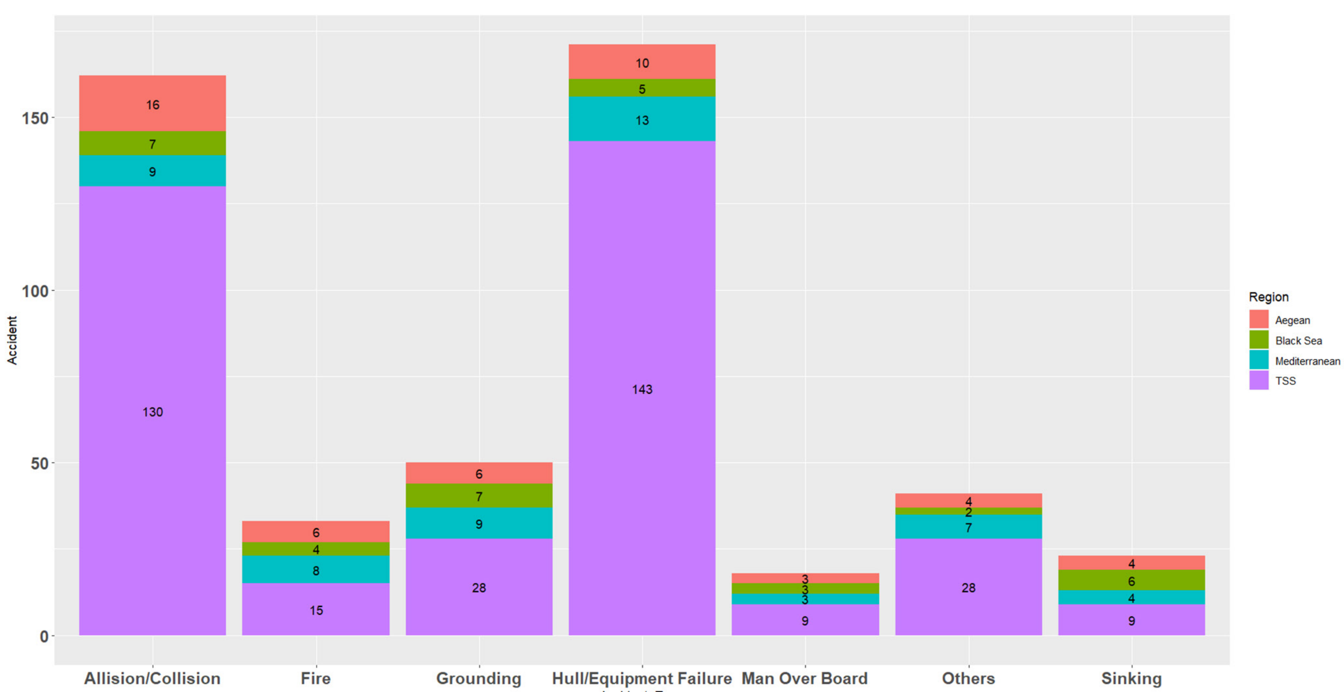

Figure 5. Distribution of the accident types by region.

tonnage below 1000 GT, 24.7% (n=123) vessels with a gross tonnage between 1000 and 3000 GT, and 65.5% (n=326) vessels with a gross tonnage above 3000 GT. Notably, the most common type of accident in two of the gross tonnage categories was hull/equipment failure, occurring in 35.8% (n=44) of vessels between 1000 and 3000 GT and 35.9% (n=117) of vessels above 3000 GT. In contrast, the most frequent accident type in the first category (vessels with a gross tonnage below 1000 GT) was grounding, with an occurrence rate of 30.6% (n=15). Additionally, sinking-type accidents were observed to occur with the lowest frequency in the highest gross tonnage category (2.1%, n=7). Similarly, man overboard was notably infrequent in the 1000-3000 GT and >3000 GT categories, with occurrence rates of 2.4%

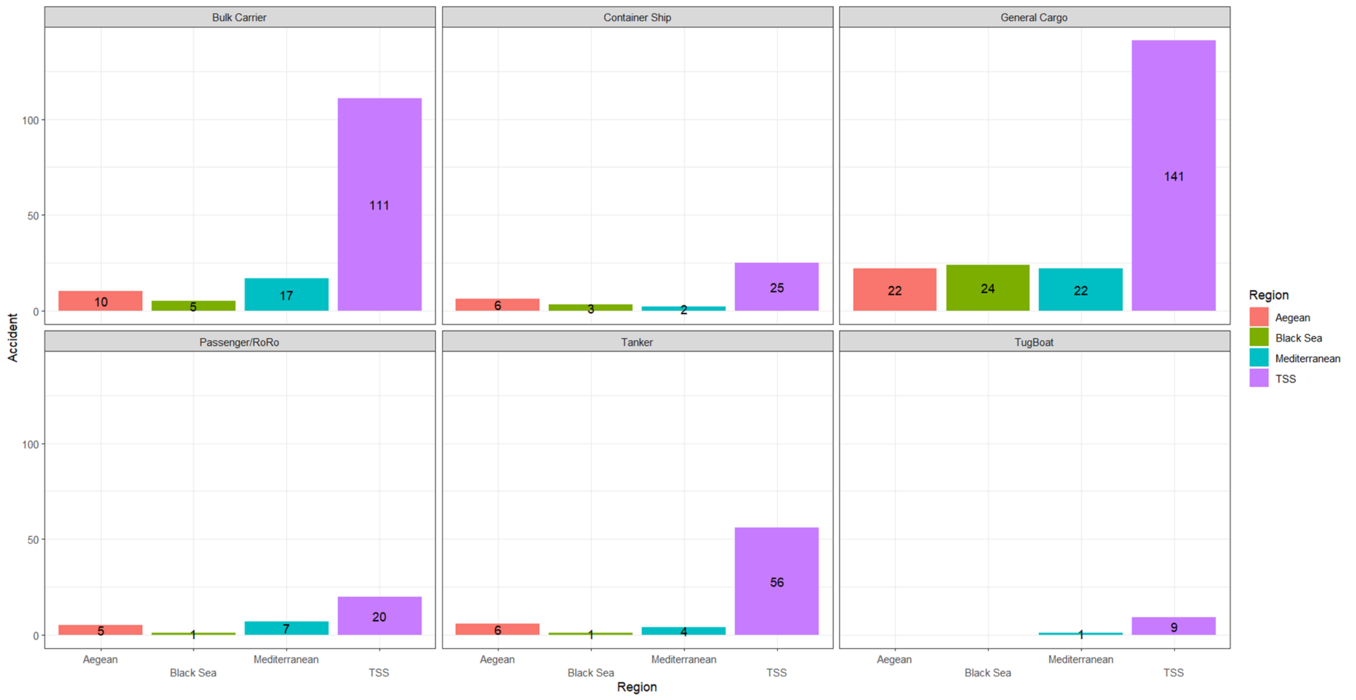

Figure 6. Distribution of the vessel types by region.

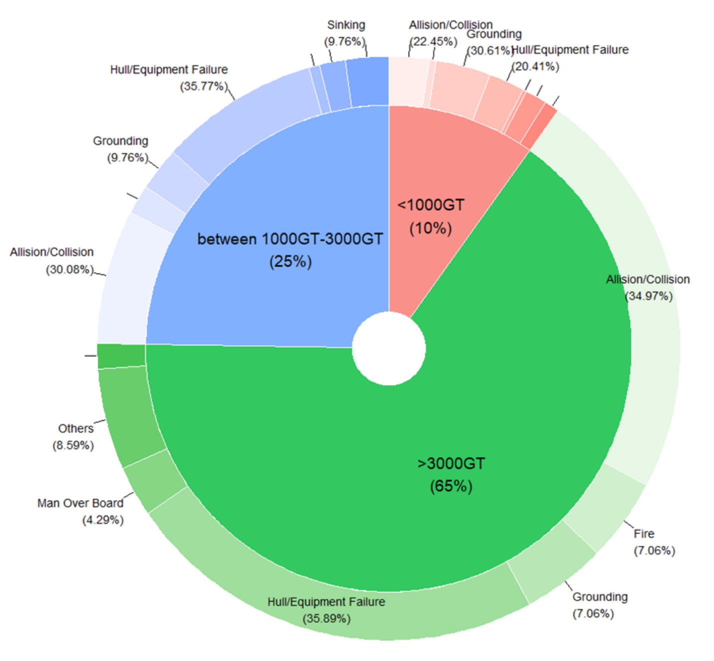

Figure 7. Distribution of the vessel gross tonnage by accident type.

(n=3) and 2% (n=1), respectively. The results of the chi-square test indicated a significant relationship between the vessel's gross tonnage category and the types of accident, χ^2 (12, n=498) =45.424, p=0.001. This suggests that, within the three gross tonnage categories, certain accident types occurred more or less frequently. The post hoc analysis using the Bonferroni correction was conducted to explore the significant differences in accident types across gross tonnage categories (<1000 GT, 1000-3000 GT, and >3000 GT). No statistically significant differences were found across the gross tonnage categories for allision/collision, fire, hull/equipment failure, man overboard, or other accident types, as all p-values exceeded the significance threshold after Bonferroni correction. The post hoc analysis revealed notable differences in the frequency of grounding and sinking accidents across gross tonnage categories. Grounding accidents were significantly more frequent in vessels with a gross tonnage of <1000 GT (p<0.01), whereas vessels in the >3000 GT category exhibited a significantly lower frequency of grounding accidents (p=0.047). No statistically significant differences were observed for the 1000-3000 GT category. Similarly, sinking accidents occurred significantly more frequently in vessels within the 1000-3000 GT category (p=0.037) but were significantly less frequent in vessels >3000 GT (p=0.006). No significant differences were found for vessels with a gross tonnage of <1000 GT. These findings suggest that grounding accidents are more prevalent in smaller vessels (<1000 GT), while sinking accidents are notably more frequent in medium-sized vessels (1000-3000 GT) but less common in larger vessels (>3000 GT).

3.2. Kruskal-Wallis H test

The first Kruskal-Wallis H test was conducted to examine whether the number of casualties (dead/loss) varied across different types of accidents, including sinking, allision/collision, man overboard, grounding, hull/equipment failure, fire, and others. The results indicated that there was no statistically significant difference in the number of fatalities between the accident types (Kruskal-Wallis H=5.059, p-value=0.536). This suggests that the distribution of casualties did not significantly differ depending on the type of accident, indicating that the type of accident may not have a direct impact on the number of casualties in the dataset. The mean ranks for each accident type, as shown in Table 1, provide a summary of the relative severity of casualties across different accident types. Although the test did not yield significant results, the mean ranks can offer insights into how the accident types were ordered in terms of casualties, with higher mean ranks indicating accident types associated with higher casualty numbers.

Another Kruskal-Wallis H test was conducted to investigate whether the number of casualties differed across the four regions: the TSS, the Aegean Sea, the Mediterranean Sea, and the Black Sea. The analysis revealed no statistically significant differences in the number of casualties between the regions (Kruskal-Wallis H =1.411, p-value =0.703). This suggests that the number of casualties did not vary significantly based on the region, indicating that the region of occurrence may not have a substantial effect on casualties outcomes. The mean ranks for each region, as shown in Table 2, provide a summary of the relative casualty outcomes in each region. Although the test did not yield significant results, the mean ranks can still offer insights into how casualties were distributed across the regions, with higher mean ranks indicating regions with higher casualty counts.

The last Kruskal-Wallis H test was performed to examine whether the number of casualties varied across the three vessel length categories: small (0-99 meters), medium (100-200 meters), and large (greater than 200 meters). The results (Table 3) indicated a statistically significant difference in

Table 1. Kruskal-Wallis test results (accident type-number of casualties).

Accident type	n	Mean Rank	Kruskal-Wallis H
Sinking	23	236.00	Test Stat=5.059 p-value=0.536
Allision/collision	162	251.37	
Man over board	18	264.03	
Grounding	50	250.76	
Hull/equipment failure	171	246.29	
Fire	33	243.45	
Others	41	260.00	

Table 2. Kruskal-Wallis test results (region-number of casualties).

Region	n	Mean Rank	Kruskal-Wallis H
Mediterranean	53	245.56	Test Stat=1.411 p-value=0.703
TSS	362	249.73	
Aegean	49	256.38	
Black Sea	34	243.24	

Table 3. Kruskal-Wallis test results (vessel length-number of casualties).

Vessel length	n	Mean Rank	Kruskal-Wallis H
Small	161	253.07	Test Stat=6.130 p-value=0.04
Medium	269	244.28	
Long	68	261.72	

the number of casualties between the length categories (Kruskal-Wallis H =6.130, p=0.04). This finding suggests that vessel length significantly influenced the number of casualties, with variations observed across the different length categories. The mean ranks for each category, presented in Table Y, offer a summary of the relative casualty outcomes for each vessel length group. These mean ranks indicated that casualty outcomes varied across vessel sizes. While small vessels had a slightly lower mean rank compared to large vessels, the difference between medium and small vessels appeared relatively modest. The higher mean rank for long vessels suggested that they might have experienced more casualties than medium-sized vessels, although the differences between medium and small vessels were less pronounced. Post-hoc tests revealed that the differences between small-medium and small-large vessel categories were not statistically significant (p-value =0.097 and p-value =0.374, respectively). However, the comparison between medium and long length vessels revealed a statistically significant difference (p-value =0.048), indicating that long length vessels were associated with a significantly higher number of casualties compared to medium-sized vessels. This result implies that, although both medium and long length vessels may experience casualties, large vessels tend to have a notably higher casualty rate.

This study analyzed 498 marine accidents involving various vessel types (bulk carriers, container ships, general cargo, passenger/RoRo, tugboats, and tankers) between 2016 and 2022. The accidents occurred in the Mediterranean, TSS, Aegean Sea, and Black Sea. Several parameters, including vessel type, accident type, region, gross tonnage, vessel length, and casualties (dead/missing), were examined. Statistical methods, such as frequency analysis, chi-square tests, and Kruskal-Wallis H tests, were employed to explore patterns and relationships. Significant differences in accident characteristics and casualty distributions were found across different parameters. Post-hoc analyses further identified specific differences between groups, offering valuable insights into the factors influencing accident severity and casualty outcomes.

4. Discussion

Analysis of the accident frequency between 2016 and 2022 indicated that incidents were most commonly observed during the winter months, with the highest frequency recorded in 2022. Chi-square tests and subsequent post-hoc analyses identified significant year-season variations, particularly highlighting increased accident frequencies in autumn 2016 and summer 2017. These findings underscore the influence of temporal patterns on maritime accident rates, aligning with the studies of Akten [28] and Liu et al. [29], who emphasized the role of temporal dynamics and operational conditions in shaping maritime incident trends. The variation in accident numbers between 2016 and 2022 may also reflect improvements in reporting and investigation practices in Türkiye in recent years. Enhanced focus on maritime safety and systematic documentation likely contributed to the higher number of recorded incidents in 2022 compared to the potential underreporting in 2016. This limitation should be considered when interpreting temporal trends in the dataset.

Regarding vessel types, general cargo vessels were involved in the highest number of accidents compared to other vessel types. However, the chi-square test revealed no significant relationship between vessel types and the seasons in which the accidents occurred, indicating that seasonal factors do not play a major role in the occurrence of these accidents. This result aligns with previous studies that highlight the greater influence of other factors, such as vessel-specific characteristics, operational challenges, and traffic density, in investigating accident patterns rather than seasonal changes [30].

An examination of accident types revealed that hull/equipment failure was the most common type of accident across all vessel types, with bulk carriers experiencing the highest frequency of such incidents. The chi-square test revealed a significant relationship between vessel type and accident type, indicating that certain types of accidents were more prevalent in specific vessel categories. However, post-hoc tests found no statistically significant differences for most vessel types, except for general cargo vessels, where grounding accidents occurred more frequently than expected. This finding is consistent with studies in the literature showing that certain types of ships are more prone to specific types of accidents [31,32].Seasonal variations in accident patterns were also explored, revealing that winter had the highest frequency of hull/equipment failure, as well as allision/collision, grounding, and other accident types. Conversely, autumn, summer, and spring had the highest occurrences of sinking, man-overboard, and fire-related accidents, respectively. However, the chi-square test indicated no statistically significant relationship between accident types and seasons, suggesting that the occurrence of specific accident types is not significantly influenced by seasonal variations. Post-hoc analyses confirmed a consistent distribution of accident types across different seasons. These results are consistent with prior research, indicating that while certain accident types may exhibit seasonal peaks in frequency, such patterns often lack statistical significance when analyzed comprehensively [33,34].Regional differences in accident frequency were also evident, with the TSS region exhibiting the highest frequency of vessel accidents, particularly involving hull/equipment failure. Other regions, such as the Mediterranean, Aegean, and Black Sea, showed varying accident patterns, with allision/collision and grounding being more common in the latter two. Chi-square analysis confirmed a significant relationship between accident type and region, reflecting distinct regional accident trends. Notably, fire-type accidents were significantly less frequent in the TSS, highlighting that strict safety regulations, traffic control, and advanced fire safety measures aboard vessels contribute to the reduced occurrence of such incidents. The shorter transit times and more predictable weather patterns in this region may also play a role in mitigating the risk factors associated with fire incidents. Conversely, hull/equipment failure accidents were found to be particularly common in this region with post-hoc comparisons, consistent with the findings of several key studies [35,36]. These studies suggest that the high frequency of hull/equipment failures in the TSS can be attributed to the complex navigational conditions, dense traffic, and operational difficulties typical of the area. In addition, post hoc test results revealed that sinking-type accidents were more prevalent in the Black Sea, a finding consistent with previous important studies that attribute the higher frequency of such incidents to the Black Sea region's challenging environmental conditions, including weather patterns, difficult navigation routes, and rough seas [37,38].

The regional distribution of vessel accidents indicated that the TSS experienced the highest frequency of incidents across all vessel types. Specifically, for passenger/RoRo and tugboat vessels, the TSS recorded the highest accident counts, followed by the Mediterranean region. Conversely, the Aegean Sea ranked second for container ship and tanker accidents, while the Black Sea held the second position for general cargo vessel incidents. The chi-square test revealed a significant association between vessel type and accident region, suggesting certain vessel types were more susceptible to accidents in particular areas. However, post-hoc analyses identified no significant regional differences for most vessel types, except for general cargo vessels, which exhibited a significantly higher accident frequency in the Black Sea compared to other regions. Existing studies, such as [39,40] emphasize the elevated accident risk for general cargo vessels in the Black Sea, attributing this trend to operational and navigational challenges, complex maritime traffic, adverse weather conditions, poor visibility, and high traffic density.

The frequency analysis revealed that the dataset consisted of vessels classified into three gross tonnage categories: below 1000 GT, between 1000 and 3000 GT, and above 3000 GT. Hull/equipment failure was the most common accident type in the two larger categories (1000-3000 GT and >3000 GT). In contrast, grounding accidents were the most frequent among vessels with a gross tonnage below 1000 GT. Sinking accidents occurred at significantly higher rates in medium-sized vessels (1000-3000 GT), while both grounding and sinking accidents were notably less frequent in the highest gross tonnage category (>3000 GT). The chi-square test indicated a significant relationship between gross tonnage categories and accident types, confirming that accident frequencies vary depending on vessel tonnage. Post-hoc analysis revealed that grounding accidents were significantly more frequent in smaller tonnage vessels (<1000 GT) and significantly less frequent in larger tonnage vessels (>3000 GT). Similarly, sinking accidents were significantly more prevalent in medium-tonnage vessels (1000-3000 GT) compared to the other categories. These findings partially align with prior research suggesting that smaller tonnage vessels are more prone to grounding accidents due to their limited stability and vulnerability to harsh weather conditions, as noted by Chen et al. [41]. Furthermore, the elevated occurrence of sinking accidents in medium-tonnage vessels (1000–3000 GT) observed in this study underscores the operational challenges and safety issues highlighted by Akten [42], which are often associated with vessels in this tonnage range.

In addition to frequency analysis and chi-square procedures, this study conducted three Kruskal-Wallis H tests to examine the factors influencing the number of casualties in maritime accidents. The first analysis evaluated whether casualty numbers varied across different accident types, including sinking, allision/collision, man overboard, grounding, hull/equipment failure, fire, and others. Notably, the analysis showed no statistically significant differences in the number of casualties across various accident types, suggesting that accident type alone does not have a substantial effect on casualty outcomes. Instead, factors such as vessel size, weather conditions, and human error appear to play a more critical role in influencing the severity of casualties. These findings are consistent with prior research [41,43] which highlights the importance of vessel-specific and situational factors, such as emergency response capabilities and crew preparedness, in determining casualty outcomes. This study reinforces the need for targeted safety measures that address these broader influences rather than focusing solely on accident types. The second Kruskal-Wallis H test investigated whether casualty numbers differed across four regions: the TSS, the Aegean Sea, the Mediterranean Sea, and the Black Sea. The findings indicated no statistically significant differences between regions, implying that the geographical location of accidents does not play a major role in determining casualty outcomes. Despite the lack of statistical significance, the mean rank values offered a comparative understanding of casualty distributions across regions. The Marine Accident Investigation Branch (MAIB) report on accidents in Scottish waters concluded that casualty severity was more closely related to vessel characteristics, human error, and operational factors than to the geographical region of the accident [44]. Also, recent studies reinforce the notion. For instance, a by Zhang et al. [45], it was emphasized that marine accidents do not differ according to geographical region and accident outcomes are generally determined independently of geographical location. The results of a last Kruskal-Wallis test revealed a significant relationship between vessel length and casualty rates, showing that larger vessels (those over 200 meters) had higher casualty rates compared to medium-sized vessels. Post-hoc analyses further confirmed that long vessels were associated with a significantly greater number of casualties than medium-length vessels, emphasizing the role of vessel size in casualty outcomes. Various studies have investigated the relationship between vessel size and the severity of casualties in maritime accidents. Montewka et al. [46] indicated that larger vessels have an increased risk of collision and that these risks are particularly pronounced in narrow waterways and heavy maritime traffic. Similarly, Chen et al. [41] noted that the high tonnage and large volume of large vessels tend to result in more serious consequences in collision and grounding situations. Furthermore, Gao et al. [47] suggested that ship tonnage increases the severity of collision accidents, thus larger ships cause more serious damage and loss of life. These studies collectively underscore the importance of vessel size in determining the severity of casualties in maritime accidents.

5. Conclusion

In conclusion, this study provides a comprehensive analysis of maritime accidents recorded between 2016 and 2022, based on data from the official records of the Directorate General of Coastal Safety, emphasizing the influence of temporal patterns, vessel types, accident types, and regional differences on accident frequencies and casualty outcomes across the Mediterranean, TSS, Aegean Sea, and Black Sea regions. The findings reveal a concentration of accidents in winter months, with a peak in 2022, possibly linked to improved reporting practices. General cargo vessels were the most involved in accidents, though seasonal influences were minimal, with vessel-specific factors playing a greater role. The TSS recorded the highest accident frequencies, while the Black Sea saw a higher prevalence of sinking accidents due to environmental challenges. Smaller vessels were more prone to grounding, while medium-tonnage vessels experienced more sinking incidents. Larger vessels showed higher casualty rates, emphasizing the need for improved design and emergency strategies.

By providing a comprehensive analysis of vessel accidents across different types, regions, and accident categories over a six-year period, this study offered significant insights into maritime accident patterns. By examining the role of vessel type, region, and temporal factors, the research contributed to understanding the complex dynamics of maritime accidents. Overall, this research enhanced the understanding of maritime safety by revealing significant relationships between accident characteristics, casualties, and environmental variables, and provides valuable insights for the development of more effective maritime safety policies and strategies to prevent future accidents.

Footnotes

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