

Potential Impact of Earth's Reversal Polarity on Safety of Navigation

Prepared By

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المستخلص

تتناول هذه الورقة البحثية بالتحليل العميق ظاهرة الانعكاسات القطبية المغناطيسية الأرضية وتأثيراتها المحتملة على سلامة الملاحة البحرية، بالإضافة إلى استكشاف المخاطر الناجمة عن الاضطرابات المغناطيسية الأرضية. يركز هذا العمل على دراسة تأثيرات هذه الاضطرابات النوعية على الأنظمة الملاحية الحيوية، مثل النظام العالمي لتحديد المواقع (GNSS)، ونظام عرض وتوصيل المعلومات الإلكتروني للخرائط (ECDIS)، وحتى البوصلة المغناطيسية. تحلل الورقة تأثيرات هذه الأحداث على الرحلات البحرية عبر المحيطات، وتقيم مدى فعالية التقنيات الملاحية التقليدية في هذه الظروف، وتطرح استراتيجيات طوارئ مناسبة لضمان الملاحة الآمنة في المياه.

Abstract

This Paper investigates geomagnetic polarity reversals and how they may affect ships safety of navigation as well as investigates the dangers that are posed with the geomagnetic disturbances.

This activity involves focusing on the impacts of particular disturbances on vital navigation systems like GNSS (Global Navigation Satellite System), ECDIS (Electronic Chart Display & Information System), and even the compass. The paper analyzes the impacts of such events on oceanic voyages as well as assesses the use of conventional techniques during these situations and developing appropriate contingency plans for the safe wet passage.

The methodology followed a mixed methods approach, which included a questionnaire, which was sent to foreign and Egyptian maritime professionals (shipmasters, navigators, and instructors); this was done in an attempt to gauge the industry awareness and preparedness. In addition, it is felt that the current levels of preparedness are inadequate for the potential alterations that may occur.

The study contributes novel insights into the specific technological vulnerabilities and operational challenges posed by geomagnetic reversals, offering actionable recommendations for improving navigational reliability for facing magnetic disturbances.

The primary results reveal major deficits in knowledge related to influences of geomagnetic polarity reversal on navigation systems as more than 60 % of respondents have a poor understanding. The results show that the world really need to plan for research on these issues. The findings highlight the urgent need for investment in targeted education and training programs, the development and implementation of robust alternative navigation systems, and enhanced international collaboration to build resilience within the maritime industry.

Key Words: Geomagnetic polarity reversals, maritime navigation disruptions, alternative navigation means, preparedness strategies.

1- Introduction

In conjunction with international commerce, transport, and various other activities, effective machine navigation is critical for contemporary society. The staggering potential for disruptions to these systems pose significant risks, most notably within the maritime sector.

Important for many navigation techniques and technologies, the Earth's magnetic field is known to periodically reverse, during which the north and south magnetic poles change places (Coe and Prévot, 1989). These changes have presented a challenge to navigational systems as they have occurred numerous times throughout the history of Earth. NASA (National Aeronautics & Space Administration) conducts research indicating that, during a reverse, the magnetic field becomes unstable, weak, and complex see figure (1). This leads to significant inaccuracies, the intermittent outages, or the complete failure of compass and electronic navigation systems (Wardinski and Thébault, 2019).

Considering the timing of the next reversal is still not discernible, there does exist a growing concern due to the potential disruption this poses. The increasing weakening of the magnetic field also exacerbates the risk posed to satellite based navigation systems like GNSS due to solar radiation and other forms of interference. The most vulnerable sector to such weakening happens to be maritime navigation due to its heavy reliance on modern technology.

While traditional methods like celestial navigation could serve as a backup, their inherent limitations, including time consumption and potential for human error, necessitate modernization and enhancement. Despite the recognized potential for disruption, a comprehensive analysis of the specific nature and severity of the impact of geomagnetic reversals on modern maritime navigation systems remains limited. This paper addresses this gap by understanding the nature of the reversal and its impact therefore outlining various preparedness strategies.

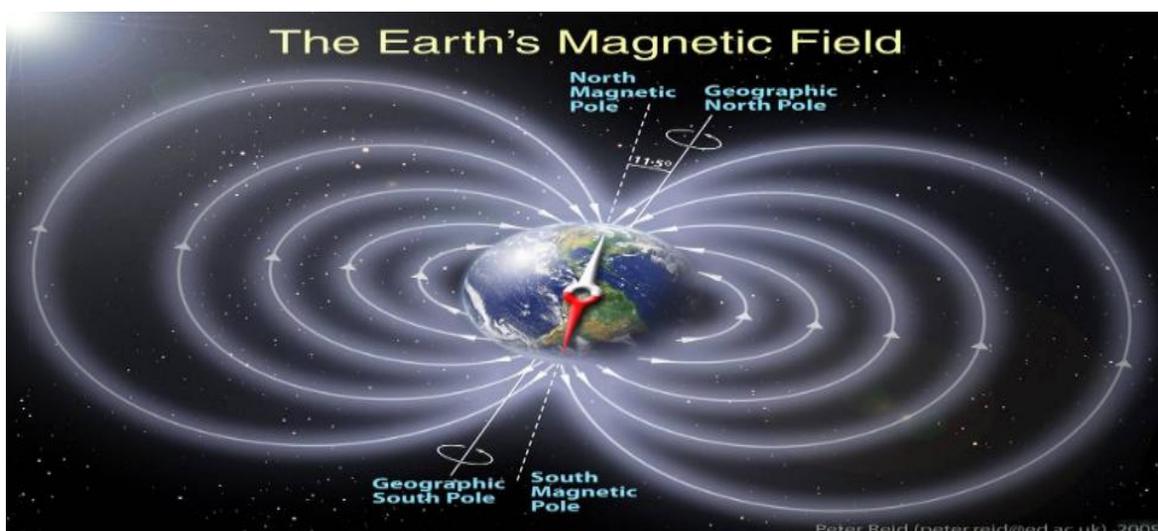


Figure (1) Illustration Depicting Earth's Magnetic Field

Source: NASA scientific visualization studio (2019)

1.1 Potential Risk on Safety of Navigation

All forms of sea tracking are crucial in almost all forms of trade and transportation, and because of this, geomagnetic polarity reversals have a great amount of importance and challenges. NASA, among other scientist's state that the last few decades are marked with extreme drawbacks to modern technology and the navigation systems in place. For starters, during this period the North and South Poles switch places which greatly messes with technology. Following this, the Earth's magnetic field undergoes extreme changes and can even go through a state in which it is completely unstable. This poses a threat to the satellites in place and other navigational techniques. This type of drastic change can result in powerful navigation faults which pose a threat to the core existence of security on maritime life forms, the biotechnology, the trade industry, the environment and living life itself. And because of this, so much importance is placed on everything regarding geomagnetic navigation adjustments.

1.2 The Research objectives

- To Investigate the nature of geomagnetic reversals and analyze the severity of their potential direct impacts on maritime navigation systems.
- To Analyze the specific vulnerabilities of existing maritime navigation systems and techniques to the disruptions caused by geomagnetic reversals.
- To Evaluate the effectiveness of various preparedness strategies for mitigating the negative consequences of geomagnetic reversals on maritime navigation

1.3 Conceptual framework diagram

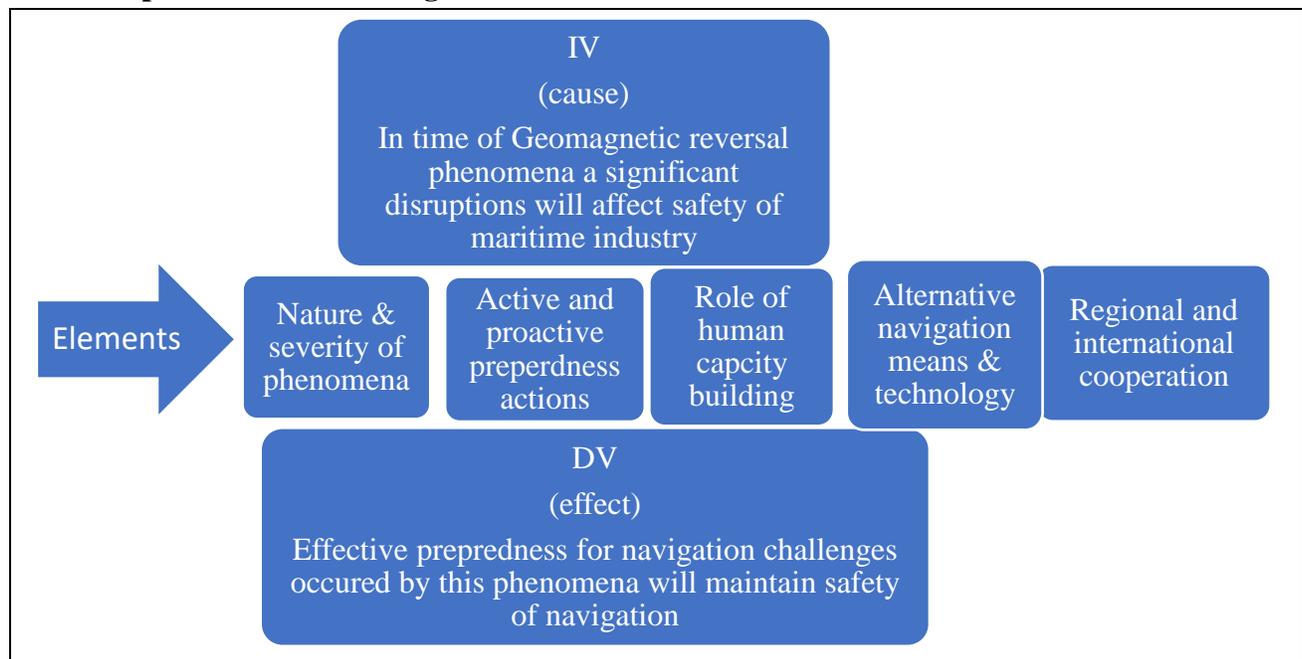


Figure (2) Research conceptual framework

Source: The Author

1.4 Hypothesis

A geomagnetic reversal will cause significant disruptions to current maritime navigation systems, necessitating Effective preparedness measures to mitigate the negative impacts of a geomagnetic reversal on maritime industry.

1.4.1 Sub-Hypotheses

- **Nature & Severity Impact of Phenomenon:** A geomagnetic reversal will be a significant disruption to the earth's magnetic field, leading to disruptions in navigation systems.
- **Effectiveness of Preparedness:** Effective preparedness measures can significantly reduce the disruptions caused by geomagnetic reversal on maritime navigation.
- **Human Capacity Building:** Investing in human capacity building programs and familiarizing personal with the nature of phenomena will reduce the negative impact of the reversal on maritime industry.
- **Alternative Navigation Means & New Technologies:** The development and adoption of alternative navigation systems & technologies can ensure safe and reliable ship navigation during geomagnetic reversals
- **Regional & International Cooperation:** Encouraging global cooperation, data sharing, standardized protocols, and adaption of strong legal frame work can facilitate effective response to geomagnetic reversal.

2- Description of The Phenomena and Literature

2.1 The Earth's Geomagnetic Field

As mentioned in the British Geological Survey (BGS). (2023, May 10) Phenomena of geomagnetic reversal events has captured the attention of scientists along the history, understanding the phenomena is essential impact measurement & adaption strategies of geomagnetic field arises from convective movement of molten iron & nickel in earth's outer core 2900- 5000km beneath, generating electric current that produce the magnetic field. This geodynamo process creates magnetic dipole near to the planet rotational axis. So any disturbance inside earth's outer core pattern will lead to disturbance for the outer (earth's) magnetic field. Chemical composition of ancient rocks serves as a testament to the dynamic data of magnetic field.

2.2 Geomagnetic Reversals

Geomagnetic reversals are recurring events where the Earth's magnetic north and south poles switch places see figure (2). These reversals are caused by turbulent motions in the outer core (Feehly, 2024), driven by Earth's rotation (Coriolis force) and internal diabetic heat. These motions weaken and rearrange the magnetic field over thousands of years, leaving a record in the magnetization of rocks (paleomagnetic record). It is the interactions between molten iron, convection currents, and the Coriolis effect may lead to the reorganization of the magnetic field.

- **Reversal Intervals:** Unlike the solar magnetic field, geomagnetic reversals are not periodic (Clement, 2010). Intervals between reversals vary significantly, from a few thousand to over

100 million years. The most recent reversal (Brunhes-Matuyama) occurred approximately 780,000 years ago, with the transition lasting around 5,000 years.

- **Reversal Phases (NOAA; National Oceanic & Atmospheric Administration):**
 - Precursor Stage: Weakening and increasing instability of the magnetic field (thousands to tens of thousands of years).
 - Reversal Transition: Significant weakening and collapse of the magnetic field (hundreds to thousands of years), rendering compasses unreliable.
 - Recovery Stage: Emergence of a new, initially weak magnetic field with reversed polarity, strengthening over several thousand years.
- **Causes and Structure (UCLA; 2014, University of California – Los Angeles):** Changes in the flow of molten iron in the outer core disrupt the geodynamo. These flow patterns are influenced by thermal convection and the Coriolis effect. External triggers, such as asteroid impacts, are also theorized. The Earth's magnetic field is predominantly a dipole, with smaller, non-dipole components that vary over time. In addition of Deep mining of hematite and iron ore on large scales.

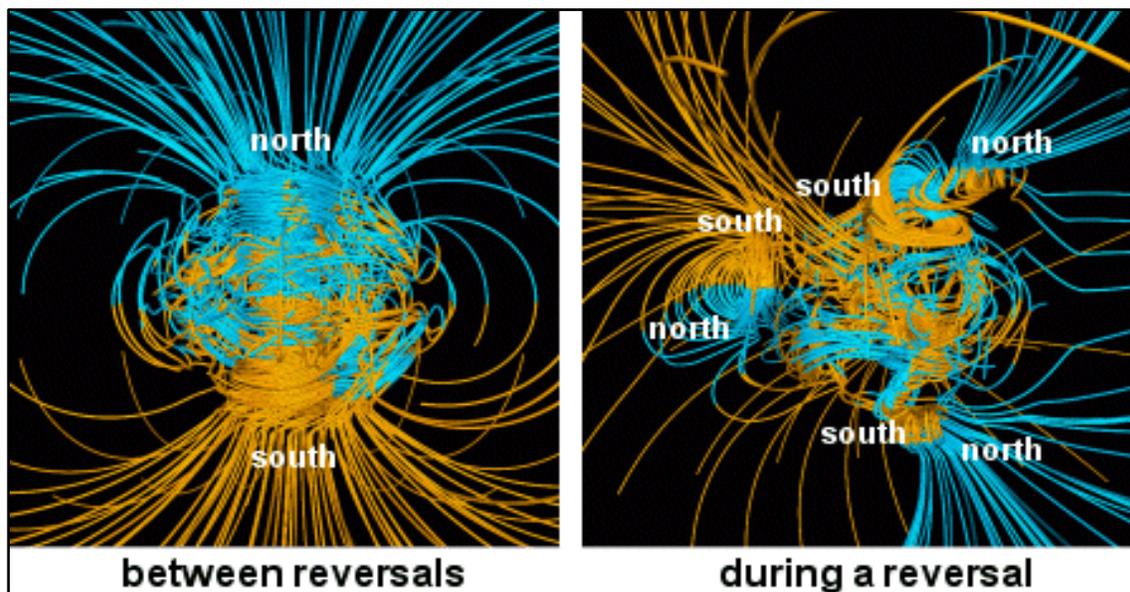


Figure (2) Geomagnetic Reversal - Source: Feehly ,2024

2.2 Simulation initiated by Takahashi in Japan 2007-2008

the simulation findings are synthesized in Table (1) Notably, the distinctive behavior of the reversed field during polarity transitions and excursions. In the context of excursions, the reversed field, originating in the deeper core regions, promptly migrates towards the shallower core interior before dissipating. Conversely, during polarity reversals, the reversed field attains growth within the core's deeper regions. Importantly, the continuity of this pattern is evident, wherein polarity changes, whether in the sequence of excursions or reversals, entail the emergence of reversed fields in both northern and southern hemispheres.

The simulation shows two main things:

1. Magnetic reversals(R): Sometimes, the north and south poles of the magnetic field completely flip. The simulation shows one full reversal and hints at others.
2. Magnetic excursions(E): These are temporary wobbles in the magnetic field where a weak "reverse" field appears near the surface but doesn't take over completely. The simulation shows several excursions.

To sum up this simulation was an evidence that geomagnetic earth's polarity happened, happening, and will happen for the long life time also excursions means that the reversal is mandatory all the time new poles appearing and trying to become dominant over the original poles but failing many times until it succeeds in one time and become a complete reversal.

Table (1) Synopsis of Reversed Field Traits Triggering Polarity Transition

| Transition | Location | Hemisphere | Polarity Change | Duration (K-year) |
|---------------|----------|--------------|-----------------|-------------------|
| R1 | Deep | One the both | Yes | 2.1 |
| E1, E3 | shallow | both | Yes | 3.1-6.4 |
| E4- E6 | shallow | one | No | 3.4-5.1 |

Source: Takahashi et al., 2007

3- Impact of Geomagnetic Reversal Polarity

The Earth's magnetic field, a crucial planetary safeguard generated by its churning outer core, is known to be non-static. At irregular intervals, spanning hundreds of millennia on average, the field undergoes dramatic reversals where the north and south magnetic poles flip positions. These geomagnetic reversals, while infrequent, hold the potential to disrupt a multitude of Earth's systems.

- **Weakened Magnetic Field and Increased Radiation:** During a reversal, the magnetic field can weaken significantly (Love j.j.,2000), allowing increased solar wind and cosmic radiation to reach Earth's atmosphere, potentially doubling cosmic ray flux at sea level. This can induce Geomagnetically Induced Currents (GICs) in conducting infrastructure, impacting power grids and potentially causing damage (ANGE0, 2022).
- **Impact on Satellites and Communication Systems:** The weakened magnetic shield increases the vulnerability of satellites to radiation damage, potentially causing malfunctions, signal disruptions, or even complete failures (Radcliffe et al., 2006). This has direct implications for satellite-based navigation systems like GNSS.
- **Impact on Ground Communications:** GICs can also disrupt ground-based communication systems by interfering with signal transmission in buried cables (Pulkkinen et al., 2012). Increased geomagnetic storm activity during reversals can further disrupt radio communications.
- **Impact on Wave Propagation:** Changes in the ionosphere due to the weakened magnetic field can distort and attenuate HF radio signals, impacting long-distance communication and some DGNS (Differential Global Navigation Satellite systems) (ANGE0, 2022).

- **Impact on Climate:** A weakened magnetic field could allow more solar particles to interact with the upper atmosphere, potentially influencing atmospheric circulation, ozone depletion, and atmospheric chemistry (Sinha & Uyeda, 2017). However, the effects on climate are still being researched and are less certain than the technological impacts.

3.1 Impact on Safety of Navigation

Magnetic Compasses: During a reversal, the shifting magnetic poles and weakened field can cause significant deviations in compass readings, rendering them unreliable (Chullikov & Parkhomov, 2002).

- **Gyrocompasses:** While less directly affected, gyrocompasses can be impacted by difficulties in calibration due to the weakened magnetic field, potentially leading to loss of precision, increased calibration frequency, false lock-on, and loss of reference during the peak of a reversal (IALA, 2024).
- **Electronic Chart Display and Information Systems (ECDIS):** ECDIS, which often integrates data from magnetometers and GNSS, can be significantly affected by a weakened or reversed magnetic field. This can lead to inaccurate position and course information, requiring substantial updates to ECDIS software and electronic navigational charts (ENCs).
- **GNSS:** As mentioned earlier, disruptions to satellite systems due to increased radiation during reversals can directly impact GNSS availability and reliability.

4- Preparedness to The Phenomena

The potential disruptions caused by a geomagnetic reversal necessitate proactive measures from the maritime industry. Recognizing the uncertainties surrounding the timing and severity of a future reversal, a two-pronged approach of active (real-time mitigation) and proactive (long-term planning) measures is essential. This aligns with the IMO's emphasis on preparedness, as highlighted in the Polar Code (2019).

4.1 Active Actions (Real-time Mitigation): These actions can be implemented during a reversal event to mitigate immediate disruptions:

- **Updating Magnetic Anomaly Charts and Databases:** This requires intensified, high-frequency, and high-coverage magnetic field surveys using specialized vessels equipped with magnetometers.
- **Real-time Monitoring and Data Analysis:** Integrating real-time magnetometer data with global networks allows for comprehensive monitoring of geomagnetic activity and rapid field fluctuations, enabling timely warnings to mariners. Advanced navigation software incorporating this data can facilitate route recalculations.
- **Redundancy of Navigation Systems:** Employing multiple independent navigation systems ensures that the failure of one system does not cripple a vessel. This includes activating backup systems independent of the magnetic field (e.g., modernized celestial navigation, inertial navigation systems).

- **Effective Communication and Collaboration:** Maintaining clear communication between vessels, shore-based authorities, international organizations, and space weather associations is crucial for coordinating responses and sharing real-time geomagnetic data.
- **Contingency Plans and Operational Adjustments:** Contingency plans should be tailored to the severity of the reversal. Milder reversals may require real-time course corrections, while more severe reversals may necessitate reducing vessel speed, enhanced training in alternative navigation, and clear reporting procedures.
- **Regular Calibration of Navigation Systems:** Continuous calibration using advanced techniques like Kalman filtering and sensor fusion algorithms (Borre et al., 2014) ensures accuracy and reliability, particularly during geomagnetic variations.

4.2 Proactive Actions (Long-term Planning): These are long-term strategies implemented in advance of a reversal:

- **Enhanced Monitoring:** Expanding magnetometer networks, dedicated satellite missions at lower latitudes, and established observatories are crucial for detecting precursory signals.
- **Enhanced Training and Education:** Comprehensive training programs for mariners on alternative navigation methods and the effects of geomagnetic reversals are essential. This includes interactive training programs and regular drills, also it will raise public awareness regarding the phenomena among mariners.
- **International Collaboration and Standardization:** Fostering international collaboration to develop standardized protocols, data-sharing mechanisms, and legal frameworks for managing navigation during reversals.
- **Development and Implementation of Alternative Navigation Technologies:** Investing in research and development of robust alternative positioning and navigation systems.
- **Augmented GNSS:** Exploring complementary technologies like Satellite-Based Optical Communication Networks (SBOC), which are immune to magnetic disruptions.
- **Radio Navigation Systems:** Utilizing systems like E-Loran and RDF (Radio Navigation Finder) for coastal and regional navigation.
- **Celestial Navigation Improvements:** Modernizing celestial navigation through digital sextants, astronomical navigation software, handheld systems using smartphone sensors, sliced-lens star trackers, and integrating celestial navigation functionalities within ECDIS.
- **Underwater Navigation Systems:** Utilizing Acoustic Positioning Systems (APS) for short-range underwater positioning and Inertial Aided Underwater Navigation (IAUN) for continuous dead reckoning.

Methodology

This research employs a mixed-methods approach, primarily utilizing a quantitative survey with qualitative elements, to investigate the maritime industry's awareness and preparedness for the navigational challenges posed by geomagnetic reversals. A targeted sample of 200 maritime professionals, including ship captains, officers, and industry experts, was recruited through a combination of purposive and snowball sampling. (creswell.2018)

A questionnaire was developed based on a thorough literature review and designed to assess industry perceptions regarding the impact of reversals on navigation systems, current preparedness levels, the potential of alternative navigation methods, and the importance of international cooperation. The questionnaire employed a Likert scale and directly addressed the awareness among mariners regarding the earth's reversal polarity and the impact of geomagnetic reversals on the maritime industry; as well as the neediness of preparation for such events.

Data was collected and analyzed using SPSS version 27. Descriptive statistics, such as frequencies and means, were used. Inferential statistical tests, including the Chi-square test, Mann-Whitney U test, and Kruskal-Wallis H test, were used to examine relationships between variables.

5- Results & Discussions

5.1 Major Results

❖ Knowledge of the earth's geomagnetic reversal polarity phenomenon and its potential impacts

This part of survey found that overall knowledge of geomagnetic reversals among maritime professionals is neutral see figure (3). This suggests that while some are aware of the phenomenon, there are still significant knowledge gaps that need to be addressed.

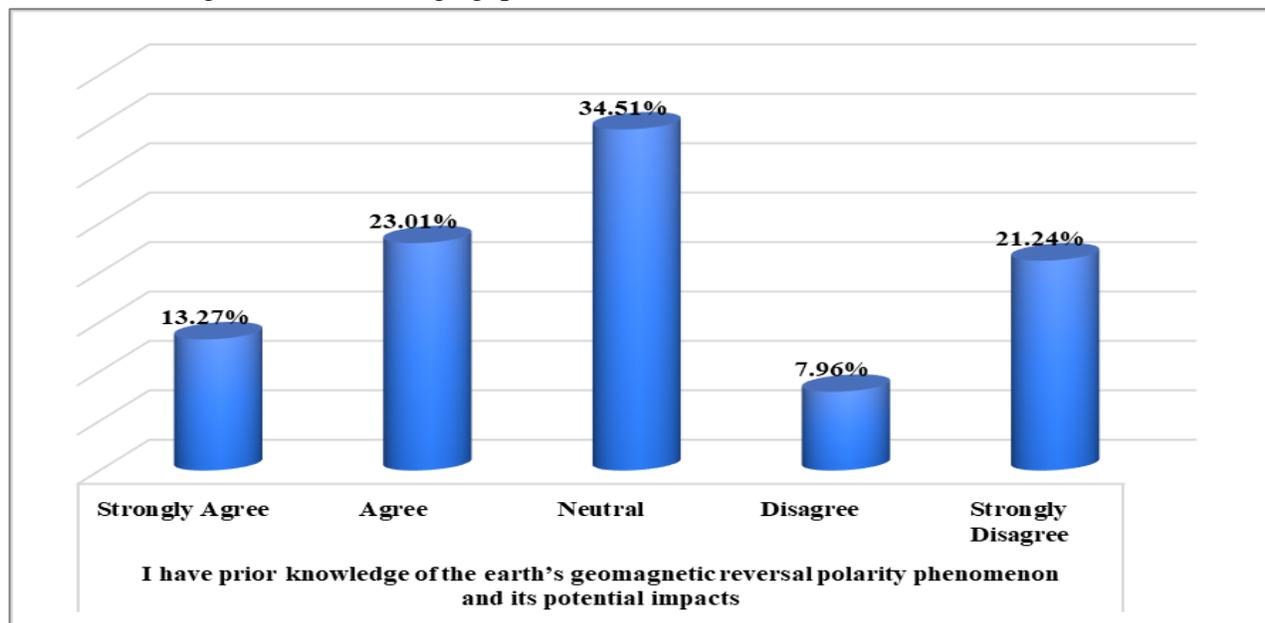


Figure (3) Results for knowledge of the earth's geomagnetic reversal polarity phenomenon and its potential impacts.

❖ Nature & Severity Impact of Phenomenon

The survey revealed a strong consensus among participants regarding the potential severity of geomagnetic reversals (M = 4.03), indicating a high level of concern about their potential impacts see figure (4).

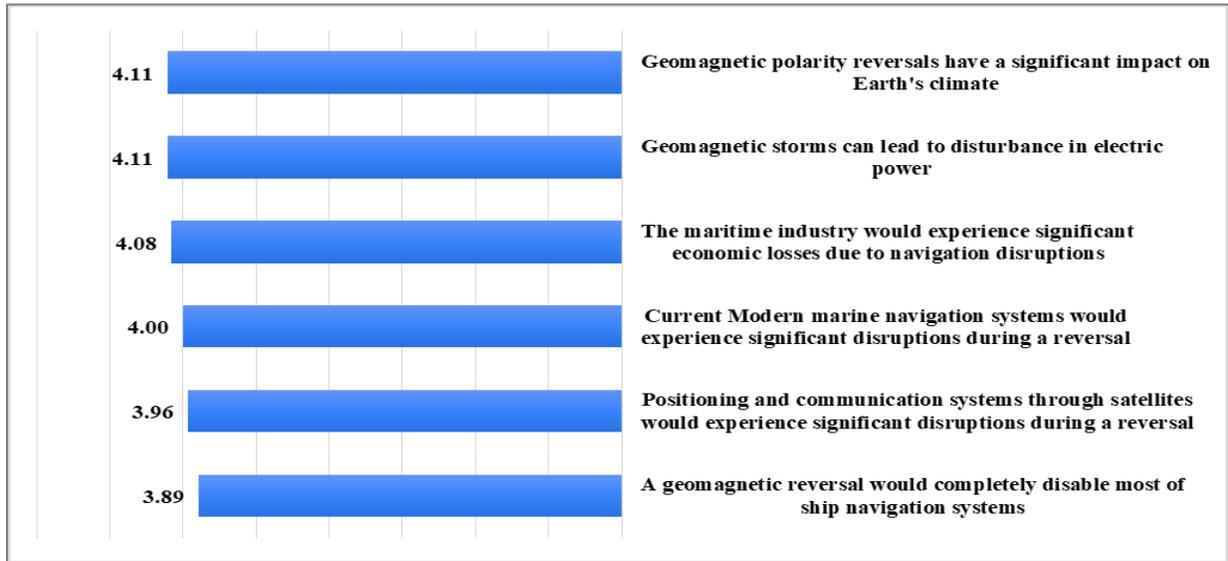


Figure (4) Results of responses for items of Nature & Severity Impact of Phenomenon

❖ **Effectiveness of Preparedness**

The survey indicated a general belief in the effectiveness of preparedness measures for mitigating the impact of geomagnetic reversals ($M = 3.70$), although confidence in the current state of preparedness was lower see figure (5).

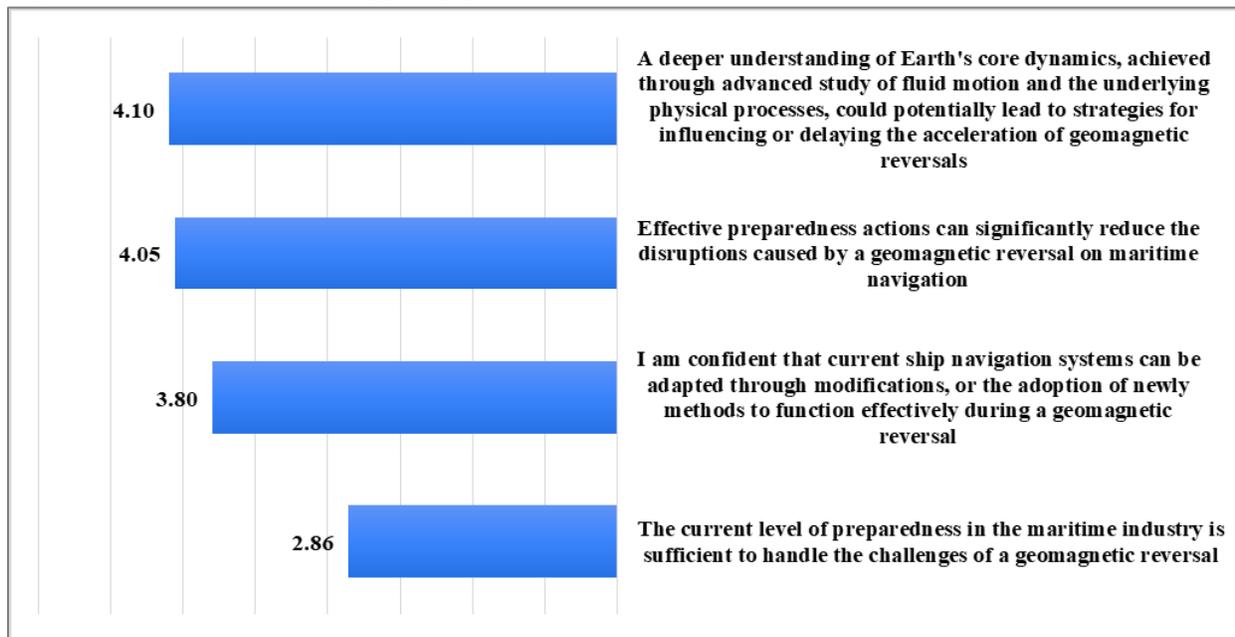


Figure (5) Results of responses for Effectiveness of Preparedness

❖ **Human Capacity Building and Training Needed for Human Factor and Awareness**

The survey revealed overwhelming support ($M = 4.38$) for human capacity building and training related to geomagnetic reversals, indicating a very high level of perceived importance see figure (6).

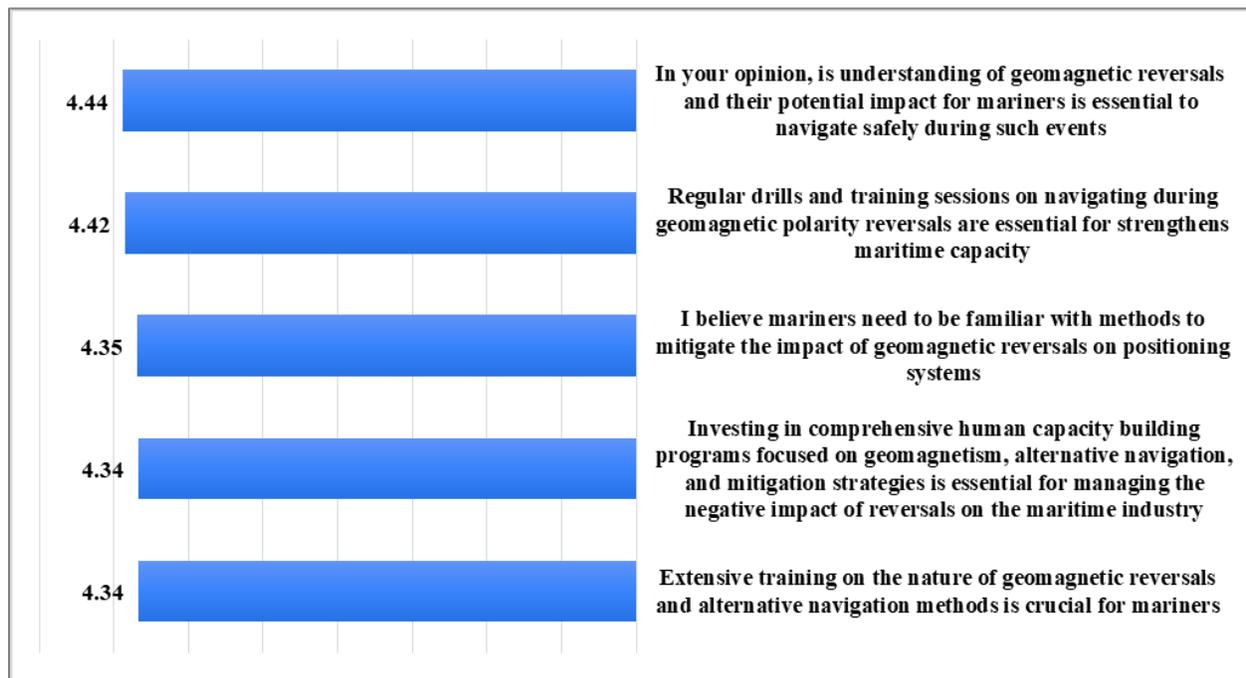


Figure (6) Results of responses for Human Capacity Building and Training Needed for Human Factor and Awareness

❖ **Alternative Navigation Means & New Technology**

The survey revealed a general agreement ($M = 3.66$) on the importance of alternative navigation means, with a strong emphasis on development and improvement see figure (7).

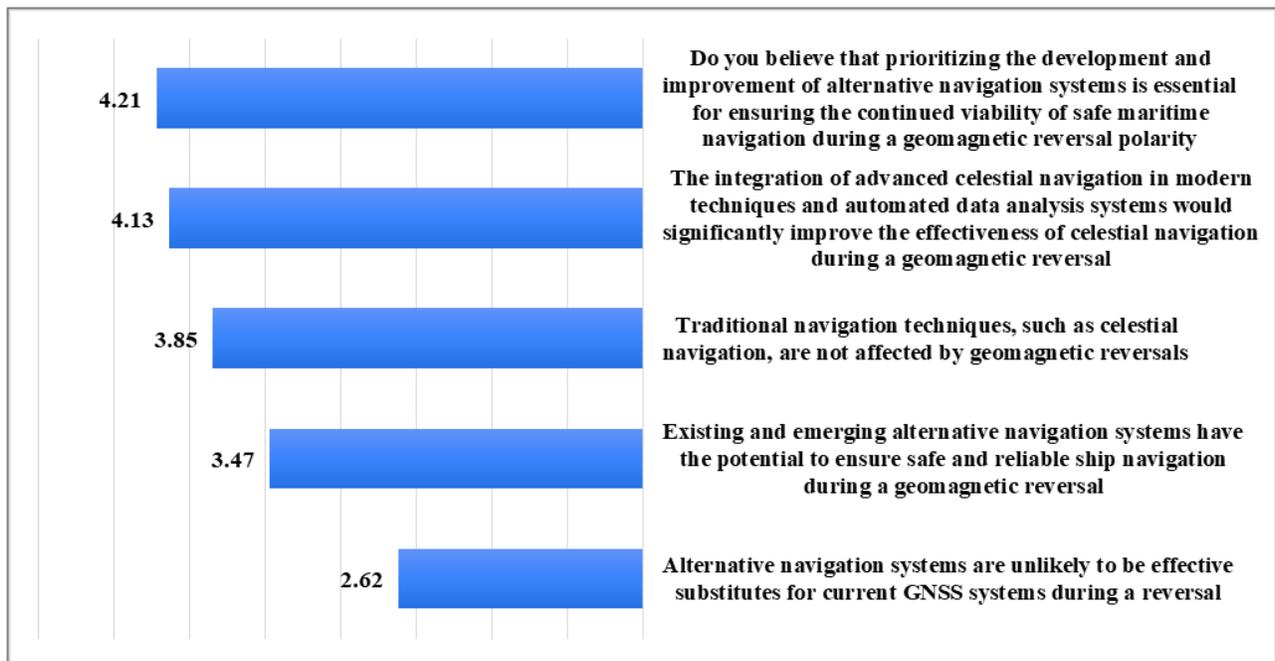


Figure (7) Results of responses for Alternative Navigation Means & Technologies

❖ **Regional & International Cooperation**

The survey revealed overwhelming support (M = 4.42) for regional and international cooperation in addressing the challenges of geomagnetic reversals, indicating a very high level of perceived importance see figure (8).

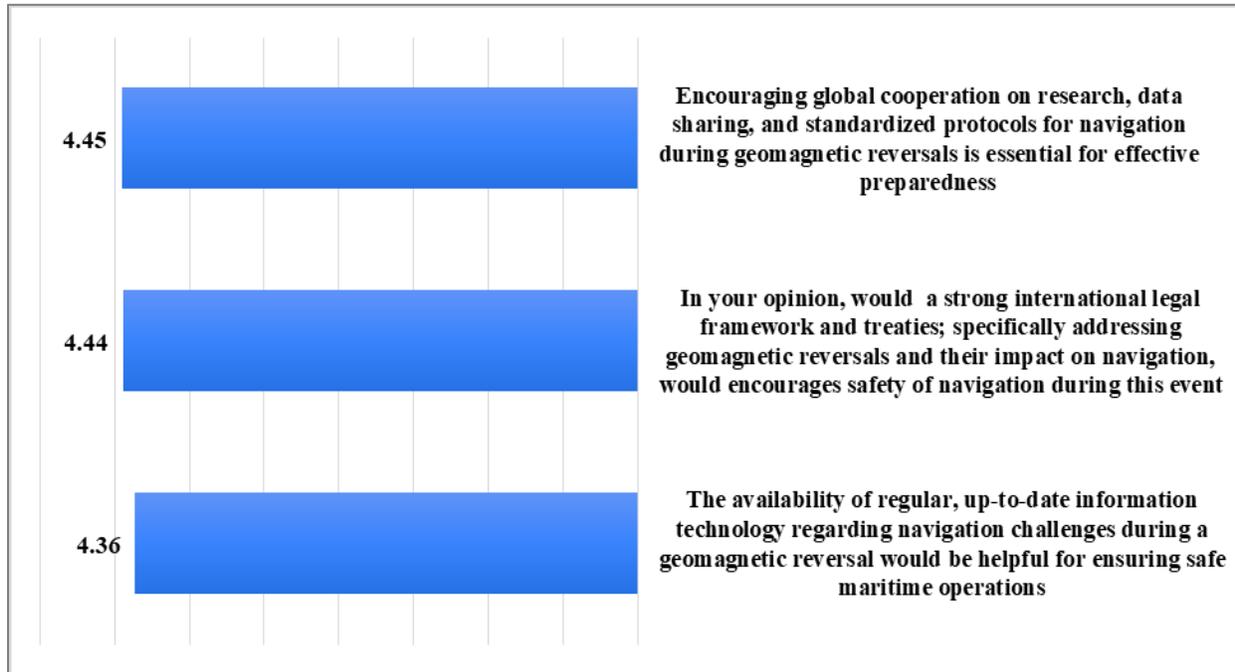


Figure (8) Results of responses for Regional & International Cooperation

5.2 Difference in Responses About Each Level According to Demographic Variables.

5.2.1 Difference in Responses According to Gender

Mann-Whitney test was used to study the difference in responses according to gender, the results shown in table (see table 2).

Table (2) shown Difference in responses according to gender (n =113)

| Variable | Gender | N | Mean Rank | Mann-Whitney U | Z | Sig. |
|--|--------|----|-----------|----------------|-------|------|
| Nature & Severity Impact of Phenomenon | Male | 96 | 54.38 | 564.00 | -2.04 | 0.04 |
| | Female | 17 | 71.82 | | | |
| Effectiveness of Preparedness | Male | 96 | 57.38 | 779.50 | -0.30 | 0.77 |
| | Female | 17 | 54.85 | | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | Male | 96 | 55.42 | 664.00 | -1.27 | 0.21 |
| | Female | 17 | 65.94 | | | |
| Alternative Navigation Means | Male | 96 | 58.60 | 662.00 | -1.25 | 0.21 |
| | Female | 17 | 47.94 | | | |
| Regional & International Cooperation | Male | 96 | 53.92 | 520.50 | -2.51 | 0.01 |
| | Female | 17 | 74.38 | | | |

Figure (9) shows that differences in responses about the level of Nature & Severity Impact of Phenomenon and Regional & International Cooperation according to gender are significant at the level of significance (0.05). Mean of Female responses was significantly higher, which can be interpreted as Women may be more likely to be concerned about environmental issues and the potential impacts of unpopular phenomenon also nowadays empowering women in international legal work taking a significant role.

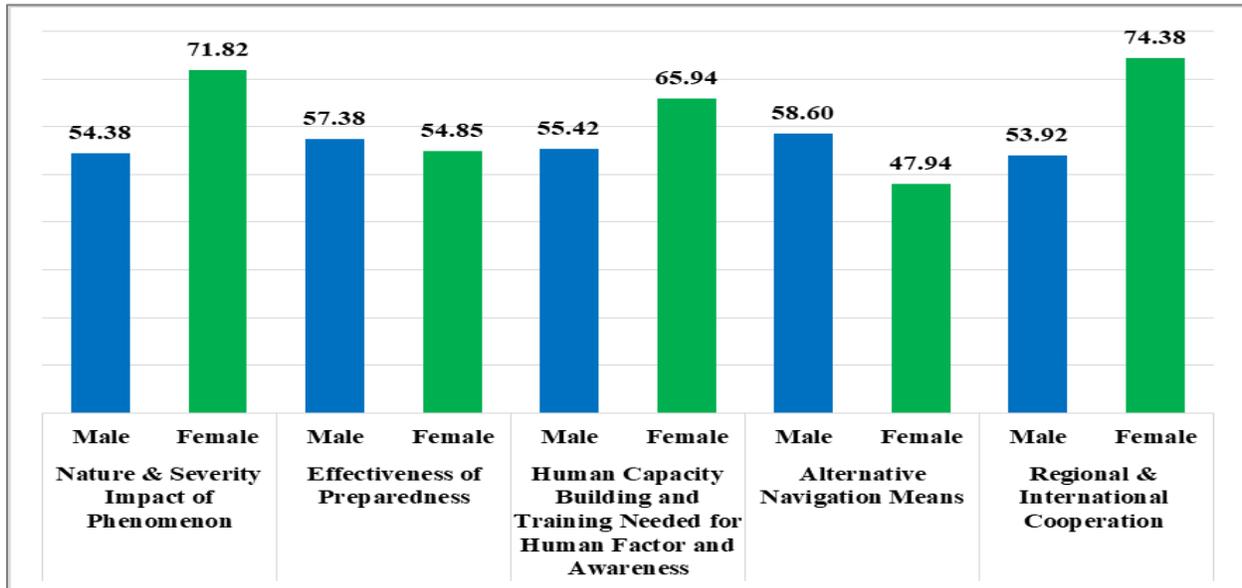


Figure (9) Results of responses according to gender

5.2.2 Difference in responses according to Age

Kruskal-Walli’s test was used to study the difference in responses according to age, the results shown in table (see table 3).

Table (3) shown Difference in responses according to age (n =113)

| Variable | Age | N | Mean Rank | H | Sig. |
|--|-------------|----|-----------|------|------|
| Nature & Severity Impact of Phenomenon | 18-24 | 5 | 75.70 | 2.51 | 0.64 |
| | 25-34 | 42 | 58.90 | | |
| | 35-44 | 33 | 53.59 | | |
| | 45-54 | 15 | 58.17 | | |
| | 55 or older | 18 | 52.64 | | |
| Effectiveness of Preparedness | 18-24 | 5 | 83.10 | 5.33 | 0.26 |
| | 25-34 | 42 | 59.10 | | |
| | 35-44 | 33 | 50.17 | | |
| | 45-54 | 15 | 53.20 | | |
| | 55 or older | 18 | 60.56 | | |

| Variable | Age | N | Mean Rank | H | Sig. |
|---|-------------|----|-----------|------|------|
| Human Capacity Building and Training Needed for Human Factor and Awareness | 18-24 | 5 | 62.80 | 3.01 | 0.56 |
| | 25-34 | 42 | 51.60 | | |
| | 35-44 | 33 | 58.56 | | |
| | 45-54 | 15 | 67.07 | | |
| | 55 or older | 18 | 56.75 | | |
| Alternative Navigation Means | 18-24 | 5 | 53.50 | 2.58 | 0.63 |
| | 25-34 | 42 | 56.37 | | |
| | 35-44 | 33 | 54.59 | | |
| | 45-54 | 15 | 69.23 | | |
| | 55 or older | 18 | 53.67 | | |
| Regional & International Cooperation | 18-24 | 5 | 71.10 | 2.59 | 0.63 |
| | 25-34 | 42 | 52.27 | | |
| | 35-44 | 33 | 58.47 | | |
| | 45-54 | 15 | 62.60 | | |
| | 55 or older | 18 | 56.75 | | |

Figure (10) shows that differences in responses according to age are insignificant at the level of significance (0.05).

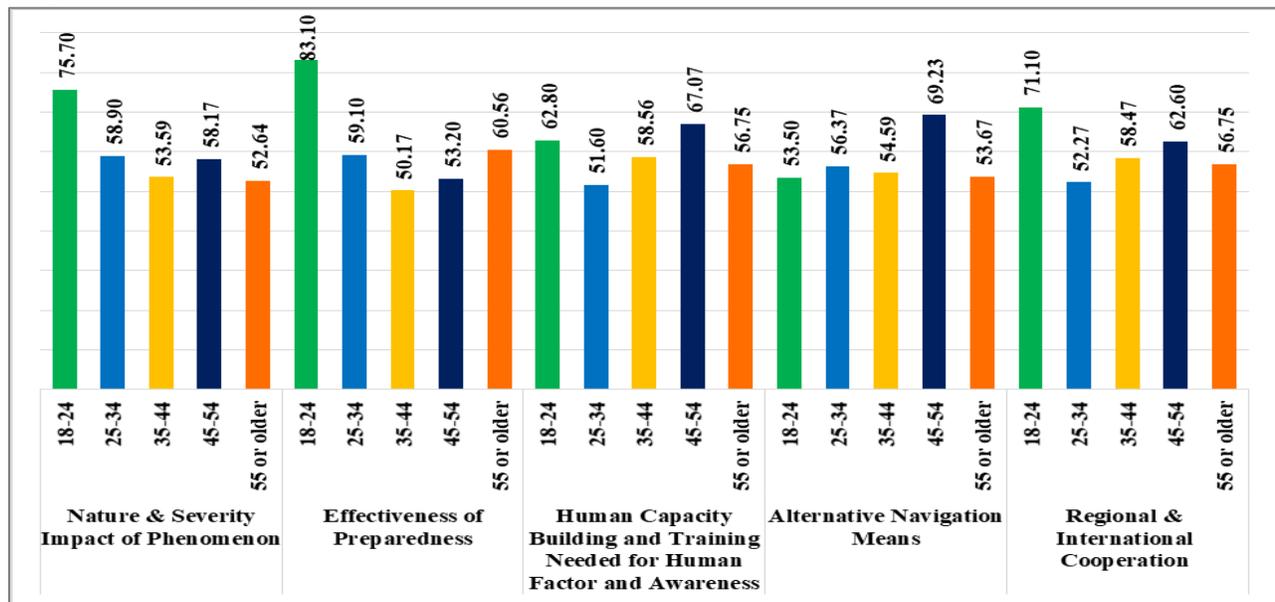


Figure (10) Results of responses according to age

5.2.3 Difference in responses according to nationality

Mann-Whitney test was used to study the difference in responses according to nationality, the results shown in table (see table 4).

Table (4) shown Difference in responses according to nationality (n =113)

| Variable | Nationality | N | Mean Rank | Mann-Whitney | Z | Sig. |
|--|-------------|----|-----------|--------------|-------|------|
| Nature & Severity Impact of Phenomenon | Egyptian | 99 | 57.00 | 693.00 | 0.00 | 1.00 |
| | Foreigner | 14 | 57.00 | | | |
| Effectiveness of Preparedness | Egyptian | 99 | 57.58 | 636.00 | -0.50 | 0.61 |
| | Foreigner | 14 | 52.93 | | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | Egyptian | 99 | 56.59 | 652.50 | -0.37 | 0.71 |
| | Foreigner | 14 | 59.89 | | | |
| Alternative Navigation Means | Egyptian | 99 | 56.94 | 687.00 | -0.05 | 0.96 |
| | Foreigner | 14 | 57.43 | | | |
| Regional & International Cooperation | Egyptian | 99 | 57.19 | 674.50 | -0.17 | 0.86 |
| | Foreigner | 14 | 55.68 | | | |

Figure (11) shows that differences in responses according to nationality are insignificant at the level of significance (0.05).

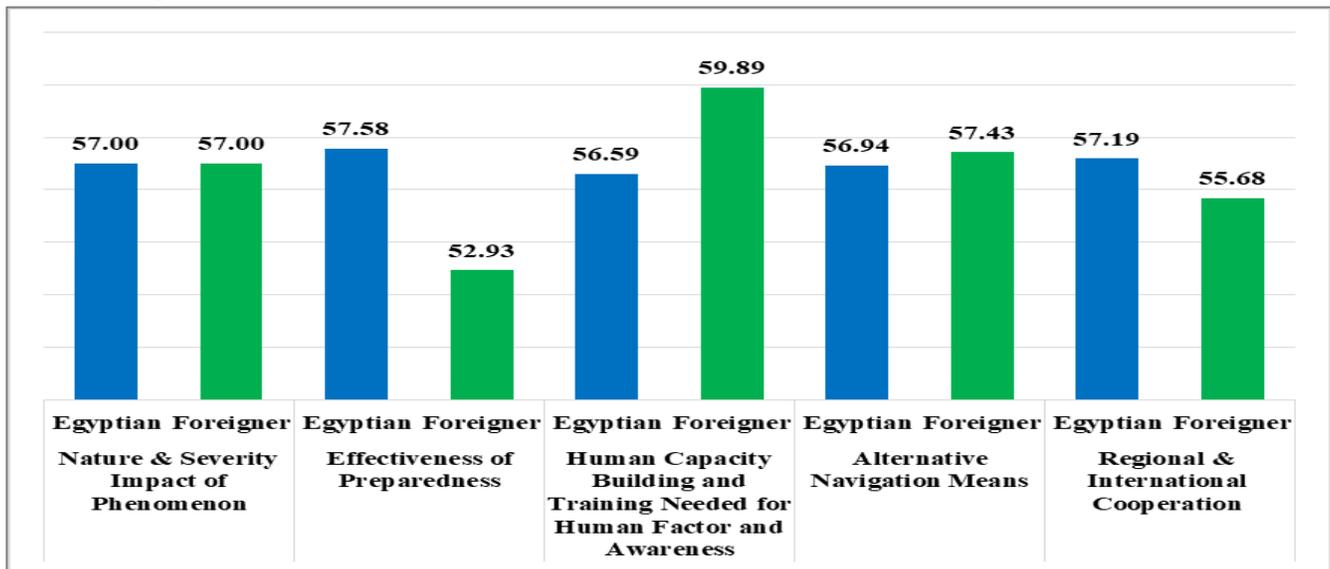


Figure (11) Results of responses according to nationality

5.2.4 Difference in responses according to organization

Kruskal-Walli’s test was used to study the difference in responses according to organization, the results shown in table (see table 5).

Table (5) shown Difference in responses according to organization (n =113)

| Variable | Organization | N | Mean Rank | H | Sig. |
|---|-----------------------|----|-----------|-------|------|
| Nature & Severity Impact of Phenomenon | Teaching institute | 17 | 42.32 | 5.30 | 0.15 |
| | Navigation co. office | 19 | 53.47 | | |
| | On ships | 62 | 60.00 | | |
| | Other | 15 | 65.70 | | |
| Effectiveness of Preparedness | Teaching institute | 17 | 57.71 | 1.11 | 0.77 |
| | Navigation co. office | 19 | 51.16 | | |
| | On ships | 62 | 59.38 | | |
| | Other | 15 | 53.77 | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | Teaching institute | 17 | 33.47 | 20.17 | 0.00 |
| | Navigation co. office | 19 | 43.71 | | |
| | On ships | 62 | 63.10 | | |
| | Other | 15 | 75.30 | | |
| Alternative Navigation Means | Teaching institute | 17 | 38.38 | 9.59 | 0.02 |
| | Navigation co. office | 19 | 49.08 | | |
| | On ships | 62 | 63.83 | | |
| | Other | 15 | 59.90 | | |
| Regional & International Cooperation | Teaching institute | 17 | 42.71 | 9.80 | 0.02 |
| | Navigation co. office | 19 | 44.92 | | |
| | On ships | 62 | 62.28 | | |
| | Other | 15 | 66.67 | | |

Figure (12) shows that differences in responses about the level of Human Capacity Building and Training Needed for Human Factor and Awareness, Alternative Navigation Means, Regional & International Cooperation, according to organization are significant at the level of significance (0.05). Mean of Teaching institute and Navigation co. office responses was significantly lower, which can be interpreted as that these organizations might have different priorities or perspectives on training needs. For instance, teaching institutes may focus on providing foundational knowledge and skills, while navigation companies might prioritize on-the-job training or specific certification.

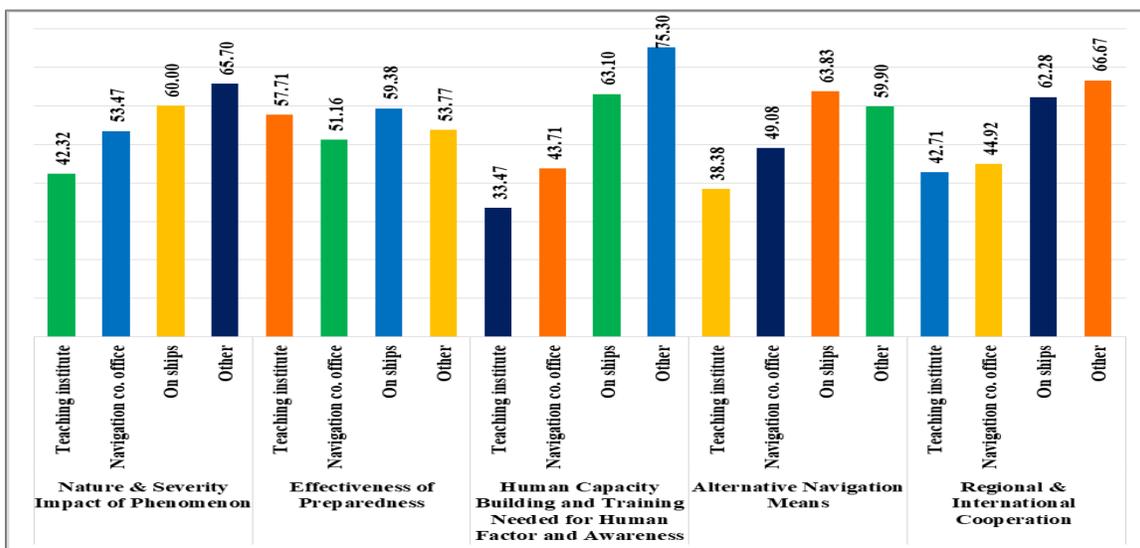


Figure (12) Results of responses according to organization

5.2.5 Difference in responses according to certificate of competency

Kruskal-Wallis’s test was used to study the difference in responses according to certificate of competency, the results shown in table (see table 6).

Table (6) shown Difference in responses according to certificate of competency (n =113)

| Variable | Certificate of competency | N | Mean Rank | H | Sig. |
|--|---------------------------|----|-----------|------|------|
| Nature & Severity Impact of Phenomenon | Master | 44 | 60.33 | 1.92 | 0.59 |
| | Ch. officer | 28 | 53.64 | | |
| | 2nd officer | 18 | 49.72 | | |
| | Other | 23 | 60.41 | | |
| Effectiveness of Preparedness | Master | 44 | 60.19 | 1.11 | 0.77 |
| | Ch. officer | 28 | 54.95 | | |
| | 2nd officer | 18 | 58.64 | | |
| | Other | 23 | 52.11 | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | Master | 44 | 53.94 | 2.74 | 0.43 |
| | Ch. officer | 28 | 55.55 | | |
| | 2nd officer | 18 | 54.39 | | |
| | Other | 23 | 66.65 | | |
| Alternative Navigation Means | Master | 44 | 59.93 | 0.62 | 0.89 |
| | Ch. officer | 28 | 55.91 | | |
| | 2nd officer | 18 | 54.47 | | |
| | Other | 23 | 54.70 | | |
| Regional & International Cooperation | Master | 44 | 52.02 | 4.36 | 0.22 |
| | Ch. officer | 28 | 60.00 | | |
| | 2nd officer | 18 | 51.67 | | |
| | Other | 23 | 67.04 | | |

Figure (13) shows that differences in responses according to certificate of competency are insignificant at the level of significance (0.05).

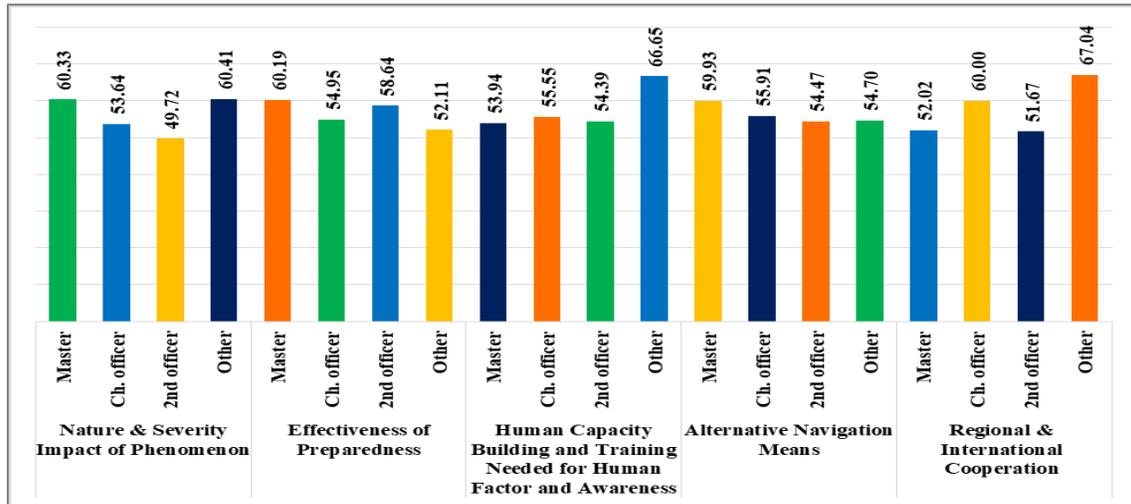


Figure (13) Results of responses according to certificate of competency

5.2.6 Difference in responses according to occupation

Kruskal-Wallis’s test was used to study the difference in responses according to occupation, the results shown in table (see table 7).

Table (7) shown Difference in responses according to occupation (n =113)

| Variable | Occupation | N | Mean Rank | H | Sig. |
|--|-----------------------|----|-----------|-------|------|
| Nature & Severity Impact of Phenomenon | Marine superintendent | 11 | 57.45 | 5.13 | 0.40 |
| | Ship master | 27 | 59.22 | | |
| | Marine navigator | 37 | 59.45 | | |
| | Marine instructor | 6 | 30.67 | | |
| | Researcher | 20 | 61.18 | | |
| | Other | 12 | 50.25 | | |
| Effectiveness of Preparedness | Marine superintendent | 11 | 52.09 | 3.93 | 0.56 |
| | Ship master | 27 | 57.56 | | |
| | Marine navigator | 37 | 63.92 | | |
| | Marine instructor | 6 | 50.42 | | |
| | Researcher | 20 | 55.38 | | |
| | Other | 12 | 44.92 | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | Marine superintendent | 11 | 39.05 | 14.33 | 0.01 |
| | Ship master | 27 | 61.20 | | |
| | Marine navigator | 37 | 65.00 | | |
| | Marine instructor | 6 | 29.67 | | |

| Variable | Occupation | N | Mean Rank | H | Sig. |
|--------------------------------------|-----------------------|----|-----------|-------|------|
| | Researcher | 20 | 63.40 | | |
| | Other | 12 | 42.33 | | |
| Alternative Navigation Means | Marine superintendent | 11 | 54.05 | 8.24 | 0.14 |
| | Ship master | 27 | 67.17 | | |
| | Marine navigator | 37 | 61.19 | | |
| | Marine instructor | 6 | 39.67 | | |
| | Researcher | 20 | 51.38 | | |
| | Other | 12 | 41.96 | | |
| Regional & International Cooperation | Marine superintendent | 11 | 39.32 | 15.08 | 0.01 |
| | Ship master | 27 | 59.74 | | |
| | Marine navigator | 37 | 63.09 | | |
| | Marine instructor | 6 | 43.50 | | |
| | Researcher | 20 | 68.73 | | |
| | Other | 12 | 35.46 | | |

Figure (14) shows that differences in responses about the level of Human Capacity Building and Training Needed for Human Factor and Awareness, and Regional & International Cooperation according to occupation are significant at the level of significance (0.05). Mean of Marine navigator and Researcher responses was significantly higher, which can be interpreted Specifically as the marine navigators and researchers rated the need for these factors higher suggests that these groups perceive the importance of human capital development and international collaboration in addressing the challenges posed by geomagnetic reversals.

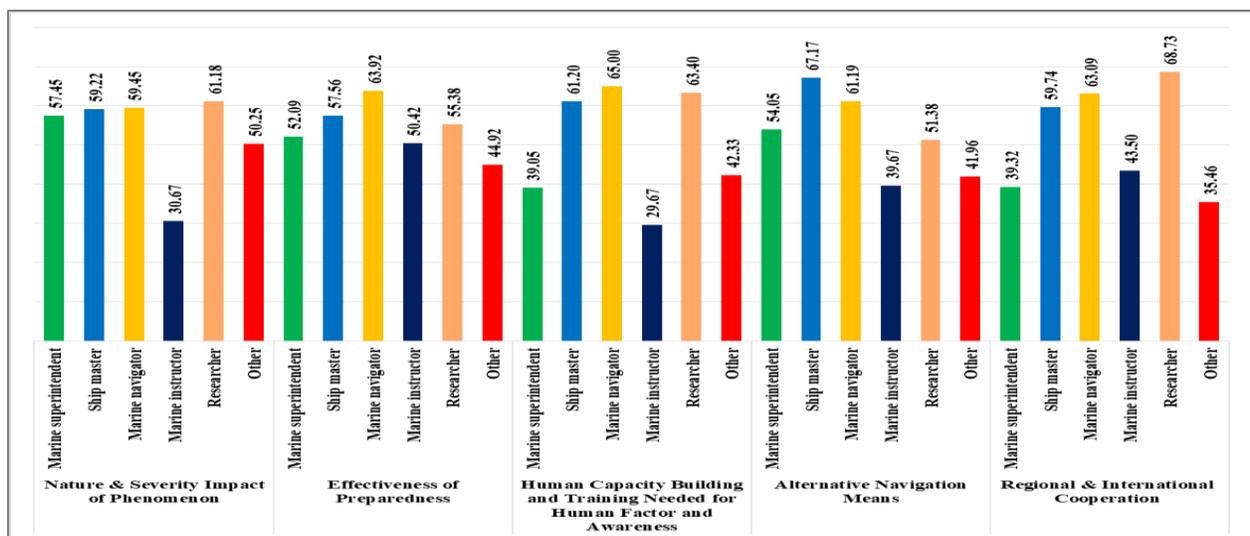


Figure (14) Results of responses according to occupation

5.2.7 Difference in responses according to years of experience

Kruskal-Wallis’s test was used to study the difference in responses according to years of experience, the results shown in table (see table 8).

Table (8) shown Difference in responses according to years of experience (n =113)

| Variable | Years of Experience | N | Mean Rank | H | Sig. |
|--|---------------------|----|-----------|------|------|
| Nature & Severity Impact of Phenomenon | < 7 years | 33 | 54.42 | 0.32 | 0.96 |
| | 7-15 years | 45 | 58.27 | | |
| | 16-29 years | 17 | 58.65 | | |
| | > 30 years | 18 | 57.00 | | |
| Effectiveness of Preparedness | < 7 years | 33 | 55.71 | 0.73 | 0.87 |
| | 7-15 years | 45 | 58.41 | | |
| | 16-29 years | 17 | 52.12 | | |
| | > 30 years | 18 | 60.44 | | |
| Human Capacity Building and Training Needed for Human Factor and Awareness | < 7 years | 33 | 53.65 | 1.51 | 0.68 |
| | 7-15 years | 45 | 55.32 | | |
| | 16-29 years | 17 | 61.50 | | |
| | > 30 years | 18 | 63.08 | | |
| Alternative Navigation Means | < 7 years | 33 | 52.61 | 2.09 | 0.55 |
| | 7-15 years | 45 | 55.46 | | |
| | 16-29 years | 17 | 65.18 | | |
| | > 30 years | 18 | 61.19 | | |
| Regional & International Cooperation | < 7 years | 33 | 59.14 | 0.89 | 0.83 |
| | 7-15 years | 45 | 53.92 | | |
| | 16-29 years | 17 | 56.85 | | |
| | > 30 years | 18 | 60.92 | | |

Figure (15) shows that differences in responses according to years of experience are insignificant at the level of significance (0.05).

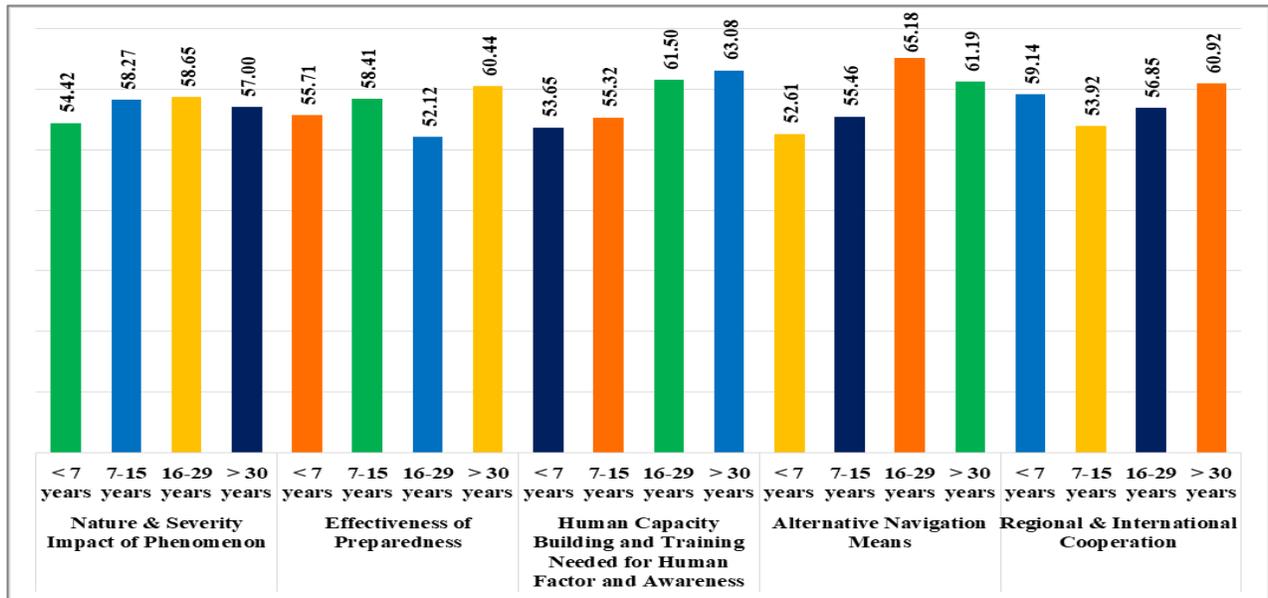


Figure (15) Results of responses according to years of experience

5.3 TEST THE STUDY'S HYPOTHESES

5.3.1 Nature & Severity Impact of Phenomenon

For Sub-Hypothesis 1: would A geomagnetic reversal would be a significant disruption.

The results in table (see table 9) shows Chi-Square test results show that differences in responses about all items of Nature & Severity Impact of Phenomenon are significant at the level of significance (0.01), Which can be interpreted as strongly agreed & accepted with the study point of view also This suggests that these factors are influencing perceptions and beliefs about the phenomenon; also achieved the research objectives “Investigate the nature and severity of geomagnetic reversals and their potential impacts on the maritime navigation.” & “Analyze the vulnerabilities of existing maritime navigation systems and techniques to geomagnetic reversals”.

Table (9) shown Results for Nature & Severity Impact of Phenomenon (n =113)

| Item | Chi-square |
|---|------------|
| A geomagnetic reversal would completely disable most of ship navigation systems | 39.53** |
| Positioning and communication systems through satellites would experience significant disruptions during a reversal | 82.27** |
| Current Modern marine navigation systems would experience significant disruptions during a reversal | 63.18** |
| Geomagnetic storms can lead to disturbance in electric power | 51.28** |

| Item | Chi-square |
|---|----------------|
| Geomagnetic polarity reversals have a significant impact on Earth's climate | 59.78** |
| The maritime industry would experience significant economic losses due to navigation disruptions | 62.61** |

(** refer to sig at 0.01)

5.3.2 Effectiveness of preparedness

For Sub-Hypothesis 2: can Maritime navigation necessitates effective preparedness significantly reduce these disruptions.

The results in table (see table 10) shows Chi-Square test results show that differences in responses about all items of Effectiveness of Preparedness are significant at the level of significance (0.01), Which can be interpreted as accepted; also achieved the research objective “Evaluate the effectiveness of various preparedness strategies for mitigating the negative consequences of geomagnetic reversals on maritime navigation.”

Table (10) Shown Results for Effectiveness of Preparedness (n =113)

| Item | Chi-square |
|--|----------------|
| 1) Effective preparedness actions can significantly reduce the disruptions caused by a geomagnetic reversal on maritime navigation | 82.53** |
| 2) The current level of preparedness in the maritime industry is sufficient to handle the challenges of a geomagnetic reversal | 15.01** |
| 3) A deeper understanding of Earth's core dynamics, achieved through advanced study of fluid motion and the underlying physical processes, | 75.54** |
| 4) I am confident that current ship navigation systems can be adapted through modifications, or the adoption of newly methods to function effectively during a geomagnetic reversal | 79.35** |

(** refer to sig at 0.01)

5.3.3 Human capacity building

For Sub-Hypothesis 3: will investing in human capacity building comprehensive programs and familiarization of the nature of phenomena reduce the negative impact of the reversal on maritime industry.

The results in table (see table 11) shows Chi-Square test results show that differences in responses about all items of Human Capacity Building and Training Needed for Human Factor and Awareness are significant at the level of significance (0.01), Which can be interpreted as strong good sample respondents agreed with the study; also achieved the research objective “To Evaluate the effectiveness of various preparedness strategies for mitigating the negative consequences of geomagnetic reversals on maritime navigation”.

Table (11) Shown Results for Human Capacity Building and Training Needed for Human Factor and Awareness (n =113)

| Item | Chi-square |
|--|------------|
| • Investing in comprehensive human capacity building programs focused on geomagnetism, alternative navigation, and mitigation strategies is essential for managing the negative impact of reversals on the maritime industry | 112.97** |
| • Extensive training on the nature of geomagnetic reversals and alternative navigation methods is crucial for mariners | 114.57** |
| • In your opinion, is understanding of geomagnetic reversals and their potential impact for mariners is essential to navigate safely during such events | 34.32** |
| • I believe mariners need to be familiar with methods to mitigate the impact of geomagnetic reversals on positioning systems | 68.06** |
| • Regular drills and training sessions on navigating during geomagnetic polarity reversals are essential for strengthens maritime capacity | 80.38** |

(** refer to sig at 0.01)

5.3.4 Alternative navigation means & new technologies

For Sub-Hypothesis 4: Is the potential of alternative navigation systems ensure safe and reliable ship navigation during geomagnetic reversals.

The results in table (see table 12) shows Chi-Square test results show that differences in responses about all items of Alternative Navigation Means are significant at the level of significance (0.01), Which can be interpreted as accepted; also achieved the research objective “To Evaluate the effectiveness of various preparedness strategies for mitigating the negative consequences of geomagnetic reversals on maritime navigation”.

Table (12) Shown Results for Alternative Navigation Means (n =113)

| Item | Chi-square |
|--|------------|
| 1. Existing and emerging alternative navigation systems have the potential to ensure safe and reliable ship navigation during a geomagnetic reversal | 68.19** |
| 2. Alternative navigation systems are unlikely to be effective substitutes for current GNSS systems during a reversal | 56.42** |
| 3. Traditional navigation techniques, such as celestial navigation, are not affected by geomagnetic reversals | 90.05** |

| Item | Chi-square |
|---|-----------------|
| 4. The integration of advanced celestial navigation in modern techniques and automated data analysis systems would significantly improve the effectiveness of celestial navigation during a geomagnetic reversal | 95.10** |
| 5. do you believe that prioritizing the development and improvement of alternative navigation systems is essential for ensuring the continued viability of safe maritime navigation during a geomagnetic reversal polarity | 104.65** |

(** refer to sig at 0.01)

5.3.5 Regional & international cooperation

For Sub-Hypothesis 5: Is Encouraging global cooperation on research, data sharing, and standardized protocols complex due to varying political priorities and resource distribution; in addition of adaption of strong legal frame work.

The results in table (see table 13) shows Chi-Square test results show that differences in responses about all items of Regional & International Cooperation are significant at the level of significance (0.01), Which can be interpreted as strongly accepted; also achieved the research objective “To Evaluate the effectiveness of various preparedness strategies for mitigating the negative consequences of geomagnetic reversals on maritime navigation”

Table (13) Shown Results for Regional & International Cooperation (n =113)

| Item | Chi-square |
|---|-----------------|
| 1. Encouraging global cooperation on research, data sharing, and standardized protocols for navigation during geomagnetic reversals is essential for effective preparedness | 140.85** |
| 2. The availability of regular, up-to-date information technology regarding navigation challenges during a geomagnetic reversal would be helpful for ensuring safe maritime operations | 118.02** |
| 3. In your opinion, would a strong international legal framework and treaties; specifically addressing geomagnetic reversals and their impact on navigation, would encourages safety of navigation during this event | 83.28** |

(** refer to sig at 0.01)

5.4 The Findings Determined Several Key Points

- **Limited Awareness:** A significant portion of the maritime industry demonstrates limited awareness of the potential risks and implications of geomagnetic reversals.
- **Inadequate Preparedness:** The current level of preparedness within the industry is insufficient to effectively address the challenges posed by geomagnetic disruptions.

- **Critical Role of Human Capacity Building:** Investing in training and education is crucial for equipping maritime professionals with the skills needed to navigate during these events. There is strong support for comprehensive training programs covering geomagnetism, alternative navigation, and mitigation strategies.
- **Potential of Alternative Navigation Systems:** While current navigation systems are considered vulnerable, participants believe that alternative technologies, particularly those integrating advanced celestial navigation with modern systems, offer potential mitigation strategies. Further development and refinement of these alternatives are deemed essential.
- **Importance of International Cooperation:** Collaborative efforts between nations, including research sharing, standardized protocols, and legal frameworks, are considered crucial for a coordinated and effective response to geomagnetic reversals.

6- Conclusion

This paper explored the complex relationship between Earth's dynamic magnetic field and maritime safety of navigation, examining the potential impacts of the expected geomagnetic reversals and the necessary preparedness measures. The paper discussed the foundational understanding of the Earth's magnetic field, its dynamic nature, and the phenomenon of geomagnetic reversals, including their potential consequences for technological systems, particularly in maritime navigation. Also, it focused on the practical implications for navigation, examining how geomagnetic phenomena can disrupt compasses, electronic navigation systems, and modern maritime practices.

The research findings underscore that while the possibility of a geomagnetic reversal is a long-term prospect, the dynamic nature of the Earth's magnetic field necessitates proactive preparation. Ensuring the resilience of navigation systems in the face of a potentially weakened or reversed magnetic field requires a multifaceted approach encompassing technological advancements, human preparedness, and international collaboration.

The paper recommended several potential solutions for emergency backup navigation, including inertial navigation systems, star trackers, handheld celestial navigation systems, and celestial navigation plugins for ECDIS. These options warrant further exploration and development to ensure their effectiveness and practicality in a geomagnetic reversal scenario.

While the weakening of the Earth's magnetic field is a concern, it is important to emphasize that a full reversal is a process that could take decades or more. The effects are likely to be gradual, allowing time for adaptation and implementation of the strategies. Therefore, understanding the potential impact of geomagnetic reversals is not a cause for alarm but a call for proactive preparation. By embracing technological advancements, fostering skilled navigators, and establishing robust international collaboration, the maritime industry can ensure continued safe and efficient navigation, even during periods of geomagnetic instability.

6.1 Recommendations

1. Prioritizing Navigation Systems “Develop and test navigation systems with minimal reliance on the magnetic field”
2. Improve magnetometer technology for enhanced accuracy during weakened fields
3. Advance Inertial Navigation System (INS) technology
4. Develop user-friendly celestial navigation tools and apps
5. Enhance collaboration with space weather forecasting
6. Encouraging human capacity building
7. Address Public Awareness
8. Promote International Collaboration

References

- ANGEO-2022 National Oceanic and Atmospheric Administration (NOAA). (2022). Geomagnetic Storms. <https://www.swpc.noaa.gov/> (SEPT. 2022)
- British Geological Survey (BGS) (2023) Earth's magnetosphere. Available from: <https://www.bgs.ac.uk/map-viewers/geology-of-britain-viewer/>
- Borre, K., Došlý, O., Rohde, P., & McEvoy, T. (2014). *A global navigation satellite systems (GNSS) performance analysis*. Journal of Applied Geodesy, 8(3-4), 137-152.
- Chullikov, V. V., & Parkhomov, V. M. (2002) Disruptions to Magnetic Compasses
- Clement, B.M. (2010) 'The duration of the last geomagnetic reversal', Nature Geoscience, 3(6), pp. 436-440.
- Coe, R.S. and Prévot, M.J. (1989) 'Evidence suggesting extremely rapid field variation during a geomagnetic reversal', Earth and Planetary Science Letters, 92(3-4), pp. 292-298.
- Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.)
- Feehly, C. (2024) Why do Earth's magnetic poles flip? Available from: <https://www.space.com/space-mysteries-why-do-earths-magnetic-poles-flip> (JAN. 2024)
- Field, A. (2009). Discovering Statistics Using SPSS (3rd Ed). SAGE, p.675
- International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). (n.d.). Retrieved June 30, 2024, from <https://www.iala-aism.org/>
- International Maritime Organization (IMO) (2019). International Maritime Organization website. (<https://www.imo.org/>)
- International Maritime Organization (IMO). (2019). *Polar Code*. London: IMO

- Love J.J., National Research Council, 2000, How people learn: Brain, mind, experience, and school. Washington, DC: National Academies Press.
- Maus, S., Rother, M., Hemming, K., Macdonald, A., Haley, A. D., Baker, J., ... & Knudsen, P. (2010). *First magnetic anomaly map from the ESA Swarm mission*. Geophysical Research Letters, 37(7). <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2001GL013685> (JUL. 2024)
- NOAA National Geophysical Data Center (n.d.) Geomagnetic Data. Available from: <https://www.nci.noaa.gov/products/geomagnetic-data> (May. 2024)
- NASA Space Weather events, 2019. <https://spaceweather.com/archive.php?View=1&day=30&month=08&year=2019>
- Pulkkinen, A., Viljanen, A., Nottmäki, H., & Nevanlinna, H. (2012). Geomagnetic reversals and their impact on life on Earth. *Annales Geophysicae*, 30(11), 1851-1859. <https://www.nature.com/articles/nature02459> (APR. 2024).
- Radcliffe, J. A., Claudepierre, S. G., & Knipp, D. J. (2006). "Geomagnetic storms and their impact on spacecraft operation". *Journal of Atmospheric and Solar-Terrestrial Physics*, 68(16-17), 1903-1912. (FEB.2024)
- Rijnbeek, R., et al. (1982) 'Observations of reverse polarity flux transfer events at the Earth's dayside magnetopause', *Nature*, 300(5887), pp. 23-26.
- Rogers, D., Moe, A. K., & Pullen, S. (2017). *An introduction to GNSS for marine applications*
- Sinha, S., & Uyeda, H. (2017) Geomagnetic Reversal and Atmospheric Effects
- Takahashi, F., Matsushima, M. and Honkura, Y. (2007) 'A numerical study on magnetic polarity transition in an MHD dynamo model', *Earth, Planets and Space*, 59, pp. 665-673.
- University of California - Los Angeles (UCLA) (n.d.) The Earth's Magnetic Field. Available from: (<https://newsroom.ucla.edu/file?fid=57ea803e2cfac20a6401a36d>) (JUL. 2023) .
- U.S. Geological Survey. (n.d.). It is true that Earth's magnetic field occasionally reverses its polarity? Retrieved from <https://www.usgs.gov/faqs/it-true-earths-magnetic-field-occasionally-reverses-its-polarity>
- Vernov, S. N., Grigoryan, L. S., & Shafer, Y. G. (1967). *Cosmic ray intensity variations in the South Atlantic anomaly*. *Planetary and Space Science*, 15(10),1243-1248. (<https://www.sciencedirect.com/science/article/pii/S0009279798000738>) (DEC. 2023).
- Wardinski, I. and Thébault, E. (2019) Modelling internal and external geomagnetic fields using satellite data. In: *Special Publications of the International Union of Geodesy and Geophysics*. Cambridge University Press, Cambridge. DOI: 10.1017/9781108290135.