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REVIEW

Roles of Geospatial Technologies in Hydrographic Practice

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ABSTRACT

Any seafarer or mariner that uses the sea knows that navigation without correct charts is impossible and hazardous because nautical charts are the most essential and indispensable tools for vessels to sail safely at sea. For vessels to safely sail at sea, the seas and the oceans ought to be charted and this falls within the domain of hydrography. However, the seas cannot be charted effectively in the absence of the deployment of human resources and adequate tools like satellite and aerial imagery, survey boats and other equipment that will facilitate the hydrographic operations. The acquisition of data and information about the sea depths, nature of sea bed, waterways, navigational hazards and navigational objects among others, basically falls within the sphere of hydrography which is primarily known as survey at sea. The paper offers a review of geospatial technologies in hydrographic practice for enhanced safety of navigation at sea. The review is important to both the mariners, shipping industry and the government in order to explore the potentials provided by Geographic Information System, Remote Sensing, cloud GIS, big data GIS and Global Positioning System to enhance the practice of hydrography. The data and materials used for the review were obtained from literature in the internet and other published works. The paper looked at hydrography as a profession, roles of geospatial technologies in hydrographic practice, benefits of hydrography to national development and finally, the weaknesses of geospatial technologies in hydrographic practice were equally examined.

1. Introduction

The oceans and the seas are gifts of nature which man can explore for his own advantage. Over 90 percent of the world's trade is conducted through the sea [1]. The maritime sector of any economy develops the capacity to bring about lasting development as different business opportunities abound in dredging and other aspects relating to maritime transportation among others [2]. For this to happen, mariners need to know the safest route to navigate their vessels, ships/crafts in order to arrive at their respective destinations safely without causing any form of structural damage to their vessels or grounding. The safe

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navigation of ships from one point to another across the seas/oceans falls with the domain of hydrography which is solely responsible for the production of charts and other nautical publications for safe navigation.

Hydrography is an applied discipline that deals with the systematic observations of the sea and all its characteristics as it affects the safe navigation of ships from one point to another. Hydrography also deals with the taking of measurement of various features of the water bodies. The profession gathers different types of information relating to the depth and height of the sea as well as tide and tidal information among others. This applied profession is the master key that is used for proper management of the seas and waterways.

Hydrography according to the International Hydrographic Organization (IHO) "is a part of the discipline of applied science that relates with the taking of relevant measurements at sea and description of various features of the water bodies for the sole aim of navigation and all other marine purposes and activities, including – inter alia- offshore activities, research, protection of the environment, and prediction services" [3]. Hydrography encompasses different activities such as measurement and exploration of various features of water bodies [4]. For the safe navigation of ships and vessels or crafts at sea, mariners need to know which aspect of the sea is deep, shallow, safe and navigable in order to enable their vessels safely arrive at their respective destinations. This is where hydrography comes in. The hydrographer who is a specialist in the field of hydrography, vast in maritime-related affairs has several options as well as methods at his disposal to ensure that the information he provides to the mariners are correct and accurate for safe navigation [4].

Among the several options and methods opened to the hydrographer is the use of geospatial technologies. Geospatial technologies involve the use of Remote Sensing (RS), cloud GIS, Global Positioning System (GPS) and Geographic Information System (GIS) to collect, collate, integrate, store, manage and manipulate geographic data in order to solve geographic problems. This review is aimed at exploring the potentials of geospatial technologies in hydrographic practice for enhanced safety of vessels at sea.

2. Materials and Methods

The materials used for this review were obtained from works of various scholars in the internet and documents of both local and international hydrographic and maritime organizations and agencies. The paper adopted descriptive methodology in this work for better analysis.

3. Literature Review

3.1 Hydrography as a Profession

Hydrographic data are generally in large demand across the globe for protection, preservation and management of the marine environment [5]. Hydrography is an applied science which is basically associated with the study of the bodies of water (including surface and subsurface) and all the varying characteristics primarily aimed at ensuring the safe navigation of ships, vessels or crafts from one point to another across the seas, rivers and oceans.

All hydrographic practices are regulated across the world by the International Hydrographic Organization (IHO). The IHO was formed in 1921 and has 93 Member States. It primarily supports the coordination and setting of hydrographic ethics and creates global awareness on the usefulness of hydrography. To achieve this, 21 of June of every year has been declared by IHO to mark world hydrography day.

Hydrography is basically associated with the production of charts and other nautical publications for safe navigation. Generally, ultimate accuracy is required in the production of nautical charts [6]. The field of hydrography cut across several disciplines like physics, cartography, geodesy, geomatics, software development, mathematics, geography, surveying, data management, remote sensing, engineering, technological designs, electronics and computer applications among others [7,8].

Through hydrography, a number of nautical publications are produced to aid the mariners for safe navigation of their vessels at sea. The hydrographer performs several tasks to ensure that vessels and ships at sea navigate safely to their respective destinations. The hydrographer conducts a detail measurement and description measures of water bodies such as rivers, lakes and oceans among others. All these tasks must be conducted in a methodical, systematic and orderly manner because any data that is correctly collected will not be useful if it is not processed diligently and logically [4].

Hydrographic data are a useful asset for any activity at sea and in coastal areas. In the context of marine GIS, hydrographic data no doubt become a primary data source [9]. The hydrographic data are collected by using various state of the art gadgets. These instruments enable the hydrographer to effectively conduct his activities both at sea and on land, as some of the instruments are integrated and mounted on sea and air platforms. Some of the equipment include sounding poles, Side scan sonar, echo sounder, GPS, Survey Vessels / Survey Boats, and Software tools like Hydro CAD, HYPACK, ArcGIS among others [4]. Figures 1, 2 and 3 respectively

show some of the various hydrographic equipment and a hydrographic survey boat used at sea.

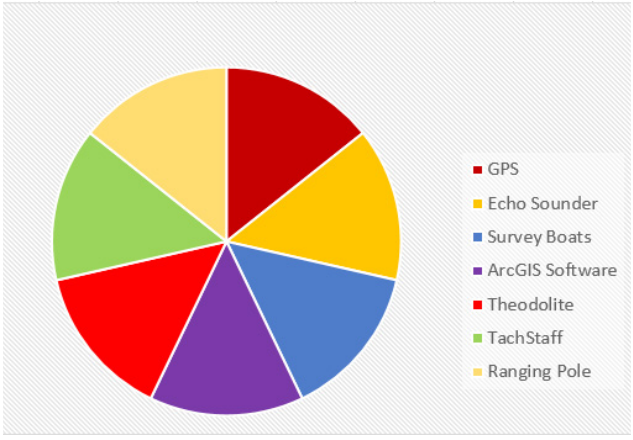

Figure 1. Some Types of Hydrographic Equipment

Source: Authors' analysis (2021)

Figure 2. A Hydrographic Survey Boat

Source: Adapted from IHO Publication M-2 (2018)

Figure 3. A Hydrographic Survey Ships and Boats

Source: Adapted from Iptes (2014)

At the international level, the IHO accredits and recognizes some institutions that offer hydrographic education to both individuals and corporate organizations. Some of the IHO recognized hydrographic institutions include RAN Hydrographic School, Balmoral Australia, Royal Naval Hydrographic School, Plymouth UK and National Institute of Hydrography GOA, India, among others.

The training programme in hydrography are generally classified into different categories. These standards are promulgated in IHO Publication S-5 [10] and S-8 [11]. These categories define the level of competence and by extension the qualifications and the expectations required from the individual in the course of his/her hydrographic training. Thus, there are category A programmes, category B programmes and unclassified programmes and the scheme system [10,4].

The programmes in Category A provides the fundamentals. The programmes in "A" Category provides a detail knowledge in all aspects of the discipline for persons who will practice analytical reasoning and decision making. The programmes in Category "B" introduces subjects from the perspective of a practical level. Category "B" programme which is a subset of category A, provides the opportunity for learners to have a full grasp of the practical aspect of the profession. Learners who have training in Category A or B may be seen as fit and competent to be certified as Hydrographers [10,4,12]. The IHO clearly defined four orders of surveys to be conducted at sea. These are: Special Order, Order 1, Order 2 and Order 3 [11]. Table 1 shows the orders of hydrographic surveys.

It is however, instructive to note that hydrography is a dynamic profession and changes from time to time due to ocean dynamics and changes, hence the above hydrographic survey orders were however modified from four to five [13] Edition 6.0 published in 2020. The five hydrographic surveys orders include: Exclusive Order, Special Order, Order 1a, Order 1b and Order 2. The general characteristics of the five orders are holistically examined in the succeeding paragraphs.

Exclusive Order: The Exclusive Order of hydrographic surveys is an elongation of IHO Special Order. This order has more rigorous uncertainty and data reporting requirements than the order sets of hydrographic survey orders. The exclusive order is planned to be limited to shallow water areas such as harbours, berthing areas and critical areas of fairways and channels where there is an exceptional and optimal use of the water column and where specific critical areas with minimum underkeel clearance and bottom characteristics are possibly hazardous to vessels. For this order, a 200% feature examination and a 200% bathymetric

coverage are mandatory. The size of features to be spotted is deliberately more tedious, strenuous and challenging than for Special Order.

Table 1. Orders of Hydrographic Surveys

ORDER	Special Order	Order 1	Order 2	Order 3
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth
Depth Accuracy for Reduced Depths (95% Confidence Level)	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023	Same as Order 2
100% Bottom Search	Compulsory	Required in selected areas	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m	Same as Order 1	Not applicable
Maximum Line Spacing	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is greater	3-4 x average depth or 200 m, whichever is greater	4 x average depth

Source: Adapted from IHO Standards for Hydrographic Surveys, Publication S-44, 5th Edition 2008

Special Order: The Special order is envisioned for those areas where underkeel clearance is life-threatening. The precise areas that is essential for this kind of order include: berthing areas, harbours, and critical areas of fairways and shipping channels. In this order of survey, a 100% feature exploration and 100% bathymetric coverage are compulsory and the size of the features to be sensed by this search is intentionally more difficult than for Order 1a.

Order 1a: The Order 1a survey is projected for areas where features on the bottom may become a source of apprehension for the type of surface traffic anticipated to move across the area but where the underkeel clearance is seen not to be critical. Instances of areas that may need Order 1a surveys are coastal waters, harbours, berthing areas, fairways and channels. In this type of survey order the search for underwater features is 100% so as to effectively find features of a stated size. Also, bathymetric coverage less than or equal to 100% is suitable as long as the least depths over all significant features are found. The bathymetry offers acceptable representation of the kind of the bottom landscape. Underkeel clearance becomes less critical as depth increases, so the size of the feature to be spotted increases with depth in zones where the water depth is greater than 40 metres.

Order 1b: The Order 1b is envisioned for places where the kind of surface vessels projected to move across the area is such that an overall representation of the bottom is seen to be suitable. 5% bathymetric coverage is essential as the minimum for the survey area. This implies that some underwater features will not be noticed, however the distance between places of bathymetric coverage will limit the size of those features. This order of survey is only suggested where underkeel clearance is seen not to be an issue. An instance of this would be an area where the bottom characteristics are such that the probability of there being a feature on the bottom that will jeopardize the type of surface vessel anticipated to circumnavigate the area is low.

Order 2: The Order 2 hydrographic survey is considered to be the smallest strict order and is proposed for places where the depth of water is such that an overall representation of the bottom is seen as appropriate. In this order, 5% minimum bathymetric coverage is mandatory for the survey area. It is suggested that Order 2 surveys are carryout in areas which are deeper than 200 metres. Once the water depth surpasses 200 metres, the presence of features that are big enough to influence surface navigation and yet still remain unnoticed by an Order 2 survey is seen to be doubtful.

3.2 Some Donor Agencies that Fund Hydrographic Projects

There are some international organizations and agencies that fund and support hydrographic projects around the world. Some funding for hydrographic projects can be obtained from these agencies as shown in Figure 4.

Figure 4. Some Donor Agencies for Hydrographic Projects

Source: Authors' analysis (2021)

3.3 Roles of Geospatial Technologies in Hydrographic Practice

Modern hydrographic practices have incorporated geospatial technologies in ensuring the production of accurate and reliable products. Geospatial technologies involve the use of GIS, RS, cloud GIS, big data GIS and GPS to collect, manage, integrate, store and manipulate geographically referenced data in order to provide solutions to geographic problems. [14] posited that there are some recent means to carryout mapping of coastline aerial and high-resolution satellite imagery and ground-based surveying. Just like what is obtainable in other professions, geospatial technologies serve as the pillar of hydrography. GIS is a tool and a container of maps stored in a digital format which can be used to solve geographic problems for the benefit of mankind [15]. The technology includes people, data, hardware, software and procedure(method) as components. See Figure 5.

It is imperative to note that without georeferencing or positioning, any hydrographic data will be incomplete. For the purposes of safe navigation of vessels, ships and crafts at sea, both the oceans, seas ought to be charted properly at all time. For this to be achieved, the use of satellite and aerial imagery need to be considered and this is the main domain and focus of remote sensing. Remote sensing is the scientific technique that deals with the collection of data without having any form of physical contact with the acquired data. This can be done through aircraft, satellites and drones. It is the acquisition of information relating to an object under investigation with instruments used in the acquisition of the data having no physical and direct contact with the phenomena under investigation [16]. Remote sensing uses a part or several parts of the electromagnetic spectrum during the acquisition of data from the earth and provides the medium to observe from the space, the activities of human beings [17]. Through this method, data relating to hydrography can also be acquired, investigated, analyzed and interpreted to solve geographic problems.

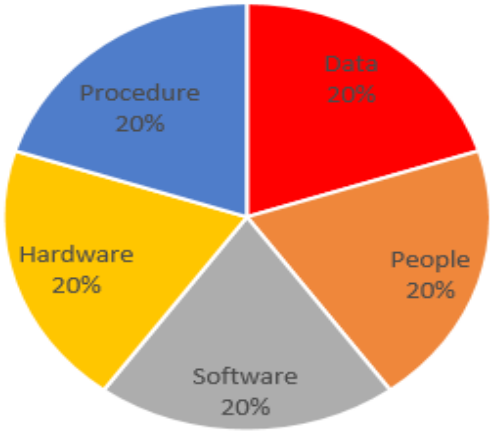

Figure 5. Components of GIS

Source: Authors' analysis (2021)

Difficult areas that are inaccessible at sea can be reached through remote sensing with the aid of aircraft and drones. The effective mapping of the oceans and the seas is necessary because, they form the resource base upon which the extraction of resources, food, medicines, transport and infrastructure rest upon [8]. In today's world, digital charts used for navigation have gradually replaced traditional nautical charts, as mariners are spared with the burden of conveying huge volume of paper charts. GIS as a modern geospatial technology has the capability of manipulating and overlaying large volume of data. With GIS, thematic layers and maps can be created and generate specific models. With GPS, coordinate points of hydrographic features of interest can be collected, stored and retrieved. The retrieved information can be interpolated and presented in a Microsoft Excel format that will later be transferred into an ArcGIS environment for further analysis, interpretation and production of various charts and maps/graphs that will aid safe navigation of vessels/ships at sea.

Geospatial technologies are very important in the collection and gathering of data and validation. One notable area of geospatial technologies in hydrographic practice is in the area of the application of Satellite Derived Bathymetry to conduct hydrographic surveys. Despite its short comings in acquiring accurate data in respect of meeting the standards required by IHO S-44 standards, the satellite derived bathymetry can still be another valuable means to carry out the planning of

surveys at sea [18]. Both cloud GIS and big data GIS are useful for spatial and analytical modelling. Satellite imagery, aerial imagery, LiDAR, GPS and drones/ unmanned aerial vehicles among others are master technologies that can actively and effectively play a crucial role in hydrographic practice [8].

3.4 Benefits of Hydrography in National Development

The development of any nation encompasses all sphere of human endeavour as the maritime sector of any nation's economy performs a critical role in the growth and advancement of most societies. For this to be achieved, vessels and ships need to move safely from one point to another without endangering the life of the crew or caused structural damage to the vessel/ships at sea or harbour. This is where hydrography comes in as the production of maritime charts is a classical illustration of a community service which is one of the known hydrographic products [19].

With hydrography, nautical charts are produced, maritime safety information and digital data are made available to the shipping industry to support and promote the needs of our maritime world. Hydrography determines the depth of the seabed, examines the various characteristics of the seabed, water, current and dangers/obstruction to safe navigation. A rich source of data for making decisions about a nation's territorial waters can be provided through the aid of hydrographic survey and remote sensing of the marine environment. Hydrography plays an important role in both maritime and coastal development of any nation [20]. The total economic and commercial benefits of hydrography are not easy to measure. Numerous studies conducted on the benefits of hydrography have estimated that the return-on-investment for coastal nations to have, maintain, develop and provide hydrographic services is on the ratio of 1:10 due to the contribution of hydrography towards the development of blue economy (IHO, 2004; cited in [19]). This ought to be a morale booster for coastal nations to develop their hydrographic offices in order to boost their national income. Both the government and private sector require hydrographic data. Hydrography supports every activity that is connected and linked with the sea, including safety of navigation, economic development, defence, port construction and environmental protection among others [21]. See Figure 6.

The science of hydrography and oceanography help both mariners including members of the armed forces to safely navigate their vessels to their various destinations by uninterruptedly monitoring courses and steering areas as well as charting the water depth, the shape of the coastline, and potential navigational threats provided by underwater features. It is also critical in managing all key actors involved in both fishing and maritime sectors, coastal zone management, port construction and dredging among other [22]. The collection and recording

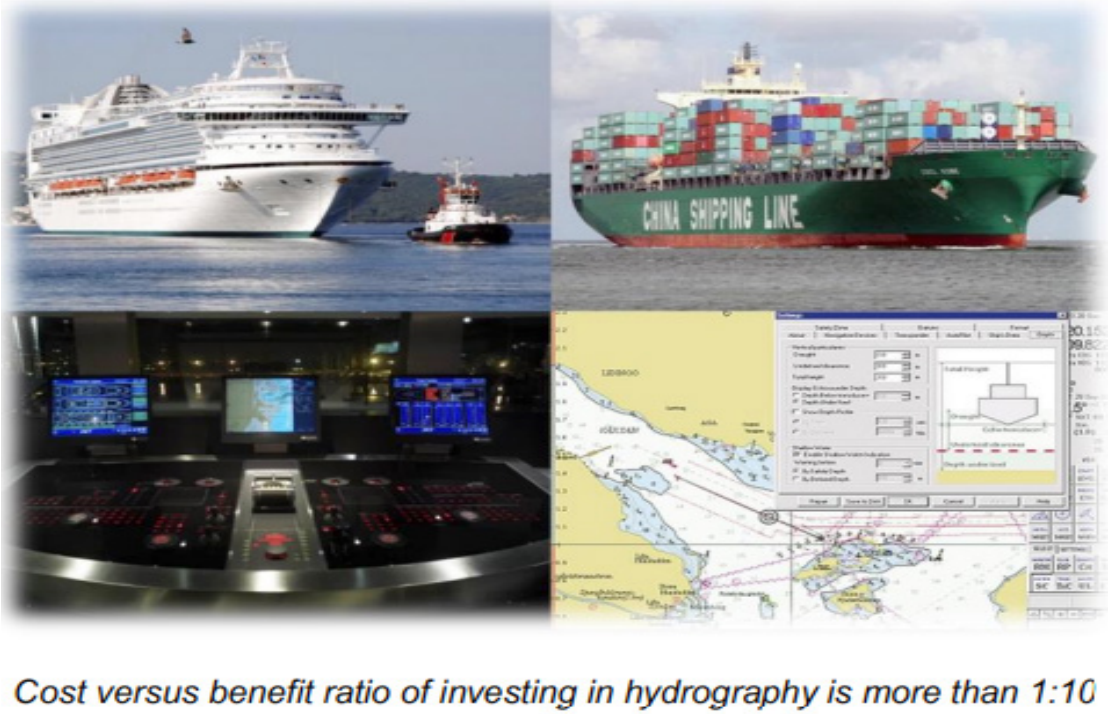

Figure 6. Cost Vs Benefits Ratio of Hydrography

Source: Adapted from IHO Publication M-2, (2018)

of data to support maritime operations and trade is not a novel concept. It all began with the need for seafarers to understand how to navigate rivers and oceans safely and efficiently by understanding hazards, where they are located, and safe passages around them. Competing exploring and trading nations were sometimes denied access to vital hydrographic and charting information for economic, military, and territorial gain. This attitude changed in recent years with the establishment of national hydrographic offices around the world [23].

It is imperative to note that every activities of human that take place on the planet earth, or under the sea need a fair knowledge of the hydrography of that environment, which comprises of the nature of the seafloor, and hazards to navigation. This is because, without hydrography, vessels cannot sail effectively, construction of sea ports will be impossible, and the development of coastal infrastructures will be difficult and there will be no delimitation and enforcement of maritime boundary. The safe and efficient navigation of vessels at sea, engendering of national maritime development, safeguarding life and property at sea, supporting the protection of the marine environment and aiding the management and sustainable development of the national maritime zones are some of the areas Hydrography plays a dominant role. Hydrography is also useful to national security and maritime defense [24]. The expansion of global trade has been enhanced through hydrography in recent years. Furthermore, many coastal state governments are oblivious of the significant contribution that hydrography and nautical charting services can render to their country 's economic growth [24]. Additionally, hydrography is critical in the collection of bathymetric data in the field of marine science. Bathymetry from national hydrographic services is used in local and regional models for different scientific studies such as, positioning and placement of scientific equipment and other aspects of marine science [24].

Maritime accidents are prevented through hydrographic data in different ways. First, it identifies navigational hazards and allows ships to safely avoid them. Second, they help to reduce human error in navigation, which is currently one of the leading causes of shipwrecks, by "providing data for electronic navigation (in which ships' positions from satellite are continuously displayed with chart information [25]. [26] opined that hydrography supports the blue economy. To him, the blue economy, which generates jobs and wealth for the World We Want, is built on Hydrography. He further defines hydrography as the production of nautical charts and publications, as well as the sharing of Maritime Safety Information (MSI). The IHO considered MSI as the first phase in hydrographic capacity building [27]. This MSI contains all information relating to the safety of navigation of vessels at sea, including notices to mariners, navigational warnings, and information about the seafloor that may pose a danger to vessels. Thus, one of the primary responsibilities of hydrography is the complete search of the seafloor using side scan sonar. Figure 7 depicts a side scan sonar used to detect and image objects on the seafloor.

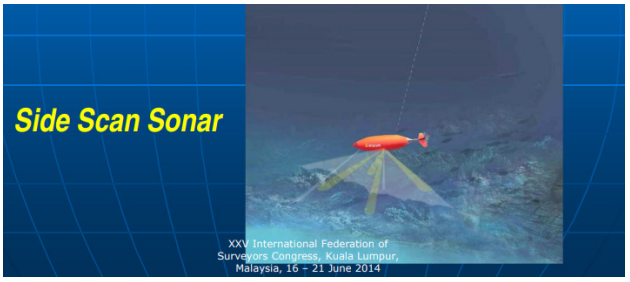

Figure 7. A Side Scan Sonar for Detecting and Imaging Objects on the Seafloor

Source: Adapted from Iptes (2014)

Hydrographic survey helps in the control and planning of engineering projects like bridges, dams and reservoirs among others. Other useful aspects of hydrography to national development are succinctly discussed in the succeeding paragraphs:

3.4.1 Maritime Transport/Navigation

The chief cornerstone and mainstay of global trade are maritime transportation. A major obstacle militating against the progress of most countries' economy, especially coastal states is the lack of a well maintained and adequate port facilities. For safe navigation of ships/vessels/crafts at sea, the mariner needs navigational or nautical charts for direction. Nautical charts show the depth of the sea and associated dangers. This is where the profession carries out a dominant work in producing nautical charts, sailing direction, tide tables and other relevant nautical publications. Over 90 percent of the world's trade is conducted through the sea [1]. One of the major elements to consider for a nation's economy is maritime commerce.

3.4.2 Maritime Defence and Security

Maritime defence and national security are becoming a major aspect of national defence policy of most nations across the world. The role of the navies/coast guards of nations is gradually expanding on daily basis as the navies/coast guards need critical information about the territorial waters for safe navigation of their ships/vessels and amphibious crafts/boats. For successful amphibious

assaults to be conducted by the navy/coastguards against all sorts of maritime criminals, the navy needs vital hydrographic information relating to the depth of the assaulted area, and an in-depth knowledge of tidal information in planning for marine based operations [28].

The navies/coast guards are major users of nautical charts produced by hydrographic offices around the world. The navies/coast guards must be ready at all time for deployment of both human and material resources to different parts of the world either for peace keeping or assault operations, hence they need to maintain a sizable number of charts. The maritime data and information provided by hydrography, aid a variety of products used in naval warfare [3].

3.4.3 Coastal Zone Management

Coastal nations need the effective management of their coastal areas; hence, the government needs the input of hydrography. Relevant hydrographic information is needed for effective coastal management. Bathymetric charts and nautical charts among others are very necessary for an effective and efficient coastal zone management including flood control and erosion management [4].

3.4.4 Maritime Boundary Delimitation and Delineation

Hydrography also plays a dominant role in maritime boundary delimitation and delineation of territorial sea baseline around the world. Maritime boundaries require technical skills and are necessary for good international relations among countries [28]. Nautical charts and other products associated with hydrography are useful for different activities, including delineation and demarcation of boundaries. Charts are important in the graphical representation of maritime zones [29], and this is where hydrography comes into play as the production of nautical charts falls within the domain of hydrography.

3.4.5 National Marine Spatial Data Infrastructures

Spatial Data Infrastructures (SDI) provides the basis for arranging geographic data, metadata, tools and users with clear set out guidelines and rules, relationships and standards. Marine SDI is not meant to be disconnected from other SDIs but plays a complementary role in the coastal zone and oceans [9]. Many nations around the world establish national spatial data infrastructures because they believed that good quality spatial data are key to economic growth and prosperity. SDI integrate various data sets such as bathymetry, topography and geodesy among others of major national spatial data providers thereby enhancing nations' national and economic development [3,4]. For effective national marine spatial data infrastructures, hydrographic data are necessary. Within the context of a marine spatial data infrastructure for wider use, hydrographic data acts as the basis for building a maritime data management system [9]. Figure 8 shows the summary of the benefits of hydrography as a profession.

There are various stakeholder ministries that collaborate with the development of hydrography across the world according to [24]. These stakeholders are very important to hydrographic practice. See Figure 9 for the different stakeholders that contribute to the growth, advancement and development of hydrography around the world.

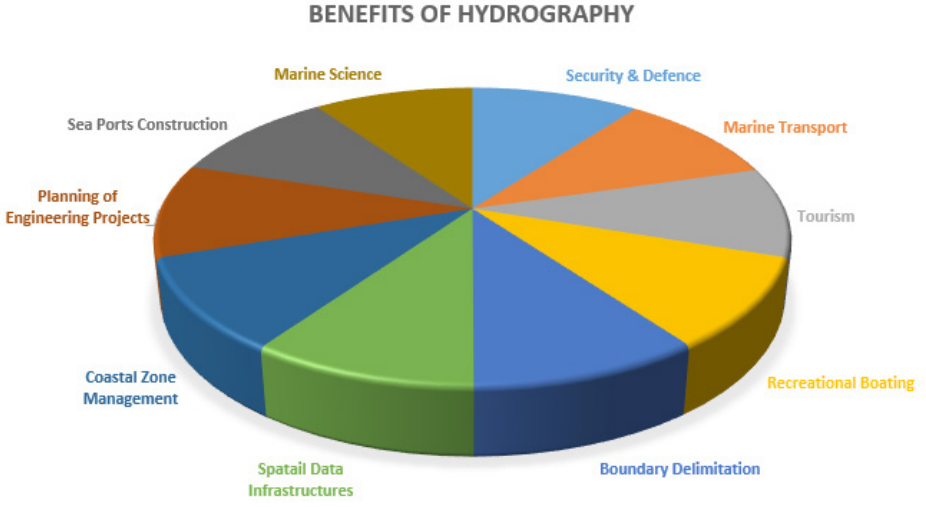

Figure 8. Benefits of Hydrography

Source: Authors' analysis (2021)

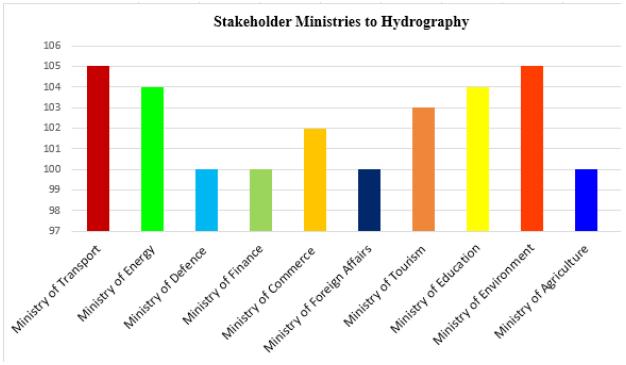

Figure 9. Stakeholder Ministries to Hydrography

Source: Authors' analysis (2021)

4. The Weaknesses of Geospatial Technologies in Hydrographic Practice

Despite the strength of geospatial technologies, there are some weaknesses that are associated with these technologies. Acquired remote sensing data are expensive and the technology itself is equally expensive to come by. The effective analysis of remote sensing data and images needs a kind of specialized skills. Extra training and skills are needed by the users of the technology to be able to effectively interpret imagery. Also, the cost of acquiring aircraft, drones and UAVs is high to come by and the maintenance of the various parts and accessories is always difficult and tedious. Extreme weather conditions can also affect the effective deployment and use of aircraft, drones and UAVs, hence the need to properly liaise with before

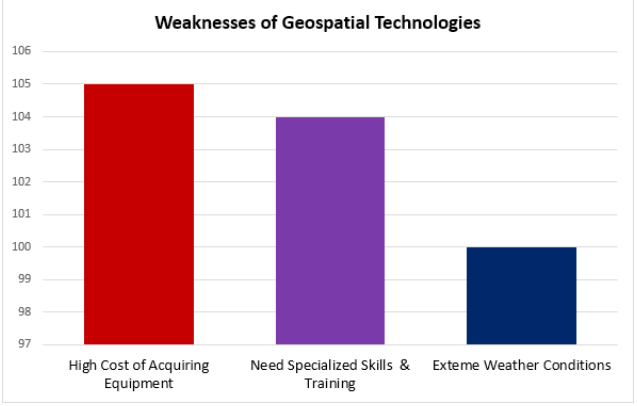

Figure 10. Weaknesses of Geospatial Technologies in Hydrographic Practice

Source: Authors' analysis (2021)metrological stations

embarking on the use of these devices. The failure to adhere to weather conditions can lead to blurred data and images which will invariably affect the quality of the end products. GIS also has its own weaknesses, for instance, GIS technology requires trained and skillful experts that need to interpret, analyze and interpolate all collected data. Besides, GIS software are expensive to acquire and this could hinder effective data gathering, analysis and interpretation. The summary of the weaknesses of geospatial technologies in hydrographic practice is shown in Figure 10.

5. Conclusions

The roles of hydrography in national development cannot be overemphasized. With the aid of hydrography, nautical charts and other nautical publications that are required by the mariners to safely navigate their ships/vessels from one point to another across the vast seas and oceans of the world are produced. Hydrography and geospatial technologies are twins and inseparable as they help in fostering safe navigation at sea. With hydrography, coastal nations can develop and maintain their coastal zones, improve on their marine transport and maintain marine spatial data infrastructures among others. Having critically and holistically reviewed hydrographic practice and geospatial technologies, the paper therefore recommends that coastal nations around the world should integrate and incorporate geospatial technologies into their hydrographic practices for enhanced navigational safety of vessels/ships at sea.

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