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Application of GIS and Artificial Intelligence in Military Operations: Prospects and Challenges

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Abstract

Geographic Information System (GIS) and Remote Sensing have been considered significant in the military due to their spatiality in nature. Recent military developments have seen various military institutions depending on spatial mapping tools, for the purpose of command, control, communication and coordination in military operations. In this study, the qualitative-analytical method was used to illustrate the applications of GIS in military operations, drawing lessons from land based military developments from selected studies. An online survey was conducted to extract information from a sample of forty (40) students undertaking War Studies at the University of Zimbabwe, who were conveniently selected for the study. In-depth interviews were also done with two (2) military experts from the university. Data collected was analyzed using descriptive statistics and qualitative interpretation of recent developments in military GIS. The benefits of GIS and machine learning in military operations included access to information; improved data management; information dissemination; improved terrain analysis; object, target or pattern recognition; quick data processing algorithms; autonomous systems; and predictive analysis. The study also notes some challenges associated with GIS and machine learning in military operations include expensive to set up which constituted of respondents; training requirements; cyber-security; software issues; offensive in nature, as well as misinterpretation of situations. The study recommends the need for human-AI collaboration and the development of a regulatory framework at national, regional and international level in ensuring sustainable implementation of GIS technology in military operations.

Keywords: GIS and Remote Sensing, Military Operations, Artificial Intelligence, Drone Technology

1. Introduction

In the recent decades, military developments have often seen various military institutions around the globe depending on reliable and accurate spatial mapping tools, in order to take quick decisions for operational orders during military operations [1,2]. This concept of "Information advantage," has revolutionized the ability of military personnel to make quick decisions than their adversaries. The use of GIS applications in military has transformed the way in which the entity function. Geospatial technologies have prompted military organizations to utilize spatial data in attaining dominance in military power, and the art of acquiring information in real or near real-time has allowed military forces to dominate and take control of the war [3,4]. In this study, GIS applications essential for military operations include route network analysis and terrain analysis, as well as GIS integration with machine learning or artificial intelligence (AI) applications for object detection, information sharing and dissemination. The purpose of this paper is to present fundamental issues related to modern development in military GIS, with focus on prospects and challenges, and to come up with strategies to manage these modern technological developments. The study's focus is on ground-based GIS military operations and the adoption of AI in the military.

2. Problem Statement

Geospatial Intelligence and its integration with machine learning, have been a transformative part of artificial intelligence (AI) in various fields, including security and defense [5]. Though GIS and AI have enhanced military planning and decision making through situational awareness and predictive capabilities. However, if these developments are not monitored and accounted for, there are likely to pose security threat at national, regional and globally. Therefore, this study seeks to explore the capabilities of GIS and machine learning in military operations, with focus on prospects, challenges, as well as strategies which could be employed to enhance national security.

3. Purpose of the Study

The purpose of the study is to increase security awareness for military experts, engineers, security personnel and policy makers on the implications of GIS and machine learning in military operations. The following objectives seeks to achieve this purpose;

i. Examine the GIS and machine learning applications in military operations.

ii. Assess the benefits of GIS and machine learning in military operations.

iii. Examine the challenges associated with GIS and machine

learning.
iv. Develop strategies to enhance the security of GIS and machine learning in military operations.

4. Literature Review

4.1 GIS and Remote Sensing

Various military institutions have invested in GIS in order to understand the enemy location, location of community settlements, and terrain evaluation and climatic conditions in addition to directional data [6,7]. GIS are systems designed to store, manage and display spatial data and aid in the analysis and interpretation of such data [8]. Various data sets can be overlaid (figure 1), allowing spatial analysis to be performed on socio-economic and environmental data, in order to understand implications of various land uses on national security.

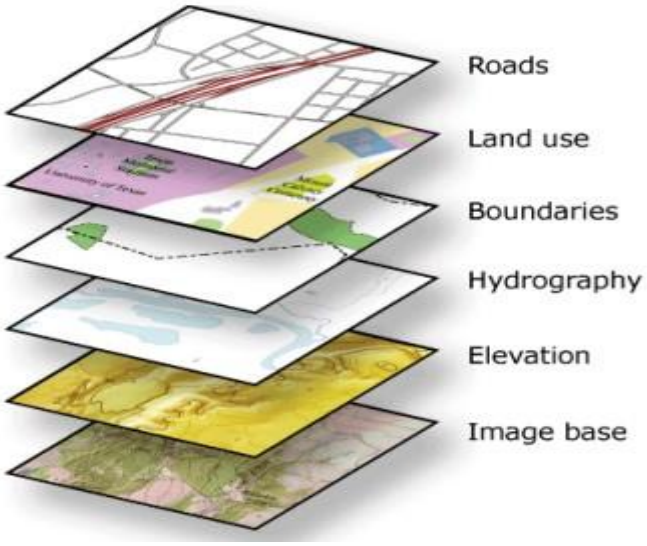

Figure 1: Overlaid datasets (http://webhelp.esri.com/ arcgisdesktop/9.2/printBooks_topics.cfm?pid=22).

Therefore, digitization of maps within the GIS framework, presents military personnel with many visual benefits, ranging from battlefield simulation, military briefing and planning, information sharing and command control [9].

4.2 GIS Components

The main components of GIS (figure 2) include: the organization, GIS professional, data, software, hardware and output. In the context of this study, the military organization utilizes the expertise of GIS professionals to obtain and analyze spatial and attribute data with the aid of hardware and GIS software. The output consists of GIS generated reports, tracking decision making and planning course of action. GIS software consist of open source and proprietary (licensed), with QGIS and ArcGIS being commonly used, respectively. The application of these GIS tools are discussed in the next section.

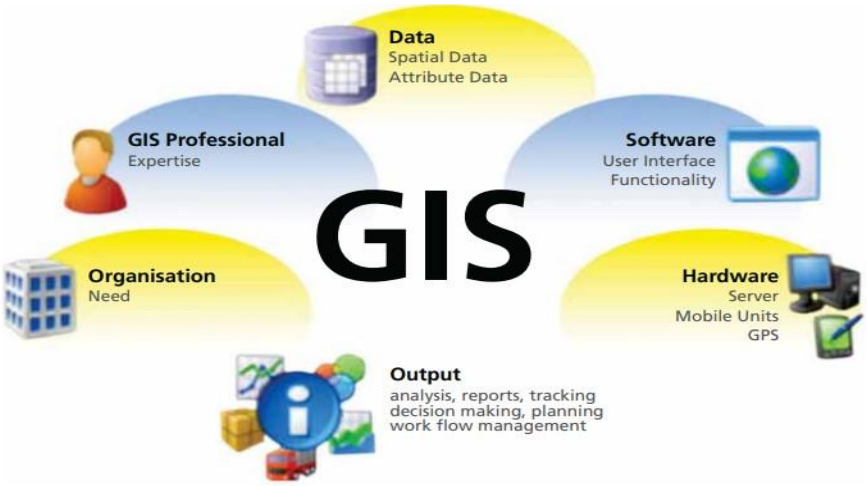

Figure 2: GIS Components (UN-Habitat 2013).

4.3 GIS Application in Military Operations

This section discusses various GIS applications in military operations which include; spatial data storage and visualizations, use of GIS applications, spatial analysis techniques, historical construction,

5. Spatial Data Storage and Visualizations

Spatial data visualization is vital as it allow field commanders to control battle with the aid of a map or photograph. A spatial database integrated with GIS supports command requirements to specify an authorized map for operational reasons. GIS and

its link with spatial databases such as Postgres SQL can be used to store spatial and non-spatial military data, allowing efficient manage military resources and tasks. Data include location of armory at military bases, records of military operations, costs of operations, thereby providing an effective way to store institutional knowledge, as well as modelling capabilities for analyzing alternative military strategies.

Spatial data storage and visualization is also crucial in military logistics management. Therefore, GIS plays an important role in military logistics such as moving supplies, equipment and troops where they are needed at the right time and place. By using GIS to computing routes for convoys in spatial databases, forces are able to determine and map alternative routes.

5.1 Use of Open Source and Proprietary GIS Applications in Military

In a developing countries, licenses for a registered GIS software, vendor-exclusive training and the bureaucracy of the procurement cycle add to the time and costs of a mission [9]. In a study conducted to evaluate the use of an open source desktop GIS product, QGIS, for a military operation other than war [11], QGIS outputs were compared to those computed in ArcGIS, a proprietary desktop GIS product developed by ESRI, widely used in military operations. The results of the study showed that the QGIS was cost effective and data outputs provided the operational commanders with similar information to plan and execute a mission successfully. Thus an open source GIS is also suitable for some military operations including those with limited funding such as disaster or risk mapping.

In another study on the analysis of the possibilities of automated data visualization of topographic spatial database with open source GIS servers, utilized a Vector Map Level 2 (VML2) which corresponded to a military topographic map in a scale of 1:50 000, and data visualization was performed by developing relevant scripts. The study found that GIS servers (Mapserver and Geoserver) presented map symbols from analogue map correctly in more than 90% of cases. In terms of time taken to generate the map Geoserver had significant advantage over Mapserver in nearly all cases.

Another study was conducted to promote common understanding among stakeholders and design a GIS framework for defense [10]. The system comprised of input data, migrator, operational core, solver, output bus, geoportal and external accessory. Though the application is still under development, it already has features such as tracing routes and identifying troop access.

5.2 Spatial Analysis Techniques in Military Operations

Though there are various spatial analysis techniques which aid in planning military operations, this study's focus is mainly on "terrain analysis", which is essential in land based military operations, allowing military field commanders to consider elevation data for the movement of military tanks and other weapons. Commonly applied models of terrain are models of surface terrain based on raster data and digital models based on the TIN (Triangulated Irregular Network) data structures [11]. Elevation data obtained from satellites in form of Digital Elevation Models (DEM) are also essential for battle planning, given that when such data is computed in GIS framework, it generate contour maps, hydrological maps, allowing comprehensive analysis of the battle ground.

A study conducted on the importance of GIS in topographic support to all levels of military command, and the development of a GIS framework to support decision making for the Republic of Kazakhstan, noted that GIS contributed to better combat control of troops and armament, as well as costs reduction while generating geospatial data [12]. In modern warfare, a comprehensive map with information on land use, terrain and accessibility to habitat are essential for military operations. These maps can be generated by utilizing GIS topographic algorithms such as terrain ruggedness index (TRI) and topographic Wetness index (TWI), which can help military operatives to familiarize with the phenomenon of the enemy's territory [14,15]. For accuracy purposes, both topographic ground maps and digital maps must be available to field commanders as any discrepancy may endanger the whole operation, thereby enhancing the military's tactical, operational and strategic decisions.

Therefore, information embedded in GIS software allows commanders and field soldiers to measure shortest distances between certain points for maneuvering purposes [16]. Furthermore, spatial analysis techniques in GIS such as hot spot analysis, buffering and spatial statistics help to obtain a comprehensive analysis of specific regions of interests on quasi real-time, or in real time in cases of information display in web map applications.

5.3 Military Historical Construction

GIS has been used to support military historical reconstruction with focus on the defense line around Budapest in the Second World War [17]. This task was achieved by collecting archive maps, aerials photographs, as well as field measurements, among other data, and was managed in standard system with GIS for the reconstruction of contemporary environment, defense object and military events. The database act as a reference system for further researches and to identify new parts of the defense line.

Further studies on new achievements in WWII military historical reconstruction with GIS, saw the reconstruction of the two major World War II defense lines, Attila and Margit in Hungary. The methods allow for various spatial and attribute queries to be performed, as well as animation possibilities which could be useful.

5.4 Modern Military Warfare

Research has shown that the emergence of hybrid or modern warfare in recent decades has been enhanced through the adoption of modern geospatial technologies [18,19]. For instance, GIS is able to answers to questions relating to the location of an object or certain type of objects, and their surroundings. GIS technology assist military management and field forces with readily available data. In most developed countries remote sensing technology has been utilized by military intelligence to

acquire data on enemy's camp, taking note of activities from satellites in space. High-resolution satellite data has been used to monitor the changes in land use and terrain near international borders for national security purposes.

The role of geospatial technologies in modern military warfare has also been examined utilizing remote sensing, GIS, Global Positioning System (GPS), Big Data and locational intelligence to present solutions to geographic problems. Study findings show that effective geospatial technologies enhance military operations against various forms of criminality and insurgencies.

5.5 Drone Technology in Military Operations

In the era of new technology for collecting intelligence, unmanned aerial vehicles (UAVs) or drones have emerged as tools for collecting high resolution data from enemy's territory and necessary information for reconnaissance purposes. A study has been conducted to present a model of a system supported by GIS for computers, command, control, communications, intelligence surveillance and reconnaissance (C4ISR) in collaboration with drones for military purposes. Similar study further notes that drone application supported by GIS, C5ISR (command, control, computers, communications, cyber-defense, intelligence, surveillance and reconnaissance) and AI would give significant advantage on the ground. Therefore, integration of human intelligence with access to information and target zone, provide decisive advantage in the battlefield.

Use of drone or Unmanned Aerial Vehicles (UAV) applications in military GIS on the mountainous terrain of Azerbaijan Republic can help to generate orthomosaics and 3D models for terrain and combat control [20]. In another study, a Convolution Neural Network (CNN) was trained on UAV-based minefield data (Baur 2021), generating a model which could identify the PFM-1 anti-personnel mine from a drone survey with 91.8% accuracy, providing de-miners with field maps with identified mine locations.

5.6 UAV Cluster and Machine Learning Algorithms

In an effort to improve defense and security, advances in data analytics and machine learning methods of significance in military operations, turning geospatial imagery and data into accurate and actionable intelligence [21]. Recent developments in drone technology has seen the adoption of UAV swarm surveillance or UAV cluster becoming significant in modern warfare surveillance and disaster rescuing. The result from the study on UAV swarm surveillance based on hierarchical architecture, showed that the decentralized UAV structure outperformed the centralized structure, especially on maintaining the stability of inner UAV swarm network, while tracking moving objects [22]. Figure 3 below is an illustration of the drone cluster network.

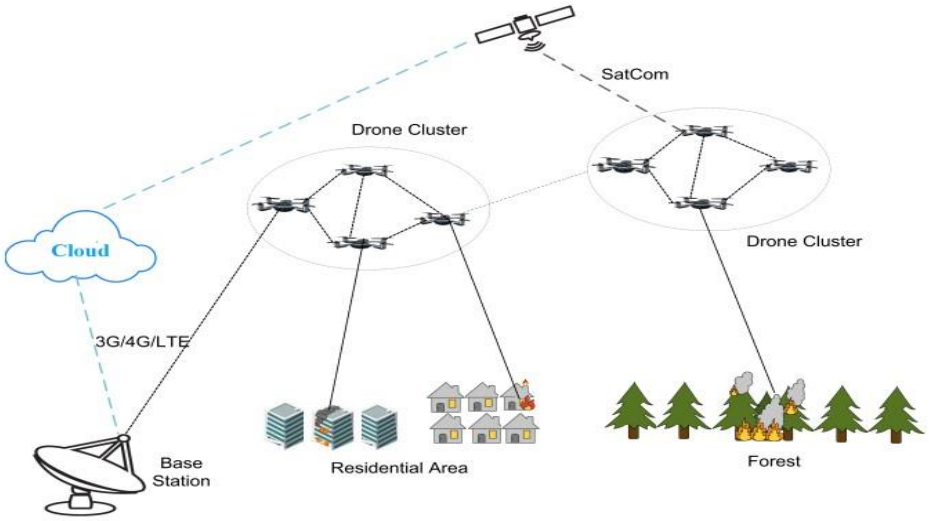

Figure 3: Fire detection using drone cluster network (Aftab 2019)

Recently, geospatial technologies have embraced Internet of Things (IoT) in the field of various intelligence services and applications. IoT is the network of connected devices using machine learning and artificial intelligence (AI), and the technology that facilitates communication between the devices themselves. In pursuit of such developments, UAV swarm or clustering has become a significant form of current UAV combat applications, commonly known for improving the performance of large-scale UAV clusters through the use of different clustering algorithms for integration purposes.

6. Methodology

The research was conducted in February 2024, and an online survey was used to extract information from a sample of forty students drawn from the Department of War Studies at the University of Zimbabwe. Participants were conveniently selected for the study. In-depth interviews were also conducted with two military experts with GIS background. Data collected was analyzed using descriptive statistics and qualitative interpretation of recent developments in military GIS and associated threats. The research provided the opportunity to assess paradigm shifts in the application of GIS and remote sensing in military operations, including the integration of AI

and its implications to national security.

7. Findings and Discussion

7.1 Benefits of GIS and Machine Learning in Military Operations

In this study, a significant number of participants noted the benefits of GIS and machine learning in military operations (figure 1) which are; access to information (90%); improved data management (75%); information dissemination (95%); improved terrain analysis (72.5%); object, target or pattern recognition (87.5%); quick data processing algorithms (82.5%); autonomous systems (90%); and predictive analysis (65%).

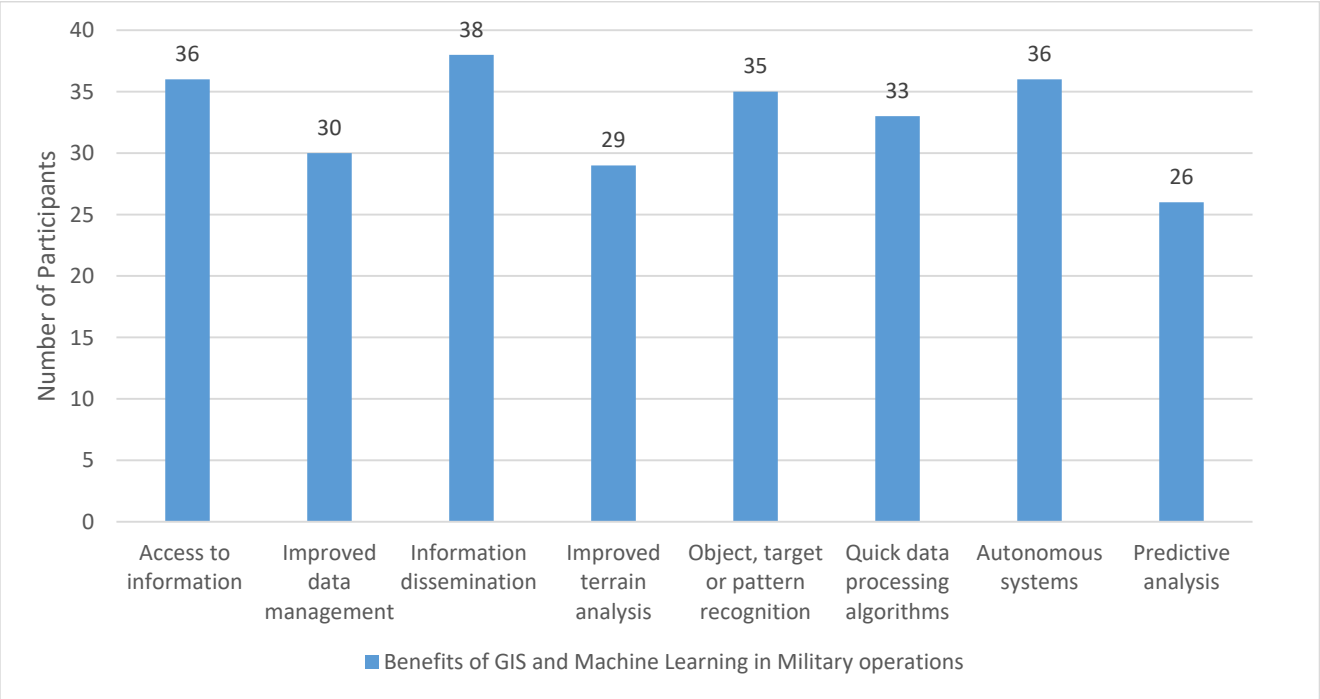

Figure 1: Benefits of GIS and Machine Learning in Military Operations

Interviews conducted with military experts from the Zimbabwe Defense Forces (ZDF) on the benefits of GIS and AI, it was noted that in addition to maps, photographs and documents used by troops, creating a military GIS system and its integration with AI, taking note of positional accuracy of information was one of the most important functions of GIS. Information obtained from this study revealed that the understanding of landscape allows military leaders to determine strategic positions for scouting enemy activities, suitable line of fire and the ability to hide troops and equipment. In support of this view, other studies have noted the significance of remote sensing applications associated with satellite imagery and UAV object detection, to understand and interpret terrain, in order to determine how troops can be deployed timely in an effective way [22]. In response to challenges associated with modern warfare, the implementation of geospatial solutions using machine and AI, achieved through automation of GIS processes, help to identify and extract objects of interest from vast quantities of imagery in real-time. This would allow military commanders and ground troops to compare emerging information against historical data.

In-depth interviews revealed that GIS and remote sensing has been useful in determining suitable military site selection. In support of this view, GIS, multi-criteria decision analysis (MCDA) and machine learning algorithms has been used to select suitable military sites nationally and globally. A study conducted by, to identify the suitable strategic military site in Adea District of Kenya [23]. The study notes that GIS, MCDA and machine learning algorithms are beneficial for decision makers and enhance in locating strategic military sites.

7.2 Challenges associated with GIS and Machine Learning in Military Operations

Participants also indicated some challenges associated with GIS and machine learning in military operations which are; expensive to set up which constituted 100% of respondents; training requirements (90%); cyber-security (95%); software issues (60%); offensive (75%) and misinterpretation of situations (67.5%).

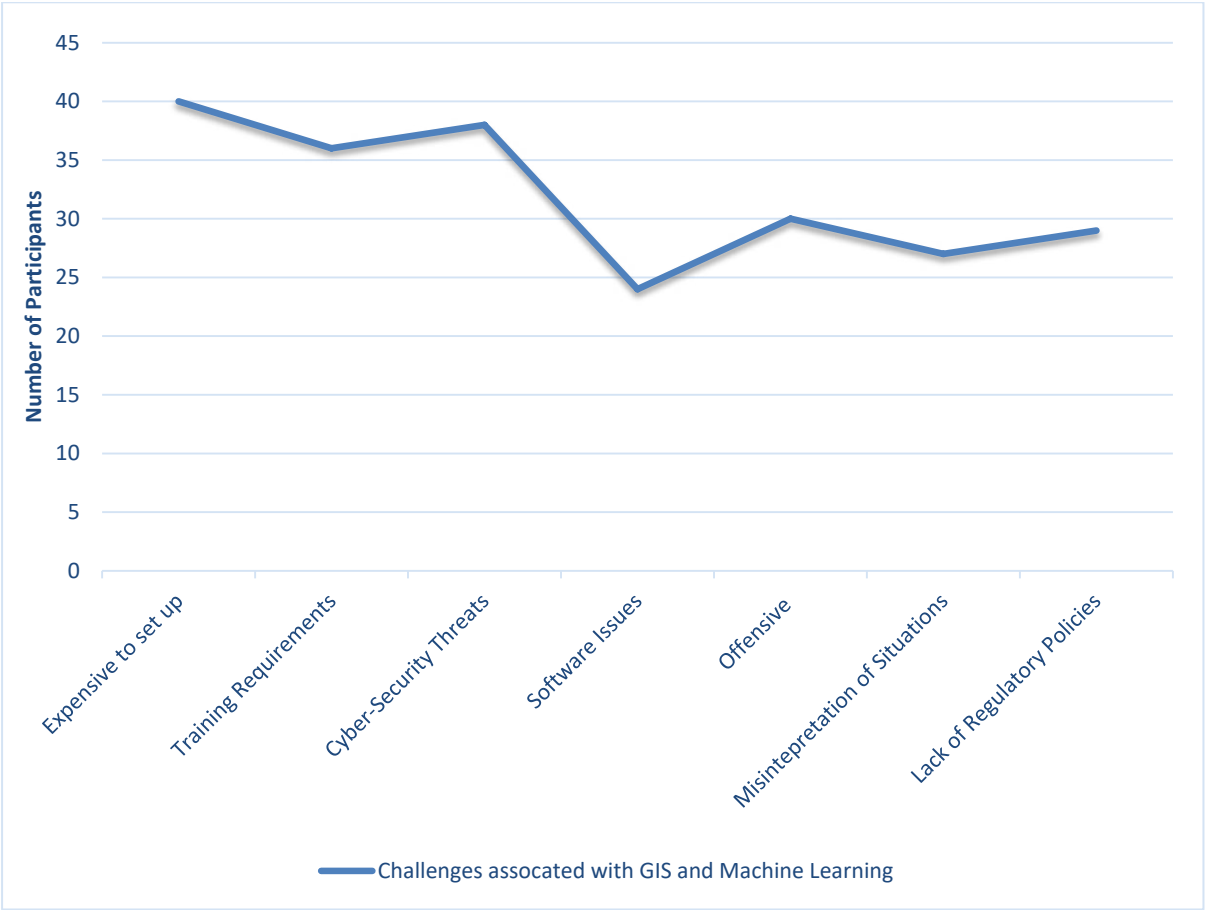

Figure 2: Challenges associated with GIS and Machine Learning

With regards to offensive military planning, interviews with military experts revealed that utilizing GIS and machine learning in space could be used for spying purposes. It was noted that GIS tools equipped with powerful cameras help to capture reality though high resolution imagery. Furthermore, the key informants noted that, given its capabilities, if it falls in wrong hands, GIS and machine learning could be used to further the interest of terrorist groups or rogue elements, a situation which has devastating effects on lives. Military experts also noted that GIS and machine learning was associated with misinterpretation of objects and situations, thereby making them unpredictable.

7.3 Strategies to Enhance Military Operations Using GIS and Machine Learning

Information obtained from both students and military experts revealed that the strategies to enhance military operations using GIS and machine included; the development of regulatory framework, human-AI collaboration and developing GIS and machine learning systems which are accountable and transparent. The study notes that the development of a regulatory framework for GIS and machine learning implementation at national, regional and international level, would go a long way in ensuring sustainable implementation of AI [24].

Worth noting was also the need for human-AI collaboration raised by participants, to which emphasis was placed on the balance between human decision making and machine learning systems in order to avoid potential ethical and privacy challenges. In this regard, the development of GIS and machine learning systems which are accountable and transparent in their decision would be essential in ensuring reliability and trust in military organizations.

8. Conclusion and Recommendations

The study notes that utilizing AI through remotely sensed data, machine learning algorithms, combined with field data, would provide a comprehensive analysis of ground situation in military operations. The results of this theoretical research stimulates the development of a model for GIS military and for monitoring information space of the security sector. The integration of AI with other emerging GIS applications, cloud computing and modern systems or Internet of Things (IoT), could enhance GIS capabilities in military operations. In pursuit of some developments in AI, international cooperation is needed to mitigate associated security risks, as well as to exploit on the technology's potential to transform military functions and operations. Although military developments across the globe have been revolutionized by AI integrating with GIS, drone technology and machine learning, there is need to mitigate the risks associated with AI, in order to determine the future of GIS applications in the military operations. Additionally, in order to enhance the efficiency of monitoring of security situation in the

country, it is necessary to improve the models of information monitoring in national security, as well as global collaboration on machine learning and AI regulation.

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