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

Ezra Chipatiso
University of Zimbabwe
echipatiso@gmail.com

Abstract

The study explores the application of Geographic Information Systems (GIS) and Artificial Intelligence (AI) in military operations, focusing on prospects and challenges. The study considers the aspect of GIS and AI in military operations since various military organisations have yet to fully adopt this technological development into their systems. Therefore, the need to embrace recent military developments for command, control, communication, and coordination in military operations becomes significant. Military institutions have adopted geospatial and/or AI tools to improve their capabilities of detecting and monitoring national security threats. The rationale behind this study was to identify the benefits and factors interfering with GIS and AI in undertaking military operations, with a focus on land-based military developments, to provide a direction for military transformation. A qualitative approach was employed, and interpretive content analysis of the literature supported the results and discussion of the study. An online survey was conducted to extract information from a sample of 40 students undertaking War Studies at the University of Zimbabwe, who were conveniently selected. In-depth interviews were also done with two military experts from the Zimbabwe Defence Forces (ZDF). Data collected was analysed using a qualitative interpretation of themes drawn from research objectives, and Kant's Ethical Theory was used to emphasise the need for promoting universal moral principles. Embracing GIS and AI results in improved access to information, data management, information dissemination, terrain analysis, target or pattern recognition, quick data processing algorithms, autonomous systems, and predictive analysis. However, factors which could interfere with GIS and machine learning in military operations include financial constraints, training requirements, cyber-security threats, software issues, as well as misinterpretation of situations. The study recommends the need for AI governance across all tasks relevant to military

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operations, and to come up with national defence AI strategies, policies, and guidelines.

Keywords: GIS and remote sensing; military operations; Artificial Intelligence; drone technology

Introduction

In the era of digital technology, the military as the security arm of any nation needs to keep abreast of new developments that yield efficient results when embedded in military operations. To achieve this, adopting GIS and AI is crucial in modern military operations across various domains, offering several advantages including reliable and accurate spatial mapping tools to make quick decisions for operational orders (Satyanarayana and Yogendran 2009; Ciprian 2018). This concept of "information advantage" has revolutionised the ability of military personnel to make quicker decisions than their adversaries and has transformed how the entity functions (Luckenbaugh 2023). Geospatial technologies have prompted military organisations to utilise 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 (Dawid and Pokonieczny 2019; Petrovski and Radovanovi 2021). 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 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 a 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 developments and the adoption of AI in military operations.

Problem Statement

Advances in technological developments have influenced the conduct of military operations. Most researchers and scholars have paid more attention to studying GIS and AI in the context of disaster management, mineral exploration, and other environmental research (Abarca-Alvarez 2017; Kemper and Kemper 2020; Doan 2021). However, little has been documented on the application of GIS and AI in military developments. Therefore, this study seeks to explore the capabilities of GIS and AI in military operations, focusing on prospects and challenges, to come up with a sustainable approach to modern security developments. Geospatial intelligence and its integration with machine learning, have been seen as a transformative part of AI in various fields, including security and defence (Wang et al. 2020; Okpuvwie and Toko-Mouhamadou 2023). Though GIS and AI have enhanced military planning and decision-making through situational awareness and predictive capabilities, such developments need to be accounted for, as they may pose a security threat nationally, regionally, and globally.

Purpose of the Study

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

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

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

iii. Compare the factors that could interfere with GIS and machine learning.

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

Literature Review

Overview of GIS and AI for Military Operations

Various military institutions have invested in GIS and AI to understand the location of the enemy and community settlements and evaluate the terrain and climatic conditions in addition to directional data (Juhász 2014; Baur et al. 2021). GIS are systems designed to store, manage, and display spatial data and aid in analysing and interpreting such data (Cromley and McLafferty 2011). Various data sets can be overlaid (Figure 1), allowing spatial analysis to be performed on socioeconomic and environmental data, to understand the implications of various land uses on national security. Therefore, the digitisation of maps within the GIS framework and integration with AI presents military personnel with many visual benefits, ranging from battlefield simulation, military briefing and planning, information sharing and command control.

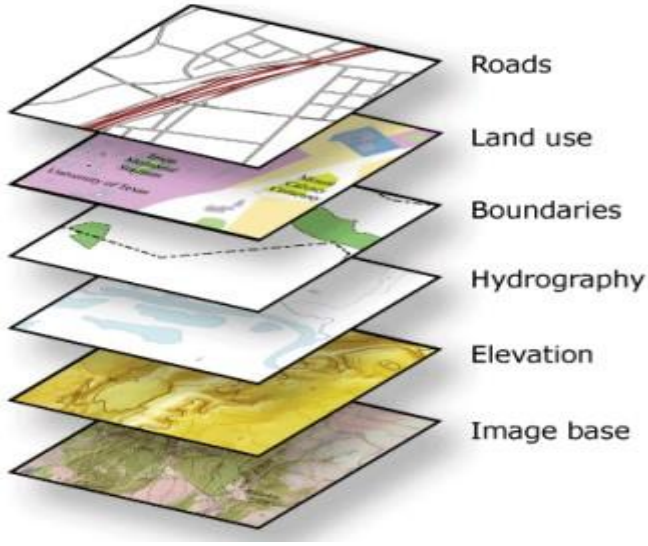

Figure 1: Overlaid datasets (http://webhelp.esri.com/arcgisdesktop/9.2/printBooks_topics.cfm?pid=22).

The main components of GIS (Figure 2) include the organisation, GIS professional, data, software, hardware, and output. In the context of this study, the military organisation utilises the expertise of GIS professionals and software engineers to obtain and analyse spatial and attribute data with the aid of hardware and GIS software. The output consists of GIS-generated reports, tracking decision-making, monitoring events and planning courses of action. GIS software consists of open source and proprietary (licensed), with QGIS and ArcGIS being commonly used, respectively. The application of these GIS tools is discussed in the next section.

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

Benefits of GIS and Machine Learning in Military Operations

This section discusses various GIS applications in military operations which include spatial data storage and visualisations, the use of GIS applications, spatial analysis techniques, and historical construction, among others.

Spatial Data Storage and Visualisations

Spatial data visualisation is vital as it allows field commanders to control a battle using a map or photograph (Dawid and Pokonieczny 2019). A spatial database integrated with GIS supports command requirements to specify an authorised 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 management of military resources and tasks. Data include the location of the armoury at military bases, records of military operations, and costs of operations, thereby providing an effective way to store institutional knowledge, as well as modelling capabilities for analysing alternative military strategies.

Spatial data storage and visualisation are 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 (Petrovski and Radovanovi 2021). By using GIS to compute routes for convoys in spatial databases, forces can determine and map alternative routes.

Use of Open Source and Proprietary GIS Applications in Military

In developing countries, licences for registered GIS software, vendor-exclusive training, and the bureaucracy of the procurement cycle add to the time and costs of a mission (Henrico et al. 2020). 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.

Another study on the analysis of the possibilities of automated data visualisation of topographic spatial databases with open-source GIS servers (Dawid and Pokonieczny 2019), utilised a Vector Map Level 2 (VML2), which corresponded to a military topographic map on a scale of 1:50 000, and data visualisation was performed by developing relevant scripts. The study found that GIS servers (Mapserver and Geoserver) presented map symbols from analogue maps correctly in more than 90 per cent of cases. In terms of the time taken to generate the map, Geoserver had a significant

advantage over Mapserver in nearly all cases. Another study was conducted to promote common understanding among stakeholders and design a GIS framework for defence (Jardim et al. 2022). The system comprises 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.

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 (Henrico et al. 2020). Commonly applied models of terrain are models of surface terrain based on raster data and digital models based on the Triangulated Irregular Network (TIN) data structures (Gigović 2018). Elevation data obtained from satellites in the form of Digital Elevation Models (DEM) are also essential for battle planning (Satyanarayana and Yogendran 2009), given that when such data is computed in the GIS framework, it generates contour maps, and hydrological maps, allowing comprehensive analysis of the battleground.

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 (Zakiev 2020) noted that GIS contributed to better combat control of troops and armament, as well as costs reduction while generating geospatial data. In modern warfare, a comprehensive map with information on land use, terrain, and accessibility to habitat is essential for military operations (Satyanarayana and Yogendran 2009). These maps can be generated by utilising GIS topographic algorithms such as terrain ruggedness index (TRI) and topographic Wetness index (TWI) (Stojilković 2022; Kopecký 2021), which can help military operatives familiarise themselves with the phenomenon of the enemy's territory. To ensure accuracy, both topographic ground maps and digital maps must be available to field commanders, thereby enhancing the military's tactical, operational, and strategic decisions. Any discrepancy may endanger the whole operation. Therefore, information embedded in GIS software allows commanders and field soldiers to measure the shortest distances between certain points for manoeuvring purposes (Kettani and Maamar 2000). Furthermore, spatial analysis techniques in GIS such as hotspot analysis, buffering, and spatial statistics help to obtain a comprehensive analysis of specific regions of interest in quasi-real-time, or in real-time in cases of the information displayed in web map applications.

Military Historical Construction

GIS has been used to support military historical reconstruction with a focus on the defence line around Budapest in the Second World War (Juhász 2007). This task was achieved by collecting archive maps, aerial photographs, as well as field measurements,

among other data, and was managed in a standard system with GIS for the reconstruction of the contemporary environment, defence objects, and military events. The database acts as a reference system for further research and to identify new parts of the defence line. Further studies on new achievements in the Second World War military historical reconstruction with GIS (Juhász 2014) saw the reconstruction of the two major Second World War defence 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.

UAV Cluster and Machine Learning Algorithms

To improve defence and security, advances in data analytics and machine learning methods are significant in military operations, as these developments help to identify, detect and locate areas of interest, and to automatically create digital maps which can be shared, allowing for the visualisation of complex data and turning geospatial imagery and data into accurate and actionable intelligence (NV5 Geospatial Technologies 2023). Recent developments in drone technology have seen the adoption of UAV swarm surveillance or UAV clusters becoming significant in modern warfare surveillance and disaster rescue. The result from the study on UAV swarm surveillance based on hierarchical architecture (Aftab 2019) showed that the decentralised UAV structure outperformed the centralised one, especially in maintaining the stability of the inner UAV swarm network, while tracking moving objects. Figure 3 illustrates the drone cluster network.

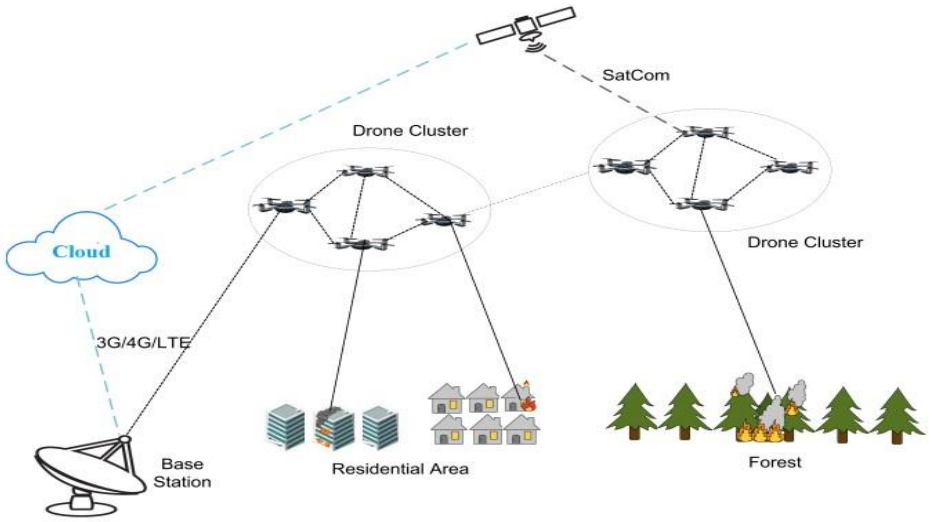

Figure 3: Fire detection using drone cluster network (Aftab 2019).

Recently, geospatial technologies have embraced the Internet of Things (IoT) in the field of various intelligence services and applications. IoT is the network of connected devices using machine learning and AI, and the technology that facilitates

communication between the devices themselves (Aftab 2019). 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 using different clustering algorithms for integration purposes (Wang et al. 2020). Previous research has shown that the emergence of hybrid or modern warfare in recent decades has been enhanced through the adoption of modern geospatial technologies (Caprian 2018; Majumdar 2021; Okpuvwie and Toko Mouhamadou, 2023). For instance, GIS can answer questions relating to the location of an object or certain types of objects and their surroundings. GIS technology assists military management and field forces with readily available data. In most developed countries remote sensing technology has been utilised by military intelligence to acquire data on enemy camps, taking note of activities from satellites in space (Majumdar 2021). High-resolution satellite data has been used to monitor the changes in land use and terrain near international borders for national security purposes (Majumdar 2021; Zakiev 2020). The role of geospatial technologies in modern military warfare has also been examined utilising remote sensing, GIS, Global Positioning System (GPS), Big Data and locational intelligence to present solutions to geographic problems (Okpuvwie and Toko-Mouhamadou 2023). Study findings show that effective geospatial technologies enhance military operations against various forms of criminality and insurgencies.

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 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 (Petrovski and Radovanovi 2021). A similar study further notes that drone applications supported by GIS, C5ISR (command, control, computers, communications, cyber-defence, intelligence, surveillance, and reconnaissance) and AI would give significant advantage on the ground (Petrovski and Radovanovi 2021). Therefore, the integration of human intelligence with access to information and target zones provides a decisive advantage on the battlefield. The use of drone or UAV applications in military GIS on the mountainous terrain of the Azerbaijan Republic helped to generate orthomosaics and 3D models for terrain and combat control (Bayramov and Hashimov 2017). 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 per cent accuracy, providing de-miners with field maps with identified my locations.

Methodology

A qualitative research approach was employed in this study. An online survey was conducted to extract information from a sample of 40 students from a total of 60 fourth-year students undertaking War Studies at the University of Zimbabwe, who were

conveniently selected for the study. In-depth interviews were also done with two military experts from the ZDF. Data collected was analysed using descriptive statistics and qualitative interpretation of recent developments in military GIS. In addition, interpretive content analysis of literature supported the results and discussion in the study. This study also employs Kant's Theory as a research paradigm. Kant's Theory was based on the concept of duty and moral obligations when making decisions (Thompson 2021). In applying Kant's Ethical Theory, this study emphasises the need for "respect for human dignity," which ensures that the rights of military personnel and civilians are protected. Though Kant's Theory may not provide a complete ethical approach to military operations, incorporating Kantian values can help promote respect for human dignity and devotion to universal moral principles. The research provided the opportunity to assess paradigm shifts in GIS application and remote sensing, including the integration of AI into military operations and its implications for national security. The study was conducted from February to April 2024.

Findings and Discussion

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%).

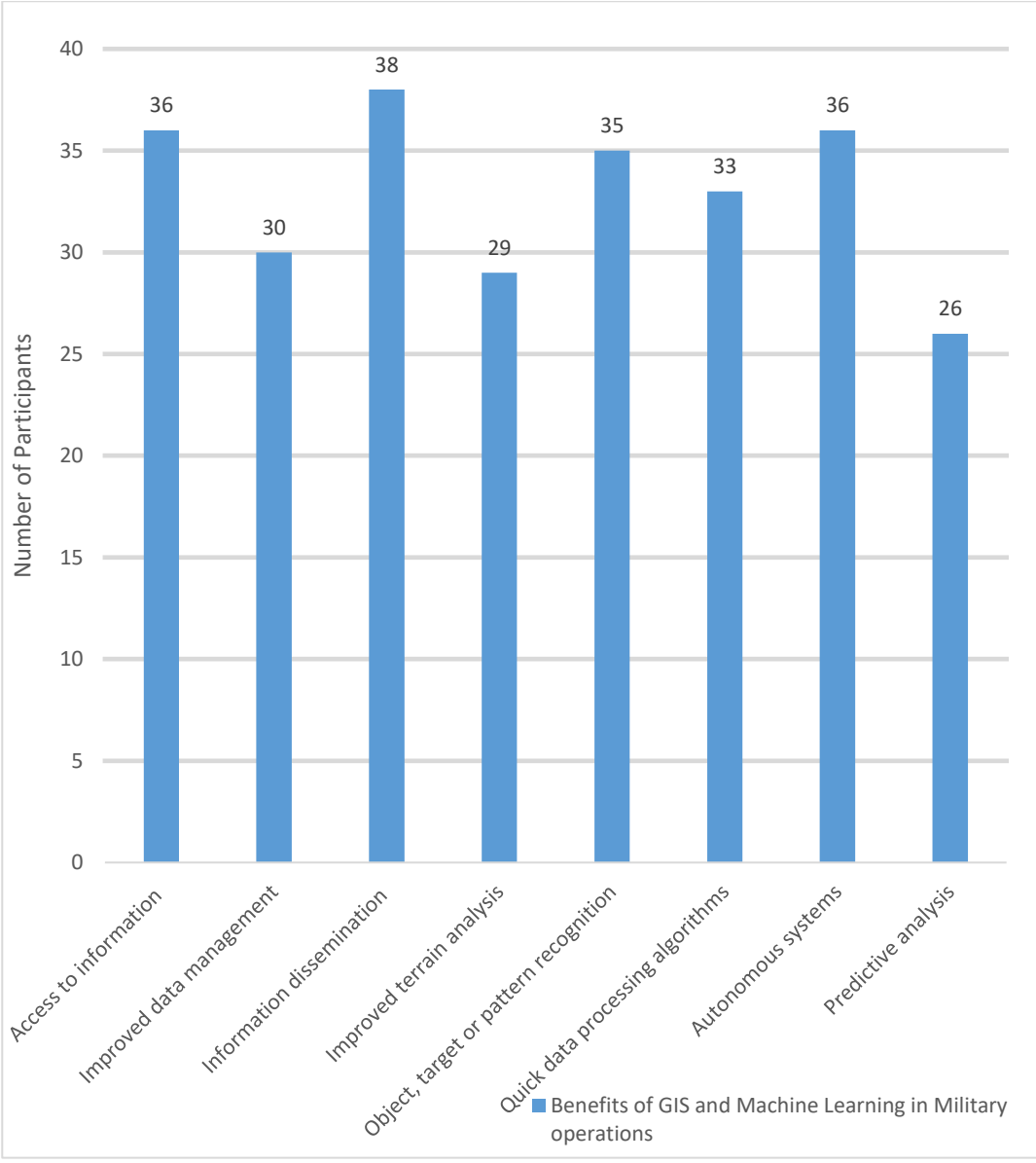

Figure 1: Benefits of GIS and Machine Learning in Military Operations

In interviews conducted with military experts from the ZDF focusing 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 understanding a landscape enables military leaders to determine strategic positions for scouting enemy activities, suitable lines of fire, and the ability to hide troops and equipment. In support of this view, other

studies (Satyanarayana and Yogendran 2009; Copley and Wagner 2008) have noted the significance of remote sensing applications associated with satellite imagery and UAV object detection to understand and interpret terrain and to determine how troops can be deployed timely and effectively. In response to challenges associated with modern warfare, the implementation of geospatial solutions using machine and AI, achieved through automation of GIS processes, helps to identify, and extract objects of interest from vast quantities of imagery in real-time (Jardim et al. 2022; Okpuvwie and Toko-Mouhamadou 2023). This allows military commanders and ground troops to compare emerging information against historical data.

In-depth interviews revealed that GIS and remote sensing have been useful in determining suitable military site selection. In support of this view, GIS, multi-criteria decision analysis (MCDA) and machine learning algorithms have been used to select suitable military sites nationally and globally. A study conducted by Bojer et al. (2023), to identify a suitable strategic military site in Adea District of Kenya, note that GIS MCDA and machine learning algorithms are beneficial for decision-makers and enhance locating strategic military sites.

Factors That Could Interfere with GIS and Machine Learning in Military Operations

This study noted various factors which could interfere with the application of GIS and machine learning in military operations (Figure 2). Participants indicated some of the factors which could interfere with GIS and machine learning in military operations, namely, expensive to set up which constituted 100 per cent of respondents; training requirements (90%); cyber-security (95%); software issues (60%); offensive (75%) and misinterpretation of situations (67.5%).

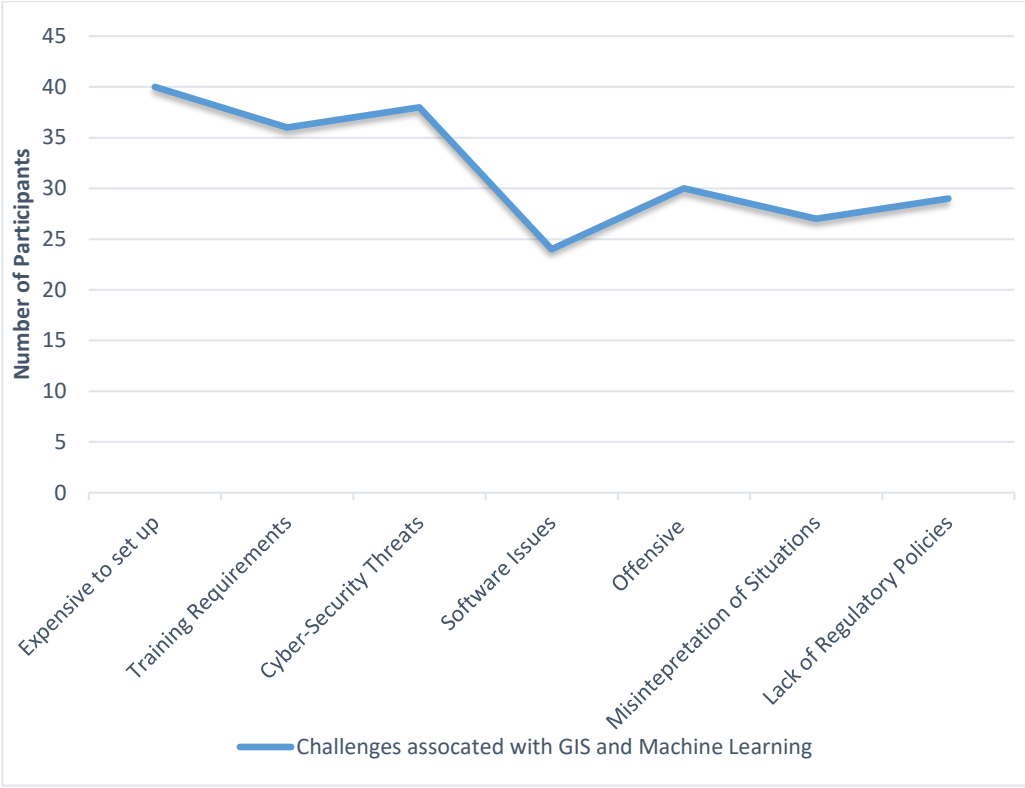

Figure 2: Factors that could interfere with GIS and Machine Learning in Military Operations

Concerning offensive military planning, interviews with military experts revealed that utilising 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 through high-resolution imagery. Furthermore, the key informants noted that, given AI capabilities, if it falls into the 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 were associated with misinterpretation of objects and situations, thereby making them unpredictable. However, Grand-Clément (2023) argued that although GIS and AI applications could result in improved information analysis, they do not consider drawbacks around the adoption of these technologies with regards to the technical aspect and the adoption of the military technology.

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 learning included the development of the regulatory framework, human-AI collaboration and the development of 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 levels would go a long way in ensuring sustainable implementation of AI (Utilities One 2023). It is worth noting that participants raised the need for human-AI collaboration and emphasised that there needs to be a balance between human decision-making and machine learning systems to avoid potential ethical and privacy challenges. In this regard, developing GIS and machine learning systems that are accountable and transparent in their decision would be essential in ensuring that military organisations are trusted and can be relied on. Similarly, Grand-Clément (2023) calls for the need for AI governance across all tasks relevant to military operations, and the invention of national defence AI strategies, policies, and guidelines.

Implications for Security Services

The application of GIS and AI in security services has remained significant in recent years. The convergence of geospatial and AI techniques can influence national security services, providing both prospects and challenges to policymakers. Displaying and exploring spatial data of a security nature, locations, and other attributes on the map, enhances comprehensive analysis of phenomena during military operations. Therefore, applying analytical methods and techniques to operations of a security nature to identify patterns, relationships, and causes and consequences of various security matters can help security experts perform network analysis and spatial statistics such as hotspot analysis and spatial regression, amongst other geospatial techniques (Boxall 2005). Given that in Zimbabwe, disaster reduction and management is the responsibility of the Civil Protection Unit (CPU) predominated by the ZNA, Air Force of Zimbabwe (AFZ), and the Zimbabwe Republic Police (ZRP) (Mavhura 2016), security services can utilise GIS and AI to improve incident response by providing situational awareness and mapping to support emergency response and providing timeous updates on disaster risk reduction. Other key implications of GIS and AI for security services include improved threat detection and monitoring through the integration of data from various sources to provide a comprehensive analysis of the security environment (Walter and Poland 2022). Real-time data analysis helps to detect anomalies, identify emerging threats, and generate predictive locational intelligence. GIS and AI also contribute to cyber security and digital forensics given the increasing cyber threats across the globe. Thus, GIS maps infrastructure and visualises cyber security threats, whilst AI helps to automate responses to cyber-attacks and forensic investigations (ESRI, 2015). The development of integrated GIS and AI technologies in the modern era has prompted the need for ethical consideration and privacy concerns (Anshari et al. 2022; Naik et al. 2022). Going forward, this study proposes an AI-Kantism Approach, which suggests the need for African governments to integrate policies related to AI, with a focus on privacy, cyber security, and access to data, while prioritising harmonisation with other governments, local and regional organisations, and academia.

Conclusion and Recommendations

The study notes that utilising AI through remotely sensed data and machine learning algorithms, combined with field data, would provide a comprehensive analysis of ground situations in military operations. The results of this theoretical research stimulate the development of a model for the GIS military and for monitoring the information space of the security sector. The integration of AI with other emerging GIS applications, cloud computing modern systems or the 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 and to exploit the technology's potential to transform military functions and operations. Although military developments across the globe have been revolutionised by AI integrating with GIS, drone technology and machine learning, there is a need to mitigate the risks associated with AI, to determine the future of GIS applications in military operations. Additionally, 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. In applying Kant's Ethical Theory, it is important to ensure that the rights of military personnel and civilians are protected when utilising GIS and AI in military operations, thereby upholding universal moral principles.

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