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Towards the Design of a GIS-Linked Agent-Based Model for the Lake Chad Basin Region: Challenges and Opportunities

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Abstract— Generation after generation of humans has experienced conflicts leading to needless deaths. Usually, it begins as a minor argument that occasionally escalates into a full-fledged conflict. There has been a lingering crisis in the Lake Chad Basin (LCB) of Africa for over a decade leading to bloodshed that has claimed thousands of lives. The terrorist group, Boko Haram has claimed responsibility for these deaths. Efforts have been made by the governments in the LCB region to end the crisis through kinetic approaches, but the conflict persists. In this work, we explored non-kinetic methods used by social scientists in resolving conflicts, with a focus on computational approaches due to the increasing processing power of the computer. Firstly, we reviewed the innovative computational methods available for researchers working on conflict, violence, and peace. Secondly, we described how an Agent-Based Model (ABM) can be linked with a Geographic Information System (GIS) to model the LCB. Finally, this research discusses the challenges and opportunities in constructing a Geographic Information System linked Agent-Based Model of the LCB region.

Keywords—Agent-based modelling, conflict, Geographical Information Systems, Lake Chad Basin, simulation.

I. Introduction

CONFLICT is one of life's unavoidable events. Small-scale arguments may lead to larger-scale conflicts like war. Although there is not a single definition for conflict, concepts like incompatibility, interdependence, interaction, and so on are frequently used to describe it. Conflict may occur when one party feels let down by another [1]. Nowadays, we experience frequent disputes across the world. They sometimes start as peaceful protests that become violent, then riots take centre stage, creating an environment that allows insurgents to proliferate and strengthen into a war situation. In the past 20 years, social scientists have conducted research on anticipating conflict causes and strategies for preventing or mitigating them. The enormous amount of data made available by the contributions of academics from all around the world has led to the advancements made in recent decades. Peacebuilding in conflict zones can benefit from data such as the Armed Conflict Location Events Dataset (ACLED) and the Uppsala Conflict Data Program Georeferenced Events Dataset (UCDP GED), which are analysed and gathered from a variety of sources. The application of computational intelligence to conflict studies has been the subject of current studies [1]-[3]. Numerous social science fields have used computational methods for crisis management. It was initially implemented in conflict areas during the Cold War [2]. The computational method makes use of both quantitative and qualitative approaches for data collection, analysis, creation, and testing of social science ideas, allowing the behavioural dynamics of crisis to be explored [4]. Digital tracing, social networking, online crowdsourcing, online field experiments, deep learning, artificial intelligence, machine learning, and the use of GIS and visualization tools are some of the techniques used. These methods have advanced the field of conflict study by enabling the identification of early warning signs that may be used to anticipate and avert potential confrontations.

The largest endorheic basin in Africa is the LCB, often known as the Chad Basin. It is mostly located in Niger and Chad but covers eight nations. The economies of the nations in the region rely heavily on the LCB. It serves as the region's centre for agriculture [5]. The terrorist actions of Boko Haram have caused instability in the Chad Basin for more than ten years. After their leader, Muhammad Yusuf was killed extrajudicially in Borno State, Nigeria, the group started engaging in violent acts in the late 2000s. By 2010, Boko Haram had become a global organization that had expanded throughout Niger, Chad, and Cameroon. It did this by working with other extremist Islamic organizations in West Africa, including Al Qaeda, Al-Shabaab, ISWAP, and others [6].

This study reviews contemporary methods for resolving disputes and shows how to use GIS with ABM to create conflict scenarios in the LCB. This approach of modelling creates an opportunity to effectively study the behaviour of the actors in the LCB region in the form of agents that relates to each other and the environment. For this reason, the concept of ABM will be explored and discussed in detail in this paper. This research attempts to answer the following questions:

Q1. Which cutting-edge computational techniques are available to researchers studying violence, conflict, and peace?

Q2. What are the possible opportunities and challenges in constructing a GIS-Linked ABM of the LCB region?

The following constitutes the remainder of the paper: A review of relevant work is presented in Section II. Section III

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focuses on computational methods for conflict resolution. Section IV describes ABM and GIS. The challenges and opportunities in constructing a GIS-linked ABM of the LCB region are highlighted in Sections V and VI respectively. Section VII presents the conclusion and future work.

II. Related Work

Human existence and life are characterized by conflict. Most of the time, it begins little, like in a peaceful disagreement, and progresses to large-scale violence, such as in a war. Heraclitus, the philosopher, proposed that warfare is an inherent aspect of human existence [7], [8]. Sociologists argue that social life necessitates a mixture of harmony and discord, like and dislike, and that it is difficult for the world to survive without conflicts [8], [9]. According to primordialism, conflict between two or more ethnic groups that are incompatible will always arise. The instrumentalists believe that ethnicity is an instrument employed by the elites to manipulate them for their selfish ends, which leads to conflicts. Constructivists also contend that elite manipulation is the root source of conflict. Constructivists have the same idea as Instrumentalists: that elites manipulate people's identities as a means of creating crises [9]. Some of these viewpoints are represented in the LCB crisis.

Chad, Cameroon, Niger, and Nigeria make up the LCB, which is situated between latitudes 6^{o} and 24^{0} and longitudes 7^{0} and 24^{0} [10], [11]. Terrorist organizations have caused havoc throughout the region. The Lake Chad region was named Africa's ‘ground zero’ for terrorism by the US in 2016 [12]. The lethal organization known as Boko Haram is one of the well-known terrorist groups destroying the LCB. The militant group was founded in Nigeria to establish an Islamic State with Sharia rule in both Nigeria and the Lake Chad region as a whole [5]. In her study on insecurity in the LCB, Kateřina [13] concentrated on the crisis's environmental origins. He proposed working with international organizations as a means of resolving the dispute. According to some research, the main factors causing violence in the sub-region are ethnicity and elite manipulation [5]. Security challenges in the LCB area have affected economic activities in the area. These activities are mainly herding, farming, and fishing. More so, investors are afraid of carrying out investments in the region [14]. Efforts made to find solutions to the insecurity problem in the LCB have been restricted to social and military warfare. There is limited research on curbing violence through the use of computational approaches like simulation.

Simulation uses computer software to model real-world events by studying phenomena while creating relationships in the process [15]. The field of crisis management has seen a great deal of study done with simulation. Vakalis et al. conducted studies on managing fire crises [16]. They focused on the impact of fire incidence and how to use optimal routing plans to mitigate the effect and save lives. Research in the health sector on infectious diseases using simulations has reduced hospital overload waiting time by between 44% to 76% [17]. Through simulation, earthquakes and bombings can be studied from the resources budgeted immediately after their occurrence [18].

Studies in conflict prediction have gained attention over the years. Mueller and Rauh [19] used topic models to predict conflict from news topics/headlines. Recent news reports data have increased predictive confidence room for warnings [20]. Schutte [21] worked on predicting conflicts in African insurgencies. He, from the assessment of validation of similar research, used geographic data to predict spatial distribution using both in-sample and out-of-sample approaches. Both prediction techniques give minimal errors when compared with the baseline threshold. Blair and Sambanis [22] built a model based on conflict resolution theories anchored on structural features. They explored techniques from the increasingly available big data and growing field of Artificial Intelligence. Specifically, they used procedural models with structural characteristics to improve predictions with higher accuracy. They devised a more direct connection between theory and practical predictions.

ABM is one of the most widely used simulation techniques for crisis management. The idea of ABM has been applied to the analysis of protest and civil unrest situations [23], as well as the investigation of the connections between civil conflict, resources, and ethnicity [24], [25]. ABM was utilized by Martagan et al. [26] to model port crises. They discovered that supply chain crises can be lessened through simulation. Dihé et al. [27] created a modular architecture for simulating actual emergencies. When used, the framework was able to lessen the crisis. Gonzalez [28] developed a multi-agent model architecture that enables crisis response organizations to be unified in their handling of various crisis scenarios by fusing discrete-event modelling with the ABM. Hetu et al. [29] modelled crisis-related situations using a perennial simulation framework. Their system handled the issue and enhanced the current expert advice, creating a symbiotic feedback loop. ABM was used in earlier research by Crooks and Wise [30] to examine how residents moved around Port au Prince, Haiti during the 2010 earthquake. Their work opened up new ground for the investigation of catastrophe response. Other ABM solutions for geographical systems presented a conceptualization of agents through human behaviours, geospatial agents, and simulation [31], [32]. This work seeks to find whether a combination of Agent-Based Simulation and Geographical Information systems can effectively tackle the security situation in the LCB.

III. Computational Methods for Conflict Resolution

Social scientists who study conflict and how to resolve it tend to focus their research on using a computational method [33]. For the purposes of social, scientific, and machine learning research, a wide variety of computational algorithms have been developed. Researchers have modelled conflict outcomes and conflict resolution using the machine learning approach [34], [35]. Research increasingly focuses on identifying potential conflict regions and preventing them as empirical data becomes readily available [34], [36], [37]. Due to flaws in their methods, no system has been able to accurately predict and prevent disputes, despite a great deal of study having been done in this field [38].

Attempts to use different qualitative computational approaches to avert and resolve crises have been studied by social science researchers. A common approach is the use of Panel Data Analysis to analyse two-dimensional panel data with repeated observations over different periods. For analysis, it combines cross-sections of units and times series [38]. This approach typically involves *n* entities, each having *T* observations, measured at 1 via a period, *t*. In panel data, *nT* is the total of all observations [39]. A case-by-case observation of the variables from an individual, group, city, state, organization, or nation is used to arrange the panel data [40]. In a study on defence spending in Western nations, Jan [41] used panel data to find a significant difference between major Western nations and world powers such as the US, France, UK, and others. This difference indicates that smaller Western nations receive defence assistance from the major NATO member states. Another study by Tranchant looked at the connection between ethnic civil war, decentralization, and regional autonomy using Panel Data Analysis [42]. He discovered that using panel data efficiently can lower the number of ethnic hostilities. Previous research has demonstrated that panel data, with a degree of freedom, less collinearity, and data variation, can be utilized to explore individual-specific heterogeneity and sophisticated behavioural models. However, there are several limitations with panel data in the areas of cross-section dependence, short time series dimension, measurement error distortion in certain situations, design, and data collection [42].

Another effective multivariate statistical modelling method for analysing structural interactions is structural equation modelling [43]. Considering that it estimates the many interconnected dependencies in a single analysis, most social scientists who concentrate on conflict resolution employ it. To analyse the structural relationship between latent constructs and measurable variables, it combines multiple regression and factor analysis [44]. This comprises route analysis, partial least squares, confirmatory composite analysis, confirmatory component analysis, latent growth modelling, and confirmatory growth modelling [45]. Social scientists frequently employ Structural Equation Modelling (SEM) because it can be used to infer correlations between latent variables, or unseen constructs, from observable variables [43]. SEM was used for conflict management in Thailand through quantitative research of questionnaire sampling. The analysis showed the model provided a good fit with empirical data using confirmatory data analysis concerning the attitudinal perspective. The study also showed an analysis of information distribution and linearity of variables which when adopted by all stakeholders will help in curtailing conflict [46]. However, since SEM is based on empirical covariances of all indicator variables, it is impossible to estimate more model parameters other than the ones in the empirical covariance matrix [47]. Additionally, the model includes a computationally complex issue that could cause the process to stall or result in an inaccurate parameter estimate [48]. Even though SEM can be used for analysing the behaviour of ABM to unveil measures for social features, the solution is however, limited by the integration of spatial characteristics in the model as well as the unexplored possibility of testing with other models [49].

By using networks and graph theory, the Social Network Analysis technique investigates social structures, in contrast to the SEM, which uses multiple and connected dependencies to resolve disputes [50]. The nodes in the networks are made up of individual actors and persons, connected by links [51]. This approach is used to examine the social and physical space structures, particularly in light of the rise of social media and crowdsourced information. Given the arrangement of the nodes, Social Network Analysis (SNA) can provide the essential details regarding an organization's functionality. Networks work like this: a given network N's structure *S* is connected to a function *F* such that there is a one-to-one relationship with the structure *S* [2].

Two forms of network analysis have been employed by researchers: ego network analysis and complete network analysis. In analysing conflict zones, complete network analysis can be used to obtain relationships among a group of respondents like actors in each crisis zone, while ego network analysis can be used to establish relationships among the various actors [7]. Relationship mapping of this kind can therefore be applied to crisis resolution in areas like the LCB where terrorism is prevalent [7]. In using SNA for conflict resolution, key agents or variables are first identified for negotiations. The network nodes which are the people are connected and analysis is carried out based on degree centrality, closeness centrality, and betweenness centrality. This technique is useful in smaller and larger study spaces in consideration.

In different organizations or social settings, misunderstandings or conflict is inevitable hence the need for resolution strategies. SNA enables the identification of key stakeholders for negotiation and resolution of such crises [52]. Gomez [53] investigated how social networks influence legal dispute resolution in Venezuela. He showed how the interaction of the parties and the relationships among social agents is critical to how legal disputes are processed both formally and informally. Despite the work's emphasis on Venezuela, other emerging nations, such as areas of the LCB plagued by Boko Haram, can use this approach. Even though some critics of Network Analysis say it is overly methodological and less theoretical [50]. Another issue with this method is that it typically produces noisy data, which can result in incorrect predictions if improperly processed [50].

As demonstrated by the qualitative approach previously discussed, quantitative methods such as Bayesian and spatial analysis can also be applied to crisis resolution. A probability-based strategy for formulating a hypothesis is the Bayesian technique [54]. It is a computational approach used by social scientists and other fields for adding new information to existing ones. It updates the changes in the probability distribution of data or parameters following the Prior and Posterior belief relationship as shown in Fig. 1. The strength of this method is the fact that it facilitates the representation of uncertainties relating to the values of the parameters, and it can incorporate prior information [54], [55].

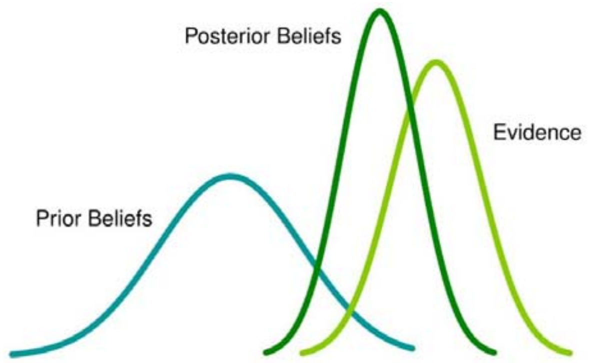

Fig. 1 Prior and Posterior concept of Bayesian method

Bayesian methods such as Bayesian updating are useful for conflict resolution through multiple views and interactions. Though this approach is limited to problems that are characterized by multidimensional interactions among different groups and ex-ante probability, which is reduced by strategic mediation information sharing by the stakeholders involved; however, sharing such information may motivate the most powerful among the warring parties to even embark on conflict/ war. To address this mishap, a Bayesian persuasion framework is used for game theoretical modelling. The process follows a pie game with the mediator and conflicting parties as players, the mediator then controls the information environment using signalling. Finally, action is taken by the parties and payoffs are accorded based on optimal information utilization [56], [57].

Another quantitative approach for resolving conflicts is Spatial Analysis. It uses geometry and mathematical analysis to explain human behaviour [58]. Despite being examined in qualitative research, its examination under quantitative research is now necessary due to the increase in computing capacity [59]. This methodical approach has the potential to both measure patterns found in conflict areas and reveal the mechanisms that gave rise to them. The Thiessen Polygons and nearest neighbour analysis are two instances of spatial analysis. They forecast geographical patterns that may appear in areas rife with conflict. Geographic Information Systems (GIS) are one of the most widely utilized forms of spatial analysis. Its multi-component environment is utilized in the creation, management, visualization, and analysis of data as well as its geographical equivalent [60]. A structured collection of computer hardware, software, and data, known as the GIS, is used to manipulate different geographic references [60]. The LCB datasets and data points can be represented in a geographical information system because they come from a single geographic location. This has the benefit of making data analysis very simple when the data points are arranged in a specific spatial arrangement. There has been an integration of ABM with open-source toolkits like Swarm, MASON, NetLogo, and GAMA which presents opportunities and challenges. These challenges are in the area of building custom models and adopting common standards for players in the field which calls for further research [61]. The potential limitations/challenges of this technique are that some spatial data or the spatial location of the entities are impossible to define and analyse, leading to incomplete information. Also, there is limited educational training in spatial methods, making skilled manpower in this area difficult [59].

IV. ABM Linked Geographical Information Systems

Apart from the qualitative and quantitative approaches used by social scientists for resolving crises, the use of simulation for conflict resolution has also been well-researched. Schelling [62] developed the concept of simulation, which has since been explored in social science fields such as political science, economics, anthropology, and so forth. It results in improved comprehension and control over the behaviour of intricate social systems [60], [63]. Computer models known as "Agent-Based Models" depict people as agents and how they interact with one another and their surroundings [23], [31]. Since they depict objects as they actually occur in the real world, they are more intuitive than statistical or mathematical models. The ABM 's straightforward design indicates that it can be combined with other methods or models in mathematics and statistics [63]. It views decision-makers or active components as agents, and uses agent-related technologies and concepts to represent and model them [64]. ABM aims to: (1) capture our understanding of a system; (2) test our understanding of the system for coherence and comprehensiveness purposes; (3) explore whether theories at the individual level can form aggregated patterns; (4) validate the theory with actual data at the individual or aggregate level; (5) predict the system's outcome and test for multiple scenarios. It can be applied to the analysis of complex adaptive systems and emergent phenomena [23], [24]. A few things must be taken into account in order to build an ABM. First, components that are often unaffected by other environmental elements should be grouped together. A description of the agents' interactions with each other and their cohort environment comes in second. Finally, there should be more components like global properties and other resources in the simulated world. According to Hare and Deadman, ABM systems necessitate local interaction, flexibility, heterogeneous representation for states and behavioural rules, and multilevel observation, particularly if the levels are unconnected [65]. ABM systems incorporate intelligent human activities based on behaviour and phenomena instead of stagnant equilibrium, learning at both the individual and community levels. The integration of ABM with GIS can improve crisis management and predictability.

Mapping, querying, pre-processing, converting, and displaying the input and output model of a geospatial nature are all made possible with the help of GIS [60]. GIS involves the manipulation and analysis of geolocation data tied to the earth's surface. Considering the widespread applications of GIS, its definition tilted towards various disciplines. Advances in GIS development are evident right from the formative years to maturing technology and infrastructure. Applications of GIS are in navigation, geology, surveying, location identification, community developments, and so on [66]. In military operations, they are used for command and control, logistic management, briefing and communication, battlefield simulation, and so on. GIS is only used in principle for dynamic modelling since they are not iteratively designed, and they need an enormous time to run a model [67]-[69]. GIS is designed in a form of one-size-fits-all and it is limited in functionality, especially in processing large datasets. A way of enhancing the performance of GIS for user needs is through linking or integrating it with a modelling system [54], [60]. The development of an API for GIS features has made it simple to connect GIS with spatial modelling. Alternatively, a model can be written in GIS commands and run by a script [68]. Scripting languages like Python have features and packages to address the limitations inherent in GIS.

However, in some applications, using only GIS has limitations as stated above. Paramasivam [70] outlines some limitations of using GIS as not coping with growing datasets with parameters giving room for geographical errors. Other disadvantages of using this system independently include inaccuracies and loss of precision which result from location data as well as privacy concerns since most GIS systems are accessible without restrictions. Some of these limitations are extended to geostatistics techniques where interpolation is important. There are also technical limitations of GIS relating to set ethics. Inaccuracies, projections on wrong planes, and inconsistencies in data formats form such limitations. Some errors such as digitization errors occur undetected because of human constraints. Using data from different sources, keeping up with up-to-date data, and unifying data formats all result in inaccuracies in GIS results. Also, professional responsibility when not taken into consideration can be problematic. There are instances where data checks and adherence to technical standards as well as understanding computational trade-offs can address these limitations [71].

There are other aggregated limitations of GISystems and GIScience to the research community. The problem of systems lacking community adoption for general innovative platforms and neglect of processes that are to be mapped remains a challenge. In detail, the community lacks a dedicated experimental and programming codebase as R is to statistics. The lack of adoption of high-performance computing systems for bigger datasets and complex analysis poses another problem. The scaling-up process will involve a review of algorithms and infrastructure upgrades. The static world of representing objects is outdated as many problems require dynamic representation for example erosion. As human needs are continuously evolving so are GISystems required to advance to cater to these new requirements. Due to the limitations of GISystems, enormous research is needed to integrate GISystems with other systems [72]. GIS and ABM can be used to address decision-making difficulties in complex systems [73]. Our recommendation in this paper is inspired by this combination pointing out why and how GIS and ABM can be used to address a regional challenge.

An already existing system with GIS can be coupled with simulation/modelling to enhance its performance [68], [69]. This is achieved by using data transfer to link two stand-alone systems [31], [54]. Model-agent systems use dynamic environments and empirical analysis. AgentScape as an implementation agent is used for the distributed system. The AgentScape comprises agents, locations, and services with a middleware for communication. The approach supports extendable development for new tasks with the possibility of reusing new agents with a redesign and constructive adaptation [74]. There are possibilities for using ArcGIS from the Environmental Systems Research Institute and Armed Conflict Location & Event Data (ACLED). Many of these platforms have access APIs that can be called for appropriate manipulation and execution with any framework or programming language.

GIS and ABM can be jointly used for policy support in creative industries majorly in addressing the problem of where to invest resources from government and stakeholders. The Creative Industries Development Urban Spatial Structure Transformation Geographic Information System (CID-USST-GIS) model which is flexible and has GIS datasets for spatial observations is used for improving the monocentric urban space-based model previously proposed [75].

There is a framework and domain-specific language for ABM and GIS integration [76]. Advances have been made by combining GIS and ABM in archaeology applied integrated techniques in a dynamic exploration of space and geospatial understanding [77]. Similar expositions have been made in reviewing systems and applications that benefit from the coupling of GIS and ABM methodologies in the domain of environmental and sustainability subjects [78]. In a geographically localized setting, ABM and GIS have been used for modelling the impact of urban development in Kuwait. With population prediction and planning policies, the aggregate model shows land-use style under the categories of shortage of housing and congestion of traffic [79]. In the LCB, the combination of GIS and ABM can provide ample opportunities not leaving out the accompanying challenges.

A. Potential Agent Behavior for LCB

To gather connected agents in a specific area and analyse their interactions over time and space, GIS and ABM integration are required. GIS-linked ABM has been applied in various human endeavours to solve issues. Over an extended period, it has been utilized to make important selections about migration and traffic control. In times of crisis, it has also been used to study how people look for food and how diseases spread in camps for refugees. It has also been utilized in the fields of biology, ecology, and geomorphology [31], [69]. GIS-ABM was utilized by Nourqolipour and Shariff [80] to model changes in land cover and use. Pires and Crooks [81] used the GIS-linked Agent-Based study and socioeconomic data from the nation to study the situation surrounding diamond mining in Sierra Leone and investigate various scenarios. Their results validate Le Billon's [82] idea that spatially distributed resources can trigger conflict.

There are not many studies on GIS-linked ABM relating to a war situation. This research intends to unveil the opportunities and challenges in using it, especially in a war situation like the LCB. The possible parameters for the model in LCB include an initial number of agents which is put between 1 to 30 million [83], the initial percentage population of the Terrorists, which is the range of 0 and 1, as well as other socio-political and environmental factors like poverty index in the region, government policy on security, and employment status. It is expected that the model will increase monthly while the decision to join the terrorists may occur in minutes or hours, though the time for the recruited terrorists to be trained for battle may take up to a month [81].

The agent behaviour in LCB will be modelled using the Physical conditions, Emotional state, Cognitive capabilities, and Social status (PECS) framework. The motivation, potential courses of action, and agent-available behaviour must all be disclosed. Agents in the LCB join terrorist organizations for a variety of reasons. These reasons include the desire to create an Islamic state under Sharia law, being manipulated by elites or their ethnicity, or seeking employment to meet basic necessities like clothing, food, and shelter. The agents can either refocus and find work, or they can join terrorist organizations to satisfy these requirements. As seen in Fig. 2, agent behaviour can be ascertained by analysing these motives and potential courses of action.

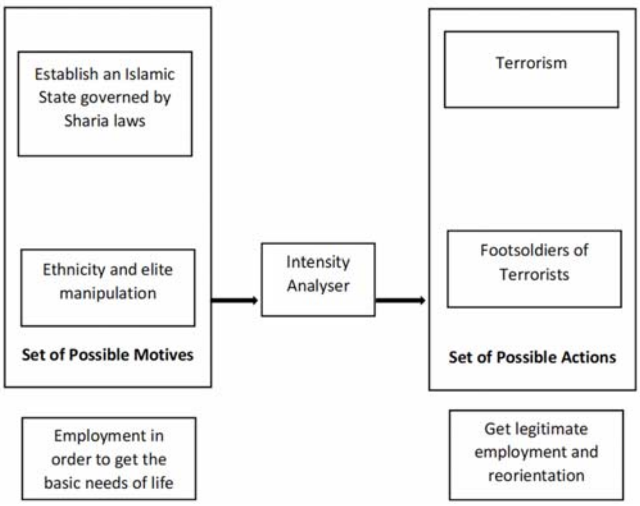

Fig. 2 Possible Intensity Analyzer for the Actors' Motives and Behaviour in LCB

V. Challenges in Constructing a GIS-Linked ABM of the LCB Region

Although GIS-linked ABM has the advantage of freedom in the design, the challenges in this method like any emerging method range from ethical, methodological, and technical. GIS-ABM creates a challenge for less experienced modelers, since the details of the model (like its elements) may not be clear enough, and the source of data collection is usually short-term [84]. Also, due to the generative nature of ABM, developing the model is often based on the use of an alternative design rather than a conventional simulation [84]. Some researchers argue that another prominent problem with GIS-ABM is that nonlinearities in the models inhibit predictions [33]. There are other challenging factors in designing an effective GIS-linked ABM. They include:

1. Deciding whether to use realistic or abstract modelling (Abstract vs. Realism)
2. How to validate a model to see if it is operating well
3. The process of choosing values for the characteristics that control their behaviour (Calibration)
4. How to configure the agents to run in the proper order (timing and synchronization)
5. How to determine whether the model can be executed on the available processing power and memory (Power and Memory)
6. Methods for lowering model error

The rest of the sections explain these factors.

A. Abstract or Realism

There are two schools of thought on modelling: those who believe that accurate models of real-world occurrences cannot be created, and others who believe that accurate models can be created and used to make predictions. Two styles of modelling have resulted from this: realistic and abstract. The processes in the abstract model are constrained and based on heuristics that are employed to manipulate elements in order to investigate system reactions. The realism model uses data from the real world to initialize the system, representing the real world [33]. Since it depends on what is being modelled, we are unable to declare with certainty which model is superior. Since real-world data will be provided, realism is the advised modelling method for the LCB, even though abstract models are simpler to construct. As a result, this becomes difficult because it needs actual data to be calibrated and validated.

B. Validation

In its simplest form, validation is the process of assessing whether simulation results agree with real-world results [85]. Verifying that the developed models can function in an actual setting is the process of validation. A realistic model needs evidence from actual data, whereas an abstract model focuses more on reproducing behaviours. One of the issues with ABM, from a scientific and practical standpoint, is validation. Obtaining sufficient empirical data for the validation procedure is an extremely challenging task [33]. The most rigorous validation method for an ABM-GIS model is to use historical data. While validation of historical data is useful, it seems to be overlooked, probably because it is hard to find data that fits multiple models and does not emphasize sensitivity analysis [85]. In the case of the LCB, real data will be required to carry out a comparative analysis between similar conflict-ridden regions. If the data are not enough or reliable as it occurs in most cases, a simpler plausibility validation approach can be carried out through one-number statistics like Total Absolute Error (TAE). This is carried out by taking the dataset from another region and summing the absolute differences [6], [33].

C. Calibration

In order to deal with the "black box" connection between the system and the outside world, a model typically has to modify its internal values and behaviour [33], [84]. For example, how far can agents covering Cameroon and the Niger Republic see each other if they try to view each other? The model's parameter values must be changed to better reflect reality. Calibration is the process of choosing the appropriate values for the parameters. Although expert information (experience) can be used for calibration, the experts may be unaware of the relationships between the parameters. Even though it will be challenging to test more than three parameters in a huge place like the LCB, it can also be accomplished through experimentation by randomly testing different values. Alternatively, AI methods could be applied here to accommodate the large area of land that the LCB covers.

D. Synchronisation and Timing

Running codes is a problem with agents as well. There are two methods for implementing this: event-based and time-based. The agent reacts following many clock intervals in the time-based approach, typically at each tick. When an agent blocks another, for example, the agents in the event-based model operate following predetermined occurrences. Although the time-based strategy is easier to construct, it performs worse when multiple agents are inactive and real data is used. A clock is also included in the event-based system to help it synchronize with other agents. Usually, the issue appears after the agents are contacted in order. The model patterns will not show up in real life if agents are always called in the same order [33], [84], [86]. An agent that moves first in the LCB scenario may benefit from it, but in the actual world, where movement is random, this sequence of events might not occur.

E. Errors

Another challenge of GIS-ABM is the occurrence of errors associated with model structure, incorrect parameters, and input data [1], [86]. The incorrect data are obtained at the point of gathering the data. In a crisis-ridden area like LCB, accurate data collection may be difficult as researchers may not visit areas of high violence to collect real data. Therefore, to determine how close the model is to reality, it is necessary to weigh its errors. Using "sensitive testing," in which variables are changed to observe how the model reacts during output, is one method of doing this.

VI. Opportunities in Constructing a GIS-Linked ABM of the LCB Region

GIS by itself is not as functional as it could be, but when combined with the ABM, it offers a more realistic way to model the LCB region. This allows for the analysis of the interdependencies and relationships between the agents and the environment. The potential for integrating GIS with the ABM is covered in the succeeding sections.

A. Freedom of Design

When it comes to situations that have been handled successfully or unsuccessfully using traditional methods, GIS-linked ABM presents a number of options. It is capable of handling issues related to intricate systems. Due to its generative character, it enables the observation and study of model dynamics at both the microscopic and local agent levels, whereby the interactions and actions of the local agent level generate the microscopic level. It follows that there are no limitations on the agent's internal organization or the level of depth and complexity of its reasoning. This allows for design freedom, taking into account the environment's and the agent population's heterogeneity [84]. The ability to integrate evolutionary processes, reorganization, explicit optimization, and multi-agent learning techniques is another benefit of the GIS-linked ABM. Conflict monitoring and prediction provide an excellent illustration of the significance of ABM. In contrast to traditional models, which employ probability distribution to address error problems, ABM incorporates simulated humans as agents into the system, endowing them with the ability to recognize errors and unexpected circumstances. Hence, in contrast to traditional modelling, this minimizes the difference between the original and anticipated values [84].

B. Successful Macro and Microscopic Simulations

The majority of current application domains that rely on ABM coupled with GIS are highly beneficial [64]. These domains, which are derived from econometric models, object-oriented simulations, Petri nets, queueing networks, cellular automata, partial differential equations, and other sources, typically contain successful microscopic and macro simulations [64]. The ABM approach and traditional macroscopic approaches differ greatly. The convention macroscopic approach's central tenet is that the system as a whole is treated as a single entity, represented by state variables that undergo periodic updates. While the standard conventional microscopic approach can easily duplicate results (if the parameters and integration procedure are known), it has the advantage of being able to determine the model in plain language because of a mathematical formula in a clear state. Only trained people can access the mathematical apparatus covering microscopic models. GIS-linked Agent-Based Microscopic Models, however, form a flexible actor behaviour and their connectivity to their neighbours is not hard-wired [84], making the model close to reality.

C. Simplicity in Coding

Because object-oriented programming, which includes classes, methods, and properties, replaces procedural languages, which feature procedures, GIS-ABM are relatively simple to code. Multiple objects can be created from the class, but they can have different methods of instruction on what to do. So, this approach creates an “Agent” class that has multiple agents (objects) acting differently. A typical GIS-ABM has an agent class that contains attributes that represent the states of the agent like the location, age, name, and so on [55]. It also has additional coded sections called procedures that regulate the agent's behaviour. Subsequently, the Model class invokes the agent methods to take action. Files for the ABM of terrorist incidents in the LCB can be created using Java, an object-oriented programming language. Terrorists and security personnel can be modelled by agents, with the terrorists able to roam freely in space and seek out targets to attack, and the security personnel able to track them down and apprehend them. A more complex version of this straightforward model including linguistic, logical, statistical, or mathematical decision-making principles can be created [84].

D. Machine Learning Integration

Although attempts have been made in the past in machine learning integrations, more can be done. Machine learning can be used for defining agent types using empirical data. Techniques like clustering present capabilities to group agents' features and environmental attributes. Modelling agent behaviour with cross-validation using derived data can be adopted through different geographical settings. With growing data sets, Machine Learning can learn simulations with agents' flexibility and design and modification of rule sets. Machine Learning's reinforcement learning consists of states, actions, environment, and interactions. Agents can learn to carry out spatial navigation mimicking humans. Spatial cognition of agent behaviour with integration with geographical models presents promising new research directions [32].

E. Power and Memory

One of the most important computer resources for modelling is memory. One of the primary problems with modelling individual things in the real world is that, if not scaled utilizing cloud computing, it demands a significant amount of memory and processing power. For LCB modelling, a significant amount of processing power will be needed because a lot of data will be produced. For example, 33, 554, 432 persons require roughly 1 Gigabyte of memory to store their location (longitude and latitude) and time (minutes, seconds, and mini-seconds) at each location [33], [86], [87]. This implies that between 100,000 and a million agents will be needed to build a GIS-ABM for LCB on a single PC. The use of cloud computing technologies provides an efficient medium for working with GIS-ABM systems where power and memory are an issue [88].

VII. Conclusion

Computational techniques have been used by social scientists to model and manage conflicts and violence for many decades now. Research has shown that computational methods perform better in prediction as compared to mathematical and statistical methods. ABM is one of the computational methods used for modelling real-life events. In some cases, they are integrated with GIS to gather geospatial data for effective modelling. The statistical and computational methods employed by stakeholders involved in conflict, violence, and peace were examined in this research. A GIS-Linked ABM of the LCB region's advantages, disadvantages, and prospects are also included. Given the numerous interacting agents and their complicated behaviours in the LCB region, this research recommends the GIS-linked ABM as a useful modelling technique. This paper highlights the criteria for applying the ABM. Subsequent research endeavours will entail gathering factual information about the conflicts within the LCB area and utilizing a GIS-integrated ABM to simulate them. Additionally, methodological measures will be implemented, ranging from defining the simulation's objective to automating the creation of model documentation.

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