THE APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS (GIS) TO ARMED VIOLENT CONFLICTS RESOLUTION IN THE GREAT LAKES REGION (GLR) OF CENTRAL AND EAST AFRICA

BY

STANISLAS RWANDARUGALI

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ABSTRACT

Armed violent conflict is a persistent global problem, and its severity is more prominent in developing countries, including Africa. In the past decades and more recently, the GLR in east Africa has experienced various armed violent conflicts, notably the 1994 Rwandan genocide, a protracted civil war in Uganda, the Burundi ethnic conflicts, sporadic persistent cross-border ethnic conflicts in Tanzania and an unending guerrilla and civil war in the Democratic Republic of Congo (DRC). Many efforts have been made through conventional approaches, notably negotiations, peace talks, peacekeeping operations (PKO), and peace stabilization, to address these conflicts but sustainable peace remains a challenge and elusive. Most of these conventional approaches emphasize on economic and political aspects and tend to ignore the spatial component in peace talks and decisions making. GIS has been recognized as an invaluable tool in the resolution of armed violent conflicts in other parts of the world. GIS has the capability of integrating, synthesizing, and modelling spatial data, which can assist in policy and decision-making. However, GIS by itself cannot resolve any conflict, but it is a decision support system that can assist different stakeholders in sustainable peace negotiations.

This study aims to explore the application of GIS to armed violent conflicts resolution in the GLR. It is built upon an array of qualitative and quantitative approaches aimed at identifying the origin and evolution of armed violent conflicts; patterns and dynamics of present conflict zones and areas that are currently not experiencing conflicts but may be prone to future armed violent conflicts in GLR in east Africa. In an attempt to trace the origin and evolution of persistent armed violent conflicts in the GLR, and the application of GIS in conflict resolution and peacebuilding, an extensive literature review was conducted. To detect past arm conflict clusters, hotspots, and areas at risk to future outbreaks of armed violent conflicts, GIS spatial analytical techniques were employed, including geocoding, autocorrelation analysis (Moran's I), Hotspot (Getis-Ord Gi*) analysis, and predictive modelling. While geocoding, cluster, and hot spot analyses were performed in ArcMap GIS software to assess the spatial distribution and patterns of armed violent conflicts in the GLR from 1998 – 2017, Microsoft Excel was used to develop a predictive Conflict Risk Model (CRM) for the probability of armed conflicts occurring from 2018 -2038. Thereafter, a conflict risk equation was developed from the CRM to predict areas at risk of future armed conflict outbreak. In response to the absence of a combined spatial data hub in the GLR, a new regional file geodatabase was created in ArcMap, ArcCatalog 10.4 using data from various referenced, survey and institutional sources.

As part of a comprehensive plan to bring sustainable peace in the GLR, this study has identified the Hima –Tutsi empire ideology and the presence of mineral resources in the region as significant factors explaining the origin and evolution of persistent armed violence in the GLR. The study also highlights the application of GIS to identify and assess the spatial distribution, clusters, hot and risk spots of armed conflicts in the GLR and as a decision support tool for armed conflict resolution. From 1998-2017, armed violent conflicts were prevalent in the whole country of Burundi, eastern DRC and northern Uganda. During the same period, there was a significant clustering of armed violent conflict in the GLR at 99% confidence ($p < 0.01$), however eastern DRC emerged as the area with the highest armed conflicts hot spots at 99% confidence. In general, the predictive CRM analysis revealed a 66% probability of armed conflict occurring in the GLR between 2018 and 2038, with DRC predicted to be the most at risk (81%) and Tanzania the least at risk (50%). Together with the newly created regional file geodatabase, these results provide a framework for armed conflict resolution and roadmap for the possibility of sustainable peacebuilding in the GLR.

Areas of future research in the GLR include the development of a geodatabase at country level, the socio-economic and environmental impact of armed conflicts in the GLR, and the development of a robust conflict risk model in the GLR and Africa as a continent. Such a robust conflict risk model including local, regional, and international stakeholders, should assist in proactively, rather than reactively identifying and managing armed violent conflicts in region.

PREFACE

The work described in this dissertation was carried out in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, South Africa. This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

Stanislas Rwandarugali Signed: ____[redacted]________ Date: 03/11/2020

As the candidate's supervisor I have/have not approved this thesis/dissertation for submission.

Dr. Njoya S. Ngetar Signed: ____[redacted]______ Date: 03/11/2020

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I am also grateful to all institutions that freely made their data available online, including the Armed Conflict Location & Event Data Project (ACLED), the DRC National Census bureau, Congo Research Group (CRG), UN Global Pulse (Uganda Project), and International Peace Information Service (IPIS). The University of Kwazulu-Natal Malherbe Library and L’Institut Royal Colonial Bulge or the Belge Royal Colonial Institute (Bruxelles) also merits my thanks for housing and lending me some of the books I consulted for this study.

DECLARATION 1 – PLAGIARISM

I, Stanislas Rwandarugali, declare that:

The research reported in this thesis, except where otherwise indicated, is my original research.

1. This thesis has not been submitted for any degree or examination at any other university.
2. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
3. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written, but the general information attributed to them has been referenced
    b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks and referenced.
4. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed: ____________[redacted]_____________

DECLARATION 2 – PUBLICATIONS AND MUNUSCRIPTS

Rwandarugali. S. and Njoya, N.S (In Review). A hidden empire: origin and evolution of violent conflicts in the Great Lakes Region of East and Central Africa. A Review. *African Journal on Conflict Resolution*

Rwandarugali. S. and Njoya, N.S (In Review). The Application of Geographical Information Systems to violent Conflicts: A literature review. *African Journal of Science, Technology, Innovation, and Development*

Rwandarugali. S. and Njoya, N.S (To be submitted). Geovisualization and Spatial Modelling of Violent Armed Conflicts in the Great Lakes Region of Central and East Africa. *Journal of Geographical Sciences*

Rwandarugali. S. and Njoya, N.S (To be submitted). Making the invisible visible: A Geodatabase development for conflicts resolution in the Great Lakes Region. *Annals of the Association of American Geographers*

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CHAPTER I

GENERAL INTRODUCTION

1.1. Armed violent conflicts

Armed violent conflict is a global challenge and a major concern to many organizations, peacemakers, and governments (Elwell, 2009; Mine, 2013; Kavuro, 2018). The concept of conflict itself is complex and harder to explain when it develops to violence. The word conflict comes from the Latin word conflictus, which means crash or collision (Haas, 2006; Walker and Young, 1997). Many authors have attempted to define conflict in a way that best suits their context. For example, Haas (2006) defines conflict as a struggle between opponents over values and claims to power, resources and scarce status. Even in the ancient/traditional societies, violent conflicts existed and were less complex but dominated by individual and neighborhood community disputes, which were resolved by traditional (local) judges (Pottier, 2002).

Contemporary armed violent conflicts are complex, characterized by more intricate issues (Elwell, 2009), challenging to mitigate and resolve peacefully. Several forms of armed violent conflicts include killings, armed rebellion, terrorism, and inter or intra-state armed conflicts that involve several social groups such as ethnic, religious, and political parties (Wood, 2000; Elwell, 2009; Omeje and Hepner, 2013). Many countries around the world, especially in Asia, some parts of Latin America, and Africa, are and continue to be devastated by persistent violent conflicts. The persistence of these conflicts raises the question of why their solutions and sustainable peace remain elusive.

1.2. Great Lake Region (GLR) armed violent conflicts profile

The GLR is a vast region, and different authors define and describe it differently. For some, the GLR may extend to nine countries (Mpangala, 2004; Prunier, 1995). For the purpose of this research, the GLR is limited to countries in Central and East Africa, including the Democratic Republic of Congo, Burundi, Rwanda, Uganda, Tanzania (Kuradusenge-McLeod, 2018; Kavuro, 2018) (Figure 1.1). In the past decades and more recently, the GLR region has experienced many armed conflicts. These include the 1994 Rwandan genocide, a protracted religious and civil war in Uganda, ethnic conflicts in Burundi, sporadic persistent cross-border ethnic conflicts in Tanzania, an unending guerrilla, and civil war in the Democratic Republic of Congo (DRC) (Mpangala, 2004; Congo Research Group, 2017; Prunier, 1995).

Conflicts in GLR are dynamic, and complex (Mpangala, 2004), and have common features relating to issues of ethnic divisions, governance, exploitation and unequal access to natural resources (Corson, 1980; Vansina, 1962; Mpangala, 2004; Shyaka, 2006; Corson, 1980 and July, 1980). Many attempts to address these conflicts and restore peace have been made through conventional approaches of negotiations, peace talks, peacekeeping operations (PKO), and peace stabilization; however, sustainable peace in the region remains a challenge and elusive. Most of these approaches emphasize on economic and political aspects using concepts to resolve local issues, which commonly ignore the contribution of regional and spatial data, especially in peace talks and decisions making.

Understanding a conflict from various points of view, notably the definition, types, causes, actors, and dynamics, is a good start to obtain clarity on the issue but needs tools and techniques to resolve it (Corson, 1980). From the 1960s (Yoffe and Fiske, 2001) onward, the significant increase in spatial data availability and computer technologies to manage and process them, including Geographic Information System (GIS) and Remote Sensing (RS) has enabled new quantitative research methods to analyses conflict drivers, and to develop predictive models for different types of violence.

GIS has been identified as one of many invaluable tools in conflict analysis, and resolution through the provision and the management of spatial data (Elwell, 2009), which is seen as a missing component in some failed conventional approaches to resolving the persistent armed violent conflicts in the GLR (Congo Research Group, 2017; Elwell, 2009). This computer-based system has the technological capability to integrate, analyze, synthesize, model, store, and displayed spatial data, which can assist in policy and decision-making (Huisman and Rolf, 2009; Yoffe and Fiske, 2001; Martin, 1996; Grimshaw, 1950). However, GIS by itself cannot resolve any conflict; it is a decision support system that can assist different stakeholders in sustainable peace negotiations. This study was conducted using an array of qualitative and quantitative approaches through GIS techniques, aimed at understanding the origin and evolution of these conflicts, identifying their patterns, the present conflict hot and risk spots and the development of a regional geodatabase that could assist in the resolution of armed conflicts in the GLR.

1.3. Research problem statement

The on-going conflicts and crises in the Great Lake Region are multifaceted, complex, and tricky, making it difficult to restore peace and promote integrated development in the region. Further to the commonly known causes of violent conflict in the GLR, Vlassenroot and Verweijen (2015:3) claim that "the escalation of violent conflicts in the Great lake region is associated with the historical development of African kingdoms and the European colonial system of indirect rule." These can be traced back to the 1300 A.D when the Nilotic (Tutsi ethnic) pastoralists from the horn of Africa migrated to different regions, including the Central and East Africa regions, and settled among the other natives, Bantu (Hutu ethnic) agriculturalists. Vansina (1962) adds that they came to the region with a hidden political agenda and aspirations to dominate the native Bantu community through a belief that they are a special race, born with leadership traits from God (Corson, 1980; Vansina, 1962). At the time, when the European colonies came to Africa and introduced new economic and political ideologies, the relationship between local ethnic communities already engaged in conflicts of leadership was further affected in different ways and in varying degrees (July, 1980). As a result, some who were unhappy immigrated to other neighbouring kingdoms (Kavuro, 2018; Chacha, 2004 and Huggins, 2005) and conflicts became a regional reality, demonstrated, and dominated by ethnic and political fighting, the killing of many civilians including political leaders, the presence of various local and international armies, the mobility of immigrants and refugees.

Although many political efforts have been made over the past decades to address these local and regional conflicts through global concepts and politico-economic approaches, notably Negotiations, Peace-making and Peacekeeping Operations (PKO), sustainable peace remains a challenge and elusive in the region. A notable aspect in the crisis of the Great Lakes Region is the failure of conflict resolution experts to acknowledge the value and the contribution of spatial data in conflict resolution, the lack of a robust regional data center or geodatabase, and mutual partnerships to deal with local and regional problems (Goddard and Graham, 1999). Because conflicts in this region are interlinked, to resolve them, regional approaches are necessary (July, 1980; Mpangara, 2004). Although there have been a number of regional inter-state partnerships, these have largely been aggressive, non constructive, compounded by lack of a regional framework and a geodatabase that would include different types of data (Mpangara, 2004). The tasks of responding to these challenges and restore peace in this region need a meaningful, and well-structured regional collaborative (Goddard and Graham, 1999), integrative, and participative model that includes the local community and the government. This lack of an appropriate regional approach, the persistence of unresolved ethnic and political conflicts and the lack of quality spatial data to support peace negotiations explain the reasons for embarking on the present study, in particular, the application of GIS techniques to assist in conflicts resolution and peacebuilding in the GLR of Central and East Africa.

1.4. Aim

Considering the background and research problem discussed (Section 1.2 and 1.3), this study aims to explore the application of Geographic Information System (GIS) to armed conflict resolution in countries of the GLR, East and Central Africa.

1.5. Objectives

The specific objectives are:

- To trace the origin and evolution of persistent armed conflicts
- To review the recent development areas of GIS application in the conflict resolution and peacebuilding
- To identify and map the spatial distribution of conflicts in the GLR
- To assess and map the conflict clusters and hot spots
- To develop a conflict risk model
- To develop a Geodatabase of armed conflicts dataset in the GLR

1.6. The study area

The study area includes the five countries in the Great Lake Region of East and Central Africa. The specific coordinates of these countries are Burundi **(**3°22'23" S 29°55'8" E), Rwanda **(**1°56'25" S 29°52'26" E **),** Tanzania **(**6°49'24.6" S 39°16'10.2" E), DRC (4°2'18" S 21°45'31.2" E**);** and the country of Uganda **(**1°22'24" N 32°17'25" E) (Figure 1.1), and borders with Sudan, Congo Brazzaville, the Republic of Central Africa, Malawi, Kenya, Angola, Zambia and Mozambique (Figure 1.1). As the name indicates, the GLR is characterised by several lakes notably Lake Victoria, Lake Tanganyika, Lake Edouard, Lake Kivu and Lake Edouard, important for social and economic development in the region (Giannini el al, 2008; Goddard and Graham, 1999).

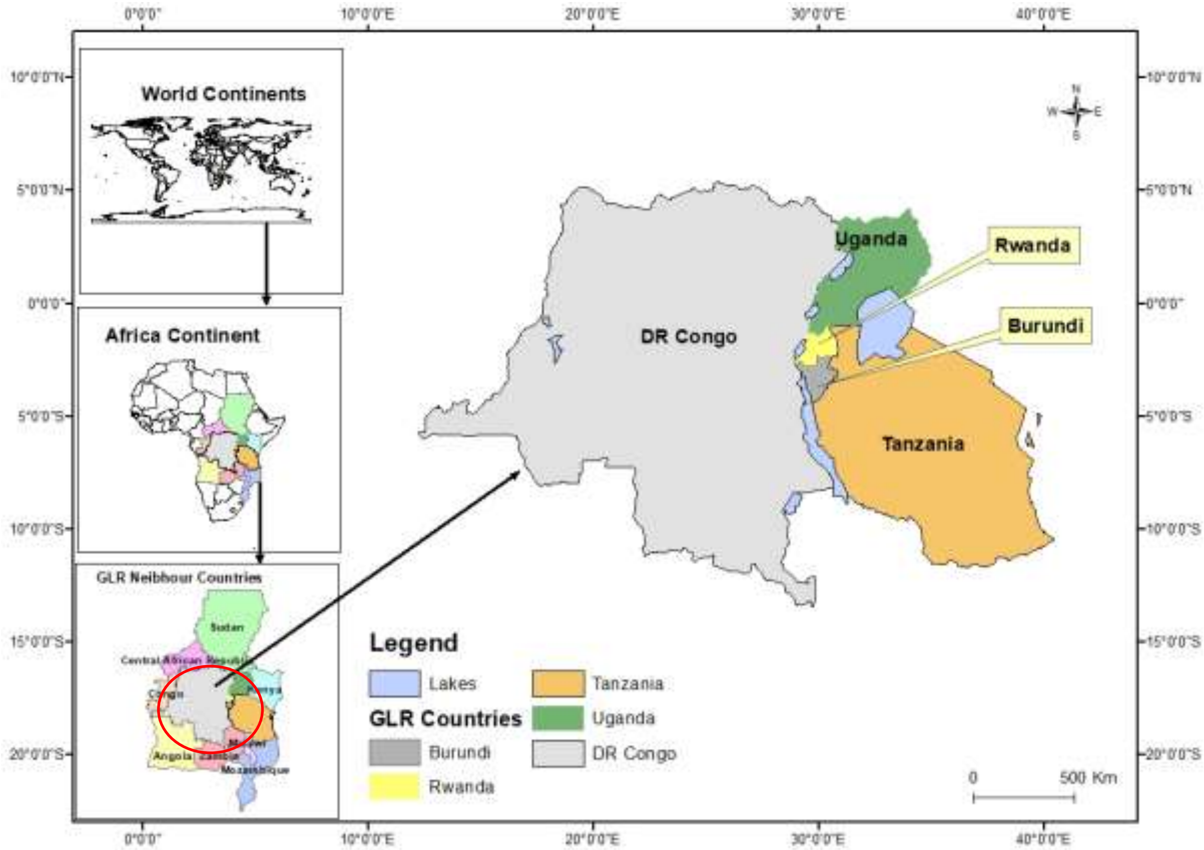

Figure 1.1 Location map of the study area (Data source: Geography Department, University of KwaZulu-Natal, and International Peace Information Service (IPIS)).

1.7. Thesis outline

This thesis consists of six chapters beginning with the introductory chapter (Chapter One) and the concluding chapter (Chapter Six). In between these chapters, are Chapters Two, Three, Four, and Five presented as a series of individual journal articles addressing the objectives of this study. Although each of the four middle chapters has been written in the form of separate journal manuscripts which can be read independently from the thesis, each chapter is linked to the main aim of the study. For this reason, there are some replications and overlaps in the introduction, method, and references of individual chapters. A brief overview of each chapter is as follow:

Chapter 1 present a general introduction to the thesis, problem statement, and outline the aim and objectives of the research as well as the description of the study area.

Chapter 2 is a more in-depth history and background on the origin and evolution of the persistent violent armed conflicts in the Great Lakes Region, providing a better and clearer context for subsequent chapters.

Chapter 3 provides an overview of recent developments on the application of GIS technology in conflict resolution. The chapter also highlights the challenges and gaps in the existing literature.

Chapter 4 focuses on the Geovisualization and Spatial Modelling of Violent armed Conflicts in the Great Lakes Region, with special attention to conflict clusters, hot and risk spots, and development of a conflict risk model.

Chapter 5 presents a newly created regional Geodatabase, supposedly, the first of such kind to assist in conflict resolution in the Great Lake Region and the limits in its applications.

Chapter 6 synthesizes the different chapters, summarizes the study findings, and presents the concluding remarks, recommendations, and directions for future research.

CHAPTER 2

ORIGIN AND EVOLUTION OF VIOLENT CONFLICTS IN THE GREAT LAKES REGION (GLR)

This chapter is based on:

Rwandarugali. S. and Njoya, N.S (in Review). A hidden empire: origin and evolution of violent conflict in the Great Lakes Region of East and Central Africa. A Review. *African Journal on Conflict Resolution.*

Abstract

This paper critically reviews the origin and evolution of armed violent conflicts in the Great Lake Region (GLR) countries of East and Central Africa (ECA), with reference to the Hima-Tutsi empire ideology. The persistence of these armed violent conflicts and the lack of a sustainable peace approach in the region are highly contested issues and motivate this study. Conflict, social dominance, mass-society, relative deprivation, leadership, great man, and trait theories guide this study. This study is conducted using an array of qualitative approaches. Data was obtained by reviewing and analyzing existing literature through interpretative, exploratory, and linguistic techniques. Attempts by various authors to offer explanations to the origin of conflicts in the GLR, have only succeeded in vaguely describing related historical and commonly known factors, notably ethnic identity, African kingdom, colonialism, nationalism, access to natural resources, and the empire ideology. However, they fail to articulate the evolution and persistence of these conflicts to the present day. This study argues that to a great extent, the Hima-Tutsi empire ideology sustains conflicts in GLR countries and is seemingly a hidden political ploy by a Nilotic ethnic group to maintain hegemony over other ethnic groups in the region.

Keywords: Armed violent conflict, origin, evolution, empire ideology, Great Lake Region

2.1. Introduction

Over many decades and more recently, GLR has experienced various armed violent conflicts notably the 1994 Rwandan genocide, a protracted civil war in Uganda, Burundi ethnic conflicts (Mpangala, 2004; Shyaka, 2006 Gounden, 2017, 2012; Cedric, 2002; Uvin, 1999), sporadic persistent cross-border ethnic conflicts in Tanzania, and an unending guerrilla and civil war in the DRC (Uvin, 1999). This study critically reviews the origin and evolution of these armed violent conflicts in the GLR countries. Certain studies, including Mpangala (2004) have attempted to unpack the origin of the GLR's armed violent conflicts and maintain that they are rooted in the historical developments of ethnic kingdoms and colonialism. Contrary to this partial view, other researchers, including Atkinson (2011) point to the long history of natural resources exploitation and trade as the major cause and persistence of these conflicts. Lemarchand (1999:15) further argues that "historical evidence lends a little credibility to prove the persistence of the conflict but ethnicity. These writers have attempted to expose their views on the causal factors and processes contributing to conflicts in the region but failed to expand on the factors fanning their evolution and persistence. This study sheds light on other hidden factors contributing to the evolution and persistence of armed violent conflicts in the GLR and argues that the Nilotic Hima-Tutsi ethnic empire ideology more vividly plays a significant role in sustaining the conflicts in the GLR. This ideology serves as a hidden political agenda for them to keep hegemony over Bantu groups in the Central and East African region and even beyond.

2.2. Description and historical background of the study area

The study area includes countries of the GLR, notably Burundi, Democratic Republic of Congo, Rwanda, Tanzania, and Uganda, situated in Central and East Africa. These GLR countries are known to share both historical, cultural, and political backgrounds that are commonly related to ethnic identity, governance, citizenship, tradition, colonial land rights and mineral resources exploitation, and trade (Vlassenroot and Verweijen, 2015). To a large extent, Vlassenroot and Verweijen (2015:3) claim that "the escalation of violent conflicts in the Great lake region is associated with the historical development of African kingdoms and the European colonial system of indirect rule." Such developments can be traced back to the 1300 A.D when the Nilotic (Hamite) pastoralists from the horn of Africa , specifically in Sudan and Ethiopia along the Nile cotters (July, 1970; Mertens, 1935), migrated to different regions including the Central and East Africa regions and settled among the Bantu agriculturalists, one of the largest African indigenous ethnic groups, already settled in the region (Mpangala, 2004). While there is no specific number of Nilotic ethnic group proportions in Africa, they are a minority group to Bantu people living in GLR countries (Linda, 2014; Lemarchand, 1999).

Generally, the “indigenous inhabitants of Africa include more than 1,000 different ethnic groups” (Conrad, 2009:10), dominated by the Bantu ethnic group. According to Linda (2014), Bantu, which means ‘the men’ or ‘human being’, constitutes about 90% of the whole African population (Stanislas, 2014). One of these Bantu tribes is the Hutu, an ethnic name given specifically to some Bantu people living in many African countries, predominantly in the GLR, notably Rwanda, Burundi, DRC, Tanzania, and Uganda (Shyaka, 2006). These Bantu ethnic groups cohabit with the Tutsis, a name given to the Nilotic people living in Rwanda, Burundi, DRC and Tanzania; and the Hima, another name to the Nilotic people living in Uganda (Shyaka, 2006). Vansina (1962) maintains that on arrival, the Nilotic (Hima-Tutsi) in the region assimilated Bantu (Hutu) customs, rituals, and dominated by taking over Bantu leadership. Paw's (2012) view was that the shift in leadership caused unhappiness to the Hutu community members, and some chose to immigrate to neighbouring kingdoms. Shyaka (2006) maintains that the Nilotic ethnic group later developed a political agenda and aspirations to dominate the

Bantu community through a belief that they are a special race, born with leadership traits from God (Corson, 1980; Vansina, 1962).

At the time, when the European colonies came to Africa and introduced new socio-economic development and political ideologies, the relationship between ethnic communities was further affected in different ways and in varying degrees (July, 1980). As a result, some who were unhappy with both the local Nilotic leadership and the new colonial administration immigrated – or put succinctly, fled their kingdoms – to other neighbouring kingdoms (Huggins, 2005 Mertens, 1935). In their new environments, they hoped to easily integrate and construct new identities" (Lemarchand, 1999:5). Unfortunately, settling and integrating into their new environments was never easy. A sense of belonging became an obstacle to their self-integration (Pottier, 2002 and Salomon, 1997), creating a suspicious living environment, mainly between indigenous ethnic groups, resulting in some tribal, violent conflicts (Vlassenroot and Verweijen, 2015 and Pottier, 2002).

2.3. Conceptual and theoretical framework

To shed light on various facets of the origin and evolution of armed violent conflicts in the GLR, a number of concepts need clarification. Understanding a conflict from various points of view, notably the causes, actors, and dynamics (Northouse, 2012), can play a significant role in informing the conflict resolution processes. Several theories provide a framework for a better understanding of the complexity of these violent conflicts in GLR and conflict resolution strategies. Some of these theories include the conflict theory (Elwell, 2009), which is the master theory for this study; the mass-society theory (Lang, 2009); the relative deprivation theory (Saleh, 2013); the social dominance theory (Rose, 1998); the leadership theory (Linda 2008; Vansina, 1962) and the great man and traits theories (Corson, 1980).

Karl Marx, the father of conflict theory, postulated that tensions and conflicts arise (Ditton and Duffy, 1983) when resources, status, and power are unevenly distributed between groups in society (Ditton and Duffy, 1983;Elwell, 2009). These genres of conflicts become the engine for social change (Northouse, 2012) and are conceptualized drivers to control material resources, accumulate wealth, acquire political and institutional power in the society (Temple-Raston, 2005).

Elwell (2009) explains conflict as a disagreement through which the parties involved, and perceive a threat to their needs, interests, or concerns. Using this explanations, for any conflict to occur, firstly, there is a disagreement (including among others, differences of opinion regarding certain facts and interpretations of reality), generating tensions and thus conflict among the parties involved. This conceptual understanding is supported by Lake and Rothchild (1996), who maintain that conflict tends to be accompanied by significant levels of misunderstanding and disagreement. Thus, an understanding of the actual nature of a disagreement will help parties to identify their actual needs, providing an opportunity to engage in conflict resolution (Elwell, 2009; Lake and Rothchild, 1996). Deutsch (2006) adds another dimension to conflicts pointing out that they only arise in situations where people are interdependent – where what people do may have a considerable effect on others.

Another aspect of conflict theory discussed by Marx is the social dominance theory, which states that group-based social hierarchy (Rose (1998) is produced by the net effects of discrimination across multiple levels: institutions, individuals, and collaborative intergroup processes (Sidanius, et al, 1995; Deutsch, 2006). Discrimination across these levels is coordinated to favour dominant groups over subordinate groups (Sidanius et al, 1995; Pratto et al, 2006). This philosophy by Karl Marx helps in understanding the complexity of conflicts and how socio-economic patterns can influence some members in society to dominate others (Lake and Rothchild, 1996). Further to Karl Marx's thought, Rose (1998) argued that the social dominance theory could better be understood by observing those with wealth and power who try to hold on to it by any means, mainly by suppressing the poor and powerless. Unlike other social theories, the social dominance theory is suitable for better understanding the prejudices and discriminatory practices in society. Marx's social dominance theory provides a basis for understanding various forms of social dominance among ethnic and social groups as well as group-based oppression in the GLR (Timsina and Karki, 2015).

Conflict in the GLR can also be related to the relative deprivation theory. The relative deprivation (RD) refers to"the tension that develops from a discrepancy between the 'ought' and the 'is' of collective value satisfaction" (Gurr and McClelland, 1971:23). He contends that people are more likely to revolt when they lose hope of attaining their societal values (Saleh 2013; Gurr, and McClelland, 1971). Application of this theory in the GLR is evident where displaced groups are denied citizenship and naturalization rights (Pottier, 2002; Shyaka, 2006), leading to political and ethnic confrontations between host communities, immigrants, and refugees.

Commenting on the role of political leadership (Leadership theory), Vansina (1962) Vandeginste (2015) indicated that the past institution of a monarchy and the power wielded by some contemporary presidents are similar. Nowadays, some of these presidents are considered kings due to their leadership style, and they often try to stay in power and create a dynasty. For instance, recently, in 2015, a Rwandan referendum paved the way for the amendment of "the constitution to allow the president to potentially stay in power until 2034" (Carter, 2017:37). Similarly, in May 2016, the DRC Constitutional Court ruled that the President could remain in office beyond his constitutional term limit until a successor was in place" (Prunier, 2016:5).

Concerning the Great Man and Trait theories, Corson (1980) goes further to describe these leaders and argues that they are more relevant to providing a better understanding of the contemporary situation from the past. Proponents of these theories, often assert that the capacity for leadership is inherent (Spector, 2016) – great leaders are born with it, not acquired by learning (Northouse, 2012). The Great Man theory came with another complicated gender-based concept in the GLR, where only men are perceived as those possessing this inborn capacity for leadership in comparison to women (Vansina, 1962). Similarly, the Trait theory, in some ways, complements the Great Man theory, maintaining that people inherit certain qualities and traits (Northouse, 2012) that make them better suited as leaders (Corson, 1980 and Northouse, 2012). Linda (2008) further explains that the Trait theory often identifies particular personality or behavioral characteristics shared by leaders.

The Leadership, Great Man, and Trait theories well explain the perception and mythology of the Tutsi or Hima ethnic group in the GLR often viewed as a special race to lead others. They believe that they possess unique leadership qualities that the Hutus majority and other ethnic groups in the region do not possess (Lemarchand, 1999; Vansina, 1962). This Tutsi perception introduces a dilemma on the question whether Hutu people also possess those unique qualities (Wagner, 2008). This dilemma is compounded by the events where Hutu democratically elected leaders, are often targeted for removal from elected office or assassination (Linda, 2008; Pottier, 2002; Shyaka, 2006).

Lang (2009) and Bennett (1982) introduced a sociological perspective of conflicts through the 'mass society' theory. Both authors agree that there is no standardized definition of this theory due to its complex interpretations and applications in different disciplines. However, its basic tenets, as applied to this study, are that masses of humanity are controlled by a small group of elites using different mass media methods for their political and economic interests (Bell, 1960 & Bennett 1982). In turn, the masses resist such elitist control through organized rebellions, uprisings, and public order disruptions (Lang 2009 & Bennett, 1982), often resulting in conflicts (Elwell, 2009). In the context of violent conflict in GLR, the control of power by a small group believed to be special (Great man and trait theories), and their control of the masses (mass society theory) play a significant role in the evolution and the persistence of conflicts in the GLR.

2.4. Methods

In this study, a qualitative method was used to collect and analyze data. Data was obtained through the review of books, journal papers, and online materials, including government and scientific reports. The interpretative and exploratory approaches (Onwuegbuzie & Teddlie, 2003) - a research technique used for a problem that has not been studied more clearly, was used to analyze the results. This technique is not only useful for decision-making but can also provide significant insight into a given situation. A linguistic approach to this study was also adopted based on the review of mainly English-language based documents. However, a few documents were in French and Swahili (a common local language spoken in most of these five countries). A considerable number of references that were suggested by other authors as essential readings and key themes related to GLR conflicts notably ethnic identity, African kingship, colonialism, nationalism, natural resources, and empire ideology, were compiled and analyzed to shed light on the roots and evolution of violent conflicts in the region.

2.5. Results

There have been several attempts by researchers and historians (some more convincing than the others) to explain the origin and dynamics of violent conflicts in the GLR region. In an attempt to shed light on the problem of conflict in the region, most writers, both historians and researchers describe and cite prominent factors such ethnic divisions, kingship, colonialism, nationalism and natural resources as the root causes of the conflicts but fail to capture their evolution over time and the main reason for their persistence.

Despite the controversy surrounding these causes of conflicts, ethnic division is the most recurring in the literature as a major factor (Lemarchand, 1999). Hutchinson and Smith (1996:6) Smith define an ethnic group as "a named human population with myths of common ancestry and shared historical memories".

Against this background, the complexity and dilemma of using ethnic heterogeneity as a catalyst of conflict are evident in Chavez (1998), who maintains that the construction of ideologies along ethnicity can sometimes lead to both conflict or social cohesion like sharing cultures, self-learning from others or education as a whole. Therefore, multi-ethnic societies can prosper in their diversity (Hutchinson, 1996; Chávez, 1998; Watt, 1996, Kanyangara, 2019). As Chavez (1998). Hutchinson and Smith (1996) further puts it, a sense of ethnic identity is developed from shared culture, values, religion, and language of individuals who are often connected by strong loyalty and kinship as well as proximity. This thought is supported by Gounden (2017), that the presence of diverse ethnic groups in a specific country, region or area by itself, is not sufficient to trigger conflict; ethnic heterogeneity does not necessarily breed war. The existence of many peaceful countries supports this view despite their ethnic and cultural diversities. Some examples include neighbouring countries like Tanzania and Kenya with a higher level of ethnic diversity (Mpangala, 2004; Shyaka, 2006), but with less and occasional reports of ethnic violence, mostly during election periods. According to Chavez (1998) and Shyaka (2006), it is then wrong to put ethnicity in one box and conclude that the presence of ethnic diversity in a society is the leading cause of conflicts. Therefore, ethnic heterogeneity does not necessarily breed a war, and its absence does not ensure peace either, as Sharma (2012) and Lemarchand (1999) explains. Lemarchand (1999:4) further and argues that ethnicity is a complex phenomenon and "is never what it seems" and may not be the real cause of conflict in countries of the GLR. Kanyangala (2016) and Gounden (2017), for instance, in their research found that in these countries, ethnicity has reportedly been exploited by political leaders for their ends, but it is not a direct cause of wars and other violent conflicts in the region. It is therefore apparent from the discourse by these cited authors that it would be fallacious to conclude that violent conflicts in the GLR are solely caused by ethnic diversity.

The role of African Kingship and/or Chiefship (Kanyangala, 2016; Vansina, 1962; Conrad, 2005) has been cited as another factor of serious debate in the literature as a cause of conflicts. According to Vansina (1962), African kingdoms are sovereign political groups, headed by a single leader, who delegates authorities to representatives in controls of territorial units into which the country is divided (Vansina, 1962; Kanyangala, 2016). Conrad (2005) asserts that the early intra and inter-kingdom conflicts in Africa, including the GLR were the results of kingship and their authorities over land rights and kingdom expansion. There is no doubt that African kingdoms played a significant role in the past armed violent conflicts during the monarchy period in the GLR (Kanyangala, 2016 and Vansina, 1962); however, these authors fail to explain why in the modern society, violent conflicts are still a significant challenge.

Another controversial factor of armed violent conflict that has been a subject of debate by authors is the role of colonialism and imperialism in Africa. Mpangala (2004) points out that the seeds of conflicts in the GLR were sown under colonialism through the insemination of divisive ethnic ideology and creation of artificial borders. In his view, the European colonial imperialism created and invented ethnicity and promoted ethnic consciousness among the colonized people. Therefore, according to Mpangala (2004), European colonialists were responsible for the origin of these violent conflicts. Ramadhani (2011) introduces another complicated thought to challenge Mpangala's view, based on the fact that most African countries were colonized, but not all have experienced armed violent conflicts up to the present (Ramadhani, 2011; Melvern, 2006; Woodward, 1996). Evidence includes the country of Malawi, Botswana, and many other African countries that are conflicts free. This argument is further compounded by the realities in other African countries that had little colonial influence or considered to have never been colonized like Ethiopia and Liberia (July, 1980; Ramadhani, 2011) but has had their share of violent conflicts. Indeed, Ethiopia is a unique case that has been severely affected by ethnic and political conflicts but was not colonized (Woodward, 1996). Based on these realities, it is probably an overstatement or a gross generalization to cite colonialism as a contributing factor to the current violent conflicts in the GLR. Historically, Shyaka (2006) and Chege (1997) are not also convinced that colonialism is a direct cause of conflicts in the GLR. However, they agree that colonial administrations played a significant role in the support and formalization of existing ethnic kingship administrations (Shyaka, 2006; Chege, 1997). For instance, in Rwanda, Burundi, and DRC, Chege (1997) affirms that the Belgian colonialist in the decade from the mid-1920s to the mid-1930s significantly supported class distinction between the Tutsi minorities and Hutu majority. Therefore, the Belgian colonial administration was a key element in formalizing ethnic divisions and strengthening the division between the Tutsis and the Hutus (Shyaka, 2006; Chege, 1997), and by so doing, sowing the seeds for conflict but not causing it among citizens who were already tired with kingship regime.

Nationalism has been named as another factor responsible for violent conflicts in the GLR in the 1960s (Lewis, 1996; Mann 1985; Mpangala, 2004; Wohlfarth, 1995). Mpangala (2004) and Wohlfarth (1995) introduce this factor, pointing out that "after the end of the Second World War, the concept of nationalism became a cause for violent conflicts in many African countries vying for independences (Mpangala, 2004). According to Mann (1985:7), Nationalism is "an ideology embodying the feeling of belonging to a group united by common history within a given territory and entitled to its own state." Such nationalistic ideologies were cited as a new source of political conflicts for oppressed citizens to regain power (Lewis, 1966), mainly through political parties. Initially, political parties and coalitions along ethnic lines were established to overthrow, firstly the monarchy rule and later the colonial administration (Mpangala 2004; Lewis, 1996). Nationalism is still a factor that divides some countries along ethnic and political lines but has not been a source of persistent conflict in many other countries. Some examples include the countries of Botswana and Zambia, which are still conflict-free. Moreover, nationalism can be tamed with proper governance that is inclusive of all ethnic groups and political parties.

Further to the factors cited above, the abundance of natural resources and their exploitation has also been named among factors of violent conflicts in Africa (Chege, 1997; Musahara, 2005). Except for few African countries like Botswana, where mineral resources have contributed to a prosperous economy (Musahara, 2005), many other African countries, rich in natural resources, have been victims of persistent conflicts and civil wars (Luka, 2012). The "way resource wealth is distributed matters a great deal" (Badeau & Wegenast, 2009:42). There are other examples of African countries like Angola and Nigeria (dominantly petrol producing countries) who have suffered from decades of violent conflicts due to the availability of mineral resources. This is also true in the GLR where, for example, "valuable minerals have been listed among the main drivers of civil conflicts," particularly in eastern DRC (De Luka, 2012:5). DRC is viewed as the richest African country in mineral resources, mostly diamond and gold, but economically poor (Gounden, 2017; Vogel, et al, 2018) and has been plagued by violent and unending civil wars– armed conflicts between the state and organized rebel groups (Basedau and Wegenast, 2009). DRC exemplifies a common situation on the African continent, where valuable natural resources are more of a curse than a blessing (Chege, 1997; Gates, 2016).

That the existence of violent conflicts in the eastern region is linked to the availability of mineral resources contrasts with the peace evident in the western region of DRC, which is not much endowed with mineral resources (Figure 2.1a&2.1b).

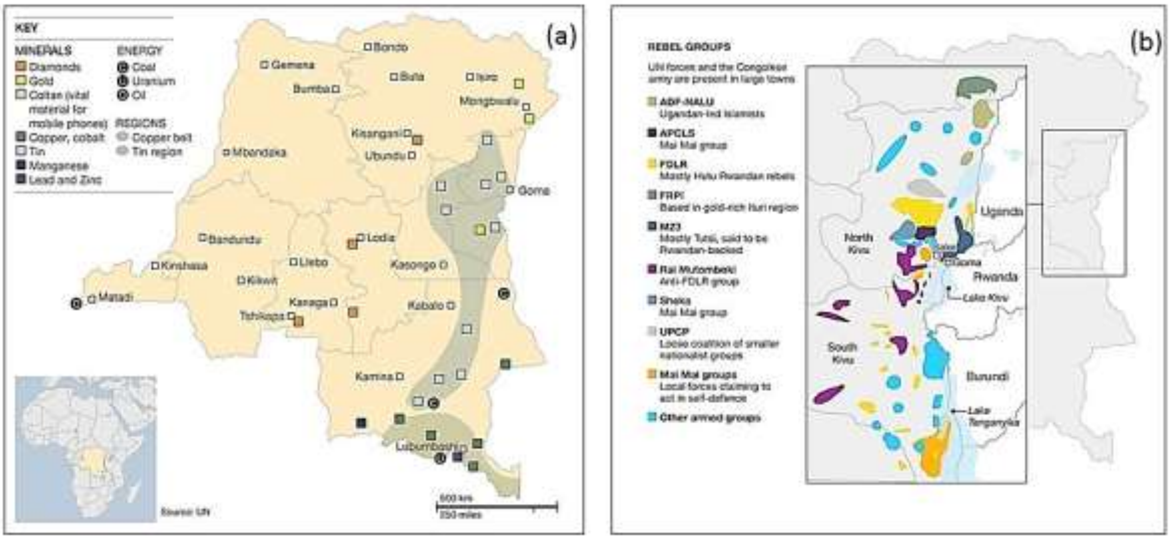

Figure 2.1 Spatial distribution of **(a)** Mineral resources and **(b)** Rebel groups, in the eastern region of DRC. (Data source: www.rovingbandit.com).

Figure 2.1a shows the concentration of various minerals in the eastern region of DRC, while Figure 2.1b shows an overlap of rebel groups with mineral resources in the same geographical region. Despite this evident link between natural resources and violent conflicts, Ramadhani (2011:3) has questions why "other countries like Botswana, for instance, with many mineral resources are not necessarily affected by violent conflicts." This discourse introduces doubts leading to the partial conclusion that the availability of mineral resources alone is not enough to justify the persistence of violent conflicts in GLR but a complex mix of factors.

2.6. Discussions

As findings indicated, the origin and evolution of violent conflicts in GLR is a complex situation. Several factors are said to contribute to the causes of violent conflicts in the region, but not merely enough to justify their evolution over time. Some of these factors considered and analyzed in this study include ethnic identity, African kingdoms, colonialism, nationalism, and natural resources. Ramadhani (2011) maintains that violent conflicts in the GLR are caused and sustained not just by a single factor but by a complex mix of factors. However, the main argument put forward in this study is that the absence of persistent conflicts in other regions of Africa with similar issues suggests that the Hima-Tutsi empire ideology was and is still the root cause and lubricator of the persistent conflicts in the GLR. This ideology has been used to achieve political and socio-economic goals related to the maintenance of power (to rule and not be ruled) and control natural resources in the region.

This quest to maintain power in the region is backed by the leadership, great man, and trait theories (Corson, 1980; Linda, 2008; Northouse, 2012; Vansina, 1962) discussed earlier in this study. Supporting this argument are Kanyangara (2016), Chavez (1998), Lemarchand (1999), and Gounden (2017), who also contend, for example, that ethnic diversity is not a justification for the persistence and recurrence of armed violent conflict in the region. Lemarchand (1999) further expands on this argument, adding that ethnic heterogeneity does not breed a war, and its absence does not ensure peace either. Perhaps a better understanding rests on the desire or ideology to establish the Hima-Tutsi empire in the GLR and, as demonstrated throughout the study, is the probable root cause of the persistence and recurrence of conflict in the GLR. The role of the Tutsi-Hima empire ideology in the persistence of violent conflict in the GLR can be justified by tracing the leadership style of previous monarchical leadership and comparing it with contemporary constitutionally democratic leadership in the GLR which bears stark similarities. Vansina (1962) provides a window into past African monarchical leaderships defining them as sovereign political groups, headed by a single leader (Northouse, 2012; Vansina, 1962), They delegates authority to representatives in charge of territorial units into which the country is partitioned. In this setting, the King has absolute powers in decision-making, and was viewed as a god and therefore not to be challenged or opposed (Lemarchand, 1999).

Uvin (1999) adds by stating that both Burundi’s and Rwanda's ancient and current leadership are in the hands of a single leader, who is a supreme leader and a sole decision-maker. These leadership styles often based on ethnic lines are evident with both monarchical and constitutionally democratic governance in the said countries and supports the argument presented in this study. The desire to establish a Hima-Tutsi empire in the GLR is the rationale behind maintaining power in the hands of Tutsi minority, sometimes backed by coup d’état, and armed violence in GLR.

Shading light on this ideology or desire, Eszterhai (2007:50) defines an empire as a "geographical component with a centre, surroundings, and peripheries, characterized by a huge territory often occupied by other countries”. Akson (2011) provides a similar definition explaining that an empire is geographically bigger than a country or a nation. To fully understand the concept of empire ideology, Ugarriza and Craig (2013 describe ideology as a set of political ideas that are bound together with a minimal level of consistency and that stand in contrast to competing sets of ideas. Thus, the Hima-Tutsi empire ideology is a set of political ideas nursed mainly by the Hima ethnic group in Uganda and Tutsi ethnic groups in Rwanda and Burundi with a view to exercise their power and influence over the geographical space engulfing the GLR. For example, Kavuro (2018:1134) argued that the current Rwandan Tutsi-dominated leadership's insistence on hunting down Hutu refugees in the DRC had turned the territory of the DRC into "a fully-fledged battlefield for Hutus and Tutsis". In its aggressions against the DRC, Rwanda further justified its actions on the protection of the Tutsi minority (the Banyamulenge) in the DRC against Hutu *genocidaires (genocidals)*. In turn, the Banyamulenge rose against the DRC government, backed by the Rwandan government.

The role of empire ideology in African conflicts is not new. While the notion of empires has been conceived by some authors to be of European origin (Eszterhai 2007; Kranigan 1976), Conrad (2005), Davidson (1996) and July (1950) contest these views pointing out that some regions in Africa had developed their own empires before the extension of European empires to Africa through imperialism. For example, while July (1950) vaguely mentions the existence of Medieval north-western African empires, Davidson (1996:51) points explicitly to the Ghana "empire in the early 300AD, followed by Mali". July (1950) further explains that ancient African empires were formed through kingship and chiefship, who engaged in territorial expansions and built empires by conquering their weaker rivals and adding their lands and commercial revenues to their domains while spreading their culture (Conrad 2005:109). It is within this context, that the Hima-Tutsi empires is being expanded.

These historical facts support the argument that the empire ideology is a long-existing African ideology that proceeds European colonialism and relates to the exercise of extended territorial political power to protect their majestic interest (Cornad, 2010; Uvin, 1999; Davidson, 1965). In the GLR, though not an empire in comparison to the west African Ghana, Songhai, or Mali empires, the Hima and Tutsi Kingdoms reigned before the arrival of colonial imperialism in the pre-colonial period, "possibly from about the fifteenth century" (Pottier, 2002:32). The Tutsi kingdom of Rwanda, for instance, antecedents of modern Rwanda, provides us with key insights into the emergence and expansion of the kingdom and its institutions (Lemarchand, 1999; Pottier, 2002; Vansina, 1962). The colonization of Tanzania mainland, Rwanda, and Burundi by the Germans (Mpangala, 2004; Gounden, 2017) and DRC (Ex-Zaire) by Belgium (Shyaka, 2006), did little to change the expansion of the Tutsi domination in the region. Thus, these colonial administrations played a double role. Firstly, colonial administrations integrated themselves with the existing indigenous administrations or in some cases establishing new ones and secondly supported the administration of Nilotic (Hima-Tutsi) minority leadership to conquer Bantu (Hutu) territories. They consolidated these territories in the hands of a Nilotic minority, assumed to be a clever people, designated by God, possessing inborn hereditary rulership qualities and capable to rule the less intelligent Bantu (Hutu) majority (Shyaka, 2006; Solomon, 1997). When borders were designed, there were Bantu rulers in Rwanda and Burundi, whose authorities were not recognised by the colonial master. To maintain power, the Tutsi groups tactfully presented themselves as a vulnerable minority to be supported and protected (Lemarchand, 1999; Shyaka, 2006; Conrad, 2010). As Raston (2005:200) puts it, the Tutsis "succeeded in convincing the European colonialists that they were victims because they belonged to an ethnic minority". For example, the Tutsis in Rwanda, Burundi and DRC argue that the Hutus planned to commit genocide against them in 1950s thereby attracting the compassion and sympathy of the international community.

This Hima-Tutsi leadership ideology, their desire to indefinitely hold and wield political and economic power and engage in territorial expansion or consolidate the Hima-Tutsi territories in the GLR is currently embedded in the fight against the Hutu genocide ideology. Thus, in their efforts to eradicate the Hutu genocide ideology, Hima-Tutsi leaders invade countries in the GLR with the blessing of some world super powers countries, engendering the persistent armed violent conflicts in the GLR that lacks criminal accountability (Pauw, 2012; Mpangala, 2004 and July, 1980). Evidence supporting this argument is the existing records of a Tutsi ethnic based ruling that can be traced to the pre-colonial monarchy. Bucyalimwe (2016) backs this line of thought, revealing that the conquest of Bantu territories has been replaced by the assassinations or toppling of Bantu democratically elected leaders. Some of these include the assassination of the Presidents of Burundi, Melchior Ndadaye, and Cyprian Ntaryamira respectively killed in 1993 and 1994 (Stanislas, 2014), the Rwandan President Juvenal Habyarimana and the President of DRC Laurent Kabila, respectively killed in 1994 and 1998 (Stanislas, 2014; Mervern, 2006).

There is no existing record of any Tutsi president reported to have been assassinated or forcibly removed from power by Bantus (Mervern, 2006). Commenting on the Hima-Tutsi empire ideology, Stanislas (2014) posits that President Habyarimana was assassinated with a view to remove Hutu majority from power and to install the Tutsi minority on power. This assassination was apparently committed by the Tutsi rebellion, who attacked Rwanda from their bases in Uganda, a Nilotic ethnic political strategy to strengthen the Hima- Tutsi empire ideology in the whole GLR region (Stanislas, 2014; Shyaka, 2006). Further supporting evidence was provided recently in 2015 (Carter, 2016; Hendricks, 2013; Prunier, 2016) by attempts to change the constitutions in some countries of the GLR to allow a longer term for the current Hima-Tutsi leadership to remain in power (Kanyangara, 2016; Lemarchand, 1999). Some historical records place Rwanda at the forefront of the Hima- Tutsi empire ideology amongst countries of the GLR (Stanislas, 2014; Chege, 1997; Lemarchand, 1999; Pottier, 2002; Vansina, 1962) (Figure 2).

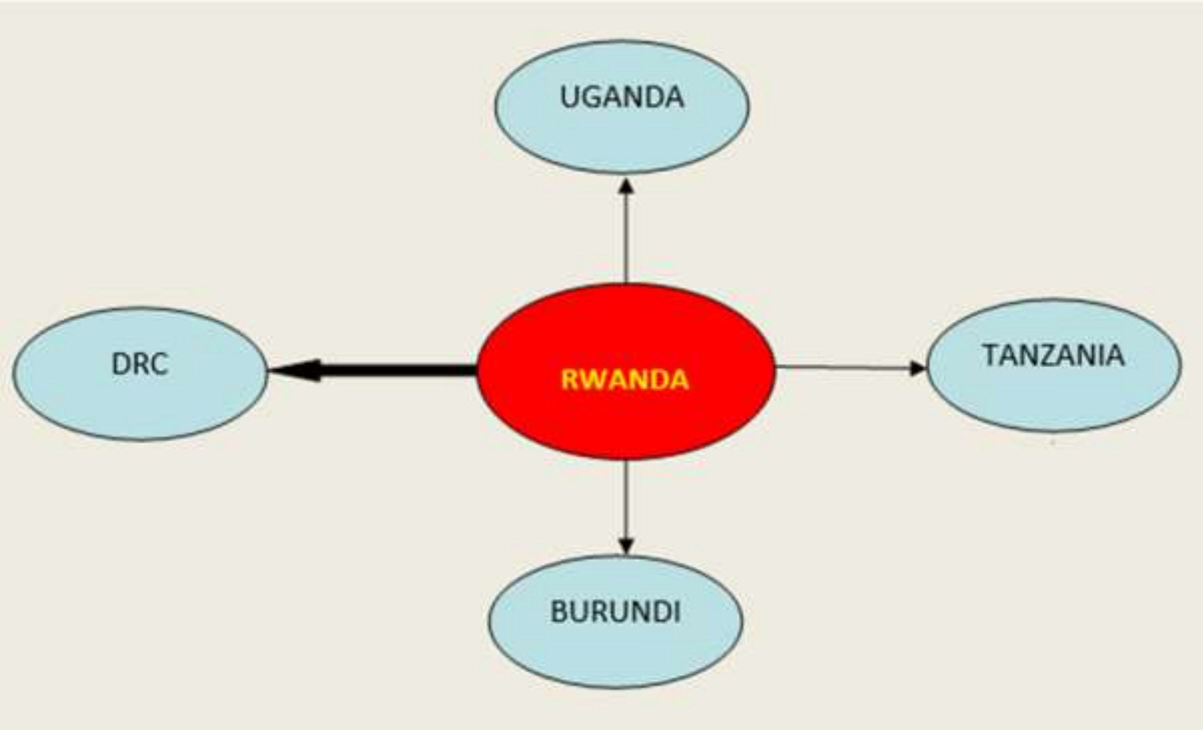

Figure 2.2 Conflict dynamics in the GLR. **(**Data **s**ource: Adapted from (Stanislas, 2014; Chege 1997; Lemarchand 1999; Pottier 2002; Vansina 1962)).

Figure 2.2 is a conceptual representation of the evolution of conflicts in GLR synthesized from the perception of various authors, which portrays Rwanda at the center of the Hima-Tutsi empire ideology in the GLR. Genocide against the Tutsis is used as a tool to campaign for the Hima-Tutsi leadership in the region. The DRC - where Hutus sought asylum – appears to be the most affected by the conflicts due to the complex historical developments that links the two countries, namely, issue of refugees, ethnic identity, the French language and common colonial history, trade in mineral resources, and shared borders.

2.7. Conclusion and Recommendations

There are controversies and paradoxes related to the origin, evolution, and persistence of armed violent conflicts in the GLR. Several authors have vaguely attempted to highlight ethnic identity, African kingdoms, colonialism, nationalism, natural resources and empire ideology as factors contributing to the origin and dynamics of violent conflict in the region, but fail to capture their evolution, persistence and recurrence over time. Not a single factor, but a complex mix of factors explains the origin and evolution of the armed violent conflicts in the region. That these factors exist in other African countries devoid of armed violent conflict presents a dilemma as to whether they are the sole determining factors for the persistence of violent conflicts in the GLR. This study went beyond the description of these factors as mere causes of the conflicts and critically analyzed their contributions. Detail analysis seems to suggest that the Hima-Tutsi empire ideology - the desire by the Hima and Tutsi ethnic groups to conquer Bantu nations and install and maintain power probably for life is at the centre of ancient and contemporary armed violent conflict in the GLR. The desire of supremacy over Bantu population is motivated by the long-held view that they are the divine chosen group to rule and control the people and resources in the region. These views tone with the conflict, mass–society, relative deprivation, social dominance, leadership, and great man and trait theories discussed in the theoretical framework.

The Hima-Tutsi empire ideology has its roots in the ancient Nilotic kingdom and leadership myths. It appears to motivate past and current Hima and Tutsi leaderships in the region and the well-documented records of eliminating Bantu leaders or preventing them from ascending to, acquiring and retaining power in the region. While this study acknowledges the role of other factors discussed, it is the view of this paper that they are secondary and have been used by successive Hima and Tutsi governments to achieve their political agenda to resurrect the Tutsi or Hima supremacy and create a lasting empire in the GLR.

CHAPTER 3

THE APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS TO VIOLENT CONFLICTS: A LITERATURE REVIEW

This chapter is based on: Rwandarugali. S. and Njoya, N.S (In Review). The Application of Geographical Information Systems to violent Conflicts: A literature review. *African Journal of Science, Technology, Innovation, and Development.*

Abstract

This paper reviews the role of Geographical Information Systems (GIS) in armed violent conflict resolution and peace building. It will examine the evidence for the claims made for and against the use of GIS as a spatial analytical tool in the prevention, resolution and post-armed violent conflicts reconstruction in the Great Lake Region (GLR). Many conventional approaches to resolving armed violent conflicts including negotiations, peace talks, and stabilization have been applied, especially in Asia and Africa but sustainable peace is still illusory. Most of these approaches emphasize on the economic and political aspects and tend to ignore the spatial component. While several other innovative technologies like smart cell phones, the internet, Global Position Systems (GPS) and satellite information exists that could provide accurate georeferenced information on armed violent conflict resolution, GIS, in its simplest technological form has been recognized as an invaluable tool in a decision support system and has the potential to assist in conflict resolution. However, like any mediation approach, GIS by itself cannot resolve any spatial problems. The quality of decisions made requires that the stakeholders engage in and reach a mutual agreement, availability of data quality and GIS personnel expertise undertaking the process.

Keywords: Role of Geographic Information Systems, armed violent conflict, the Great Lakes Region, Spatial analytical tool, Decision making

3.1. Introduction

Worldwide, several forms of armed violent conflicts including crime, civil wars or rebel-armed conflicts involving various social groups such as ethnic, religious, and political parties are taking a place (Wood, 2000; Elwell, 2009). Many efforts have been made over the past decades to address these conflicts through conventional approaches notably the United Nations Negotiations, Peace-making and Peacekeeping Operations (PKO), International Conference on the Great Lakes Region (ICGLR) and Regional Head of States peace talks initiatives, but sustainable peace remains a challenge and elusive, especially in some parts of Asia and Africa (Bjorkdahl and Backley-Zistel, 2016). While there exist several other innovative technologies like smart cell phones, internet, Global Position Systems (GPS) and satellite that could provide accurate geocoded information on violent conflicts resolution (Mancini, 2013; Stauffacher, 2011), GIS has been identified as a valuable tool to respond positively to conflicts and peacebuilding (Tooch, 2005; Ayeni, 1997). However, like any mediation approach, GIS by itself cannot resolve any spatial problems (Wood, 2000; Martin, 1996); it requires mutual commitment and transparency between parties in the conflicts. This chapter aims to provide insights into the applicability of GIS for GLR armed violent conflict prevention, resolution and post-conflict reconstruction.

3.2. Contextualization of armed violent conflicts

The concept of conflict itself is complex and even harder to explain when it develops to violence (Elwell, 2009). The word *conflict* comes from the Latin term *conflictus*, which means "collision or clash" (Elwell, 2009: 55). According to Rosein (1998) and Kyem (2006), not all conflicts result in armed violence, killings, and bloodshed. It is, therefore, any author's challenge to determine why some societies, especially in the developed countries live for decades without major outbreaks of armed violent conflicts, while many other African and Asia countries experience prolonged civil wars and rebels armed violence.

Several politico-economic authors and experts in conflict resolution and peacebuilding have long been in a quest for solutions to questions related to armed violent conflicts. They have attempted to analyse and define conflict from different perspectives (Mine, 2013). Understanding a conflict from various points of view, notably the definition, types, causes, actors, and dynamics is a good start to shed light on conflict resolution tools. The violent conflict dates to ancient/traditional societies and was related to individuals and communities disputing or fighting for access to land rights, naturalization, citizenship or the extension of their administrative boundaries (Pottier, 2002; Shyaka, 2006). While such conflicts still exist in contemporary societies, they have become more complex, involving various global and local armed actors. As Dr. Weisi Guo, one of the Syria conflict resolution specialists and the world's leading data scientists stated, "you have to zoom out a bit and think about the global flux" in order to resolve some contemporary local level conflict challenges" (Corera, 2018:5). These conflicts include gender violence, terrorism or civil wars characterized by ethnic, religion, local and cross-national armed conflicts (Corera, 2018; Elwell, 2009; Muller and Muller, 1990; Omeje and Hepner, 2013), and sometimes supported by external powers notably United States of America, France, Belgium, European Union and United Nation peace experts, all for different politico-economic reasons (SIDA report, 2004; Lang, 2009; Bennett, 1982).

Given the complexity related to these conflicts and the term 'conflict' itself, some authors have provided definitions that are easy to understand at different levels of conflicts. For, example, Elwell (2009) explains conflict as a struggle between opponents over values and claims to scarce status, power, and resources. Whilst this definition contains a fundamental and generalised knowledge of conflicts, it has been critiqued for being narrow with little attention paid to the role of causal mechanisms and the societal level (Soytong and Perera, 2014; Beber and Blattman 2009). Other authors have interrogated the type of society where political violence occurs or what groups (intergroup or intersociety/nations) are most involved or likely to use violent repertoires (Balcells and Justino, 2014; Goodwin, 2001; Kalyvas and Kocher 2007). Such details knowledge will assist to understand the nature and perseverance of conflicts in some societies than others.

The difference between intergroup and intersociety conflicts lies in the size of the protagonists (Balcells and Justino, 2014); for example, intergroup conflicts take place between various groups; including conflicts between the trade unions and government or between students and lecturers (Ohlson, 2008). Intersociety conflicts relate to larger organisations or institutions including large political, religious, social and economic groups (Starr, 1978; Balcells and Justino, 2014; Ohlson, 2008; Soytong and Perera, 2014). While the definition of intergroup and intersociety conflicts is complex and remains a challenge (Elwel, 2009; Soytong and Perera, 2014), understanding these complexities is essential to drawn attention to pertinent characteristics and approaches to the cessation of violent conflicts.

As indicated in Table 1, violent conflicts are characterised by three main stages, namely the pre-conflict, conflict, and post-conflict stages. Each stage has a classical intervention method that includes strategies for proactive prevention, resolution, and peacebuilding, respectively.

Table 3.1 Characteristics of Violent Conflicts

Features	(1) Pre-conflict	(2) Conflict/Violence	(3)Post-conflict reconstruction
General characteristics	The conflict is not yet highly visible, and neither are the forms of violence. This phase can display conflict manifestations and behavior	Communications between the Understanding conflict sides have completely broken down. The violence is at its most intense, and people on all sides are being killed.	When the violence has ended, and an agreement has been reached, the tension decreases, and relationships can be re-established between the conflicting parties.
Intervention methods	Pro-active Prevention	Resolution (conflict talks and negotiations, peace-making and keeping and stabilization among others).	Peace - building (Post-Conflict reconstruction)

According to Mine (2013:2), "violent conflicts are not inevitable". The question is why these classical PKO approaches to violent conflict resolution partially work or do not work at all. They have failed to achieve their objectives of conflict resolution and peacekeeping. Jett (2001) and Stewart & Brown (2007) argue that most of these PKO approaches are economically and politically oriented. They fail because of inadequate planning, staff incompetence and inability to act rapidly, little attention to related geospatial aspects and lack of careful rethinking of their spatial relationships, which plays a vital role in peace talks or conflict resolution engagements (Bjorkdahl and Buckley, 2016; Cedric,2002; Balcells and Justino, 2014). GIS and its simplest computer technology to collect, analyse and manage spatial and attribute data have been identified as invaluable tools to respond to these challenges (Bouchardy, 2000; Baker, 2015).

3.3. Geographical Information System (GIS) – A contested concept

GIS is currently used all over the world for a wide range of purposes and it remains a contested concept (Huisman and Rolf, 2009; Wright, 1997; Heywood, 2006). While the year 1960 saw the historical development of the world's first true computerized operational GIS in Canada by Dir. Roger Tomlinson (Waters, 2018; Dawwas, 2014), the first known use of term geographic information system (GIS) came around the year 1962 and used for land inventory and planning in Canada (Waters, 2018; Deakin; 2009). The aim of this chapter is not to examine the controversies related to the history, definition of GIS and discuss its components, rather it is to review the literature on its applicability to violent conflicts and peacebuilding. The literature will explore the general overview of the GIS concept, its applicability to conflict resolution with more focus to GIS decision making support system and technique to facilitate conflict resolution in the Great Lakes Region.

To make a sense to GIS applicability in conflict resolution, it is worthy of this research to firstly shadow a factual understanding of the utility of GIS technology to resolving some worldwide complex related physical and human challenges. Goodchild (2000:174) defines a GIS as "a computing application that allows the user to store, manipulate, create, analyse and visualize geographic information". This new technology has the capability to define locations on the earth using Geographical or Projected coordinates systems (Wright, 1997; Heywood, 2006; Goodchild, 2000). Therefore, GIS allows the user to view, query and understand data in various ways to show relationships and patterns in the form of maps, reports, or charts (Goodchild, 2000). Data is organised under vector or raster format. The client can use GIS to look at existing data whether in raster (pixels) format or vector form (three geometric forms including point, lines, and polygons) and an intuitive manner helps with answers to problem solving (Goodchild, 2000; Shmool, et al., 2018; Tu and Xia, 2008). In order for the GIS to be effective, pixels and these three types of geometry forms must work properly and provide the requested information in a timely manner (Goodchild, 2000). Typically, GIS users deal with geographical or spatial data- "where things are, or perhaps where they were or will be" (Huisman and Rolf, 2009:27).

A pertinent question is to know what sets GIS apart from other technology information systems such as smart-phones or Global Positioning System (GPS)? Many authors argue that what makes GIS technology unique is its capability to handle both spatial and attribute data (Huisman and Rolf, 2009; Yoffe and Fiske, 2001; Martin, 1996 and Grimshaw, 1950), its ability to generate visual representations and make explicit the implicit features of data (Wright, Goodchild and Proctor (2004). However, according to Bierman (2016), GIS has reached a new phase in its technological development and can now go on from the purely technical point of view of being limited by what GIS software can do.

As Yao and Hei (2018) argued, traditional geographical representation in GIS is not sufficient to manage the increased sophistication of physical and human activities, or embedded in, location-based social media data. GIS is more than a software to store and manage data; it is viewed as a scientific tool to analyse simple and complex issues of the present-day society.

According to Wright et al. (1997), there are endless debates on whether GIS is a science, tool or set of interrelated techniques. It has been defined according to a series of functions such as data capturing, storing, searching, querying, manipulating, and analysing and presentation capabilities (Heywood, 2006; Ballatore, et al., 2013; Schnur, et al., 2017; Pickles, 1997; Huisman & Rolf, 2009; Yao and Hei, 2018). The challenge with such a definition is that the absence of one or more functions could result in it being classified as something else (Martin, 1996; Grimshaw, 1950; Bierman et al., 2016). To avoid these generalisations and speculations, it seems appropriate to provide clarity and reasons why GIS is gaining momentum as a 'system', 'tool' or 'Science'. This understanding will shed light on its applicability in addressing the phenomena related to armed violent conflict resolution.

Authors who argue that GIS is a tool, maintain that it is a technology, merely a computer system to organise and manage spatial data (Goodchild, 1992; Allen & Massey, 1995 and Longley et al., 1999). This perception aligns with the view of other scientists who refer to GIS as a toolbox with useful commands to manage and organize spatial data (Bierman, et al., 2016; Kulldorff, 2007; Goodchild, 1992). Contrary to this perception of GIS as a tool, authors have counter-argued that it is a science or an applied science. In this definition, the system is significantly distinct from other normative sciences such as a computer or geographical science (Martin, 1996; Prakash, 1998; Wei and Yao, 2018). If GIS is a science, in some respects, it is a science unto itself with its own unique and logically coherent object of knowledge (Dobson, 1993. Grimshaw, 1950; Prakash, 1998).

Perhaps a better compromise would be to consider GIS as both a tool and a science (Bierman et al., 2016; Pickles, 1997; Wright, 1997) that can be applied to different disciplines and areas. This compromise and integrated perception are corroborated by its increasing use by researchers in many disciplines amongst which are geology, archaeology, the environmental, sciences, resource management, biodiversity management, town planning, and transportation. Thus, we can describe the GIS process as an approach used by different disciplines (physical or human sciences) for integrating, synthesizing and modelling data for its applicability in the real world (Martin, 1996; Longley, et al., 1999; Gimblett, 2002). Therefore, GIS is becoming essential in understanding what is happening and what will happen in the geographic space of a given society.

Generally, GIS capability is aimed at mapping, analysing and managing a wide range of geographical information including and applying it to a comprehensive range of planning and management functions (Tomlinson, 1974; Xia, 2014, Wood, 2000; Martin, 1996). The role played by GIS in society is clearly important in many contexts. Besides its common use in the research community to analyse complex issues in natural science, through building models and the integration of different data sources, GIS is now an infant but fast-growing application/tool in the social science community. It is utilised for strategic policies and decision-making through Decision Support Systems (DSS) (Xia, 2014; Wood, 2000; Wright, 1997; Heywood, 2006). Decision making is a process in which the best possible solution to a problem is sought, typically by evaluation and modelling the alternative scenarios (Sugumaran and DeGroote, 2011).

The development of a decision support system (DSS) to inform policymaking has been progressing rapidly (Xia, 2014). GIS integrates a geospatial data and DSS and has thus become a Spatial Decision Support System (SDSS) (Gyamera, 2017 et al.; Kyem, 2006). A Spatial Decision Support System can be defined as an interactive, computer-based system designed to support a user or group of users to increase its effectiveness of decision making while solving a semi-structured spatial decision problem (Leidner and Elam 1995; Kyem, 2006; Janowski and Nyerges, 1997). It supports a user by providing tools to explore the problem in an interactive and recursive fashion in all phases of the decision-making process. By exploring alternative scenarios, it creates a medium for stakeholders to exchange views about their values and interests (Janowski and Nyerges 1997; Bearman, 2016; Jordan 2002). This approach has demonstrated successful results in many conflicts ranges notably areas of water conflict management, land issues, political conflicts, civil wars and many more (Wood, 2000; Mossin, 2007; Xia, 2014).

3.4. GIS capabilities and armed violent conflict resolution - an overview

Nowadays, GIS is an approach used by different disciplines (physical or human sciences) for integrating, synthesizing and modelling data for its applicability in the real-world including conflict resolution (Xia, 2014, Wood, 2000; Martin, 1996). In the discipline of peacebuilding, GIS has the technological capabilities to facilitate decision-making in conflict resolution talks (Tooch, 2005; Wright, Goodchild, and Proctor; 2004). GIS by itself cannot resolve any conflict (Wood, 2000; Martin, 1996 and Prakash, 1998) but rather it is a decision support system, aiding different parties in a conflict to reach an agreement informed by spatial data that has been collected, transformed, and analysed (Bouchardy, 2000; Goodchild, 2004; Hardy, 2012). One of the most valuable features of GIS technology is the capability to create a geo-database.

The term *geo-database* derives from a *database*, which according to Musa, et al (2016) is a collection of one or more data files or tables stored in a structured manner, such that interrelationships which exist between items or sets of data can be utilized by the Database Management System (DBMS) software for manipulation and retrieval purposes. Such a geodatabase provides an integrated platform for further geospatial analysis including, spatial data overlays, spatial data queries, and buffer zone creation (Martin, 1996; Conley, 2005; Prakash, 1998) and the spatial display of issues and/or resources related to a conflict. For example, GIS overlays including remotely sensed imagery, digital terrain models, and other digital data layers enable the spatial visualization of the area in dispute (Soytong and Perera, 2014). It can identify the types of resources at stake or populations that might be affected by conflict (Conley,2005). Other GIS capabilities can be applied to armed violent conflict analyses. This application includes proximity analysis, digital mappings and multi-criteria analysis of causative factors to determine risks and vulnerabilities, and hotspot analysis using kernel density tools to determine areas characterized by the recurrence of violence (Mossin, 2007; Humanitarian Tracker Project, 2014). Such analyses can inform decisions on conflict prevention, mitigation, and resolutions.

The capabilities of GIS outlined in the previous paragraph harmonizes with Grimshaw (1993: 206), who pointed out that GIS enables policy or decision-makers to explore the geographical dimension of data and providing an opportunity to determine the best possible solution to a problem, typically by evaluating and modelling various alternatives (Gimblett, 2002; McCall, 2003; De Groote, 2011 and Humanitarian Tracker Project (2014). Since most, or almost all, violent conflicts occur in geographic space, GIS provides a geospatial platform for such data exploration aimed at conflict prevention planning, peace talks or/and for post-conflict reconstruction (Halls, 2008).

3.5. The Application of Geographical Information Systems to armed violent conflict prevention

Conflict prevention is a "set of instruments or measures used to prevent or solve disputes before they have developed into active conflicts" (Clément, 1997:18). There is a belief that GIS could assist in achieving better solutions to violent conflicts before they erupt (Pauw, 2012; Bouchardy, 2000; Humanitarian Tracker Project, 2014) and they spread into the neighbouring areas. For example, GIS can be used to monitor and control violent conflict activities through interpolation or prediction models and provide the right information for preventing the spread of violent conflicts. These functionalities and capabilities of GIS enable all sides in a conflict to have an improved picture of different aspects related to the conflict, enabling informed peace talks and stakeholders' decisions (Longley et al., 1999).

A worthy example of GIS application to violent conflict prevention is the case of Kyrgyzstan, a Central Asian state bordering China (Bisig, 2002; Mossin, 2007; Manchini, 2013). Since the collapse of the Soviet Union (Bayat, 2008), it has been a host to persistent low-level violence and is suffering from a multiplicity of challenges that are traditionally associated with conflict. These challenges include sky-high unemployment rates to widespread poverty, a strain on local natural water sources, inter-ethnic tensions and geopolitically volatile neighbourhoods (Mossin, 2007 and Humanitarian Tracker Project, 2014). GIS has been used to "develop a dataset for conflict vulnerability assessment, to generate practical applications to assist in identifying areas where future conflicts might break and to predict the appropriateness of future aid allocation" (Mossin, 2007:1). More importantly, several variables including areas of ethnic boundaries, natural resources competition, population susceptibility to violence (based on young unemployed and unmarried men indicators), and terrorism hotspots were analysed (Mossin, 2007).

The areas vulnerable to inter-ethnic conflicts were predicted through the calculation of Euclidean distance in GIS[1]. Areas closer to an inter-ethnic boundary were classified as being more vulnerable to ethnic conflict (Bisig, 2002; Mossin, 2007). The Euclidian distance was also used as a tool to determine water proximity to Kyrgyzstan's main rivers and lakes (Mossin, 2007; Humanitarian Tracker Project, 2014), which was then reclassified as being more vulnerable to ethnic conflict. Whether an area is prone to resource competition was established based on two criteria: proximity to natural resources, and density of population in that area (natural resources were defined as water resources including rivers, lakes, and farmable land). The population density was mapped showing their access to natural resources, and areas with greater access to natural resources being those with water proximity and arable land combined (Bisig, 2002; Mossin, 2007).

An area would be considered to have a relatively large population susceptible to violence based on three census data notably; the percentage of young, unemployed and unmarried, as well as the percentage of different ethnic groups and scarce natural resources in a region (Mossin, 2007). Regarding terrorist hotspots, areas at risk of renewed violence were identified using the

[1] *The **Euclidean distance** or **Euclidean** metric is the "ordinary" **distance** between two points that one would measure with a ruler and is given by the Pythagorean formula. By using this formula as **distance**, **Euclidean** space becomes a metric space. The associated norm is called the **Euclidean** norm.* https://www.definitions.net/definition/euclidean+distance

kernel density tool on the Global Terrorism Dataset for Kyrgyzstan for the period 1991-2011 (Humanitarian Tracker Project, 2014; Mossin, 2007). It was assumed that areas that had previously experienced violence would be more prone to future violence (Bouchardy, 2000; Mossin, 2007).

To develop a conflict vulnerability map in Kyrgyzstan, four indicators were aggregated, applying the following mathematical relationship: (Proximity to ethnic boundaries x Access to natural resources) + (Population at risk + Previous terrorism hot spots) (Mossin, 2007:8). In addition, an aid distribution map was developed based on international aid distribution data for June 2011, compiled by the United Nations Office of the Coordination of Humanitarian Affairs (UN OCHA) and the location of all ongoing international aid activities in Kyrgyzstan (Mossin, 2007). The map was created, dividing the number of aid projects in a region with the total number of populations of that region. Thereafter, the map was then rasterized and reclassified to create the population at risk dataset. Finally, "areas currently underserved in terms of aid, while scoring high on a conflict vulnerability index were found, subtracting the areas found vulnerable to ethnic conflict, from the aid distribution map" (Mossin, 2007:8).

3.6. The application of Geographical Information Systems to armed violent conflict resolution

GIS has emerged as an important source of data or decisions making in many areas of conflict resolution. The eminent case is Israel versus Palestine's persistent violent conflicts, where GIS problem-solving capabilities have been used in conflict-related negotiations (Mossin, 2007; Tooch, 2005; Wallach, 2011). The Israeli-Palestinian conflict is one of the most complex and persistent disputes in the world and it is linked to decades of repeated violence and stalled peace talks on territories like Gaza, Jerusalem and the West Bank (Tooch, 2005).

The main issues causing the conflicts were Israel's settlement expansions, border demarcations between the two opposing groups, access to natural resources (mainly the Jordan water basin rights), management of the Jerusalem city and other crucial aspects of the prolonged dispute between the two groups (Tooch, 2005; Barker, 2015; Wallach, 2011). Spatial data in the case of Israeli settlements would be their actual geographic location (Tooch, 2005; Barker, 2015). Attribute data could be the settlement name, elevation, and a host of other characteristics (Wallach, 2011). Data and insights from the analysis provided by GIS were delivered to security and peace negotiators, to facilitate the negotiation. GIS could help decision-makers assess all factors that could affect the security and stability in the region, including the lengths of various border segments, the location and number of crossings to be formed (Tooch, 2005).

Beyond the questions about settlements, security, and sovereignty, the allocation of natural resources, water is also a core component in the Israeli-Palestinian conflict that needs a solution between the two disputing groups (Silverbrand (2008; Tooch, 2005; Wallach, 2011). Silverbrand (2008) points out that the geography of water resources is particularly complex. Both Israel and the Palestinians heavily depend on the freshwaters of the Jordan River basin and aquifers under the West Bank (Silverbrand (2008). GIS was instrumental in groundwater and water quality assessment; watershed and surface water management, which were thereafter utilized by peace-making experts to resolve the water management conflict between the two countries (Tooch, 2005 and Gvirtzman, 2012).

Another prominent example of GIS application in conflict resolution includes the use of digital mapping technology in the Dayton peace accords (Johnson, 1999; Tooch, 2005; Holbrooke, 1998 between the Bosnian Serb, Croat, and Muslim ethnic factions in the former country of Yugoslavia (Johnson, 1999). Besides diplomatic negotiations, digital mapping was adopted by the peace negotiators and have positively contributed to the successful negotiations. Interestingly, what was politically and diplomatically impossible has then become reality through spatial digital maps. The spatial data and information provided by these maps such as the boundary of Bosnia-Herzegovina) or from other sources such as battlefield maps were digitized and correlated to a common geometric foundation (Johnson, 1999). Then, digitized map information such as points, lines, and areas (in vector form), names data, elevation data, scanned map images, and imagery could be pulled into the PowerScene terrain visualization systems and presented to negotiators as still screen shots, fly-through videos, or dynamic flythrough under joystick control (Holbrooke, 1998; Johnson, 1999). This was followed by further spatial analysis to reach selected and accurate data to put on the resocialization table. One of the advantages of this mapping technology is that any map change could be printed out and kept or transferred electronically for further negotiations and in a post-conflict reconstruction context (Holbrooke, 1998; Johnson, 1999).

3.7. The application of Geographical Information Systems to armed violent conflict to post – conflict reconstruction

Post-war or post-conflict reconstruction is necessary. It is a multi-disciplinary process, related not only to the planning and physical reconstruction of services, infrastructure, and buildings but also to the reconstruction of civil society (Halls, 2008; Smith, 2001, Barakat, 2018; Yaakup, 1991; Ayeni, 1997). In most cases, the post-war recovery situation involves people displaced from their homes or their countries and seeking a return or integration to normal life (Halls, 2008).

There are various case studies where the application of GIS has been successfully used in post-conflict reconstruction (Halls, 2008; Prince, 1962). Some examples include the use of GIS for territorial negotiations in Bosnia (Wood, 2000), better aid allocation in Kyrgyzstan (Mossin, 2013), as well as in Kosovo post-war reconstruction by United Nation High Commission for Refugees (UNHCR) in partnership with other Kosovo Albania organizations for decision making and emergency response (Hetherinngton, 2000; Wentz, 2002; Halls, 2008). GIS models and database support were created and used to map areas of need for reconstruction. The Kosovo post-war reconstruction has been a special and successful example because using and sharing GIS data, providing a model for organizations in search of standards for all parties involved in a conflict to agree on (Hetherington, 2000; Lenz, 2002). The new system for the regional reconstruction provided prospects for sub and regional integration, promoting collaboration, peaceful negotiations, and trust among the different conflict groups living together (Hetherinngton, 2000). This approach also provided an open opportunity for inter-regional, local and foreign investment, facilitating industrialization and regional peace.

3.8. The application of Geographical Information Systems to armed violent conflict – A Synthesis and Challenges

The evidence reviewed in this paper suggests that GIS offers considerable scope for application to armed violent conflict prevention, resolution and post-armed conflict peacebuilding. While some authors like Grimshaw (1950) and Pickles (1997) argued that GIS is a science, with its own unique, logically coherent knowledge system, others like Hetherington (2000); Halls (2008) believe that GIS remains a tool. However, a consensus to this debate has been that GIS is both a tool and a science (Ballatore et al., 2013), with its interpretation depends on the perspective of the user (Bjorkdahl and Buckley-Zistel, 2016; Bouchardy, 2000; Heywood, et al., 2006).

There is also an assumption, implicit in this paper, that GIS data can be used to inform action in operational and strategic planning, and to inform the way in which conflicts are managed in the interests of the community (Bouchardy, 2000; Sieber, 2006; Carver, 2001). However, the extent to which Geo-information is incorporated into decision-making and whether this process is a rational one can be questioned (Bjorkdahl and Buckley-Zistel, 2016; Heywood, et al., 2006). If the parties in a conflict do not mutually agree on the information provided by the

GIS, the use of GIS can have some negative impacts on the process of negotiations (Bjorkdahl and Buckley-Zistel, 2016) creating distrust and further stalling the peace process. In such a scenario of distrust, the solution would come from an independent, neutral GIS body, who would provide unbiased data to support the conflict resolution process (Heywood, et al., 2006). It is therefore imperative that the use of GIS in conflict resolution gains mutual support from the opposed parties but also expertise and integration of other approaches that are involved in the conflict resolution.

In addition to these general challenges related to GIS applicability to conflict resolution, availability, access, and accuracy of spatial data is an issue in developing countries (Mennecke and West, 2001). While governments in many Developed Countries have found GIS to be a critical tool in regional planning, resource management, and economic development (Bocco and Sanchez, 1995), many of these countries are hampered by the lack of accurate and detailed spatial and demographic data (Mennecke & West, 2001). For instance, Bocco and Sanchez (1995) have pointed out that while some political boundaries follow physical features, coastlines, rivers, and so on; others are arbitrary or have their roots in historical events. Some are disputed. Maps that have been drawn by one entity show the boundary in one location and others locate the boundary elsewhere (Gerland, 1996; Mennecke & West, 2001). Some boundaries are flexible or fuzzy whereas others may be fixed permanently (Bocco and Sanchez (1995).

In addition to data collection, accessibility, and accuracy challenges, Teefelen, et al and Gerland (1996) identified a variety of integration problems (data from different sources with different standards) that exist for spatial data in developing countries. This is the case due to the missing positional and reference information (Mennecke & West, 2001; Walker and Young, 1997)), inconsistent classifications and methodologies or the use of different spatial units and the presence of spatial data gaps (Teefelen, et al; Gerland, 1996; Bocco and Sanchez, 1995). In addition, while GIS has the inherent capability of serving as the basis for an integrated decision, the support system at the highest levels of government in the developed world (Mennecke & West, 2001), it is still a challenge in developing countries (Bocco and Sanchez, 1995), mainly due to skill capacity, data access, and quality (Mennecke & West, 2001; Gerland, 1996). These issues are relevant to decision making and output related to conflict resolution.

3.9. Concluding comments

This review has shown the application of GIS to conflict resolution and peacebuilding, with a focus on GLR persistent armed violent conflicts. As a result, the study has scrutinized the evidence for the claims made for and against GIS applicability in the prevention, resolution, and post- armed violent conflict reconstruction. Its capabilities, opportunities, challenges, and critics to conflict resolution have been reviewed. The role played by GIS in society, particularly in violent conflicts is clearly important in many contexts. Besides the use of GIS in the research community to analyse complex issues in natural science, through building models and the integration of different data sources, GIS is now infant but growing faster in the social science community for policies and decision-making. The development of a SDSS, to inform policy and decision making has been progressing rapidly. There are many successful results of GIS application in armed violent conflicts indicated in this review. One of the most successful stories of GIS application to armed violent conflict resolution and decision making includes the use of GIS in Kyrgyzstan conflict resolution. GIS has been used in Kyrgyzstan as a conflict prevention tool to assist collecting, analysing, and making right decisions. A dataset was developed to assist for conflict vulnerability assessment in identifying areas where future conflicts might break and to predict the appropriateness of future aid allocation. Another prominent and successful story is how GIS was applied to armed violent conflict resolution and peace talks decision making in the Israel and Palestine long-duration civil war. GIS was used as a problem-solving capability in conflict-related negotiations and peace talks on territories like Gaza, Jerusalem, and the West Bank. Spatial and attribute data were collected and analysed through GIS delivered to negotiators, to facilitate the peace and security peace engagement and decision-making. Likewise, GIS application in the Kosovo post-war reconstruction has been a special and successful case as well. All conflict parties in Kosovo were using and sharing GIS data agreed. GIS activity encompassed camp layout and infrastructure planning, as well as database development and population.

While GIS continues to demonstrate successful results in armed violent conflict resolution, it is noted from this review that GIS itself cannot resolve any conflict. The whole process requires a mutual collaboration of parties involved in conflicts. If the two parties in conflict do not mutually agree on the information provided by the GIS, the use of GIS can have some negative impacts on the negotiations process. Several other challenges and critics including the quality of decisions made by stakeholder engagement, the availability of data, and the expertise of GIS personnel undertaking data analysis have been highlighted, especially in developing countries. It is appropriate to conclude that solutions to these issues and challenges of GIS and conflict resolution are available through a successful implementation. We hope that by surfacing these related conflict issues, awareness will be raised amongst information systems and other organizational researchers. This is truly a rich area for performing research on the adoption and diffusion of GIS and other information technologies in conflict resolution.

CHAPTER 4

GEOVISUALIZATION AND SPATIAL MODELLING OF ARMED VIOLENT CONFLICTS IN THE GREAT LAKES REGION OF CENTRAL AND EAST AFRICA

This chapter is based on: Rwandarugali. S. and Njoya, N.S (To be submitted for publication) 2020. Geovisualization and Spatial Modelling of armed conflicts in the Great Lake Region of Central and East Africa. *Journal of Geographical Sciences.*

Abstract

Many studies in conflicts and peacebuilding ignore the particularities of local and regional spatial aspects, focusing mostly on global economic and political concepts to resolve conflict-related issues. Contrary to this approach, this chapter explores a regional GIS-based approach to identify and assess the spatial distribution and patterns of armed violent conflicts in the Great Lake Region, from 1998 - 2017 and predicts the probability of future conflict outbreak from 2018 - 2038. The approach adopted utilises a geospatial analytical technique notably Geocoding, Average Nearest Neighbours (ANN), Autocorrelation (Moran's I) and Hot spot (Getis-Ord Gi*) analyses, to geovisualise conflict patterns, clusters and hot spots. The x and y locations of armed conflicts and their attributes used in these analyses were freely obtained online from multiple sources including the Armed Conflict Location and Event Dataset (ACLED) project, the 2007 Democratic Republic of Congo (DRC) National Census (NC) report, United Nations (UN) Global Pulse (Uganda Project), and International Peace Information Service (IPIS). Additionally, a Conflict Risk Model (CRM) for predicting future conflicts outbreak was created in Microsoft Excel program through the subjective weighting and ranking technique using key conflict variables. The results reveal that the DRC has been a high hot spot of armed violent conflicts for the past 20 years (1998 - 2017) and it is predicted to remain the highest at risk to conflicts (81%) while Tanzania will be the least at risk to armed conflict outbreak (50%) for the next 20 years (2018 - 2038). The proposed approach and results of this study can be used to assist policymakers and stakeholders to determine the best approach of mitigating and preventing further armed conflicts in the region.

Keywords: Geovisualization, Conflict patterns, Conflicts hot spots, Conflict risk model, Conflicts resolution

4.1. Introduction

Geographical visualization of armed conflicts has been hampered by the lack of spatial data and proper methods to compile and analyze them. Geovisualization or Geographic visualization is defined as the creation, and use of visual representations to enable thinking, understanding, and knowledge construction about geospatial data (Mossa et al., 2019; Nöllenburg, 2007; Schnur et al., 2017). Geovisualization allows several conflict indicators to be displayed in a single view, analyzed and gives the user an improved understanding of the complex relationship between these variables (Barakat, 2018; Barker, 2015). Many studies in conflict resolution ignore regional spatial particularities and focus on global socio-economic concepts to resolve local conflicts (Stephenne et al., 2009; 2008; Checha, 2007) Pezard and Shurkin, 2015). However, the introduction of computer-based technologies like GIS and Remote Sensing has changed the way geospatial phenomena can be analyzed to aid decision making (Soytong and Perera, 2014; Longley et al. 1999; Mine et al., 2013; Mancini, 2013; Wallach, 2011). An example of a region that has endured years of armed conflicts in Africa is the Great Lake Region (GLR) of Central and East Africa, comprised of the Democratic Republic of Congo (DRC), Burundi, Rwanda, Tanzania, and Uganda. To date, there has been no comprehensive study mapping the regional distribution of conflict hot and risk spots in the GLR (Spittaels and Hilgert, 2008; Galtung, 1969). This study aims to explore the role of GIS in geovisualizing the armed conflicts, which in turn should assist in mitigating and anticipating armed conflicts in the GLR. GIS spatial analysis tools, including Geo-coding, Global Moran's I, Getis-Ord Gi*, and a Conflict Risk Model (CRM), was used to identify past, current, and potential future hot spots of conflicts in the region. The CRM is a mathematical model and was developed in this study using Microsoft Excel. The four conflict variables used in this model including Rebel groups, Mineral resources, Ethnic groups, and Political Stability are the most often cited in the literature (Alexis, 2019; Congo Research Group, 2018; Kamatsiko, 2017; Congo, 2016; Autesserre, 2012; Mpangala, 2004) related to conflict resolution and peacebuilding in the GLR.

4.2. Persistence of armed violent conflicts in the GLR – context and magnitude

Armed violent conflicts in countries of the GLR are complex events (Kabua, 2019; Alexis, 2019; Congo, 2016; Omeje and Hepner, 2013; Autesserre, 2012). In the past decades, this region has been characterized by political instability, including ethnic-political violence in Uganda and Tanzania, intractable conflicts notably, the civil wars in Burundi, DRC, and the 1994 Rwanda genocide that caused the loss of lives to many civilians (Mpangala, 2004; Prunier, 2016) (Figure 4.1).

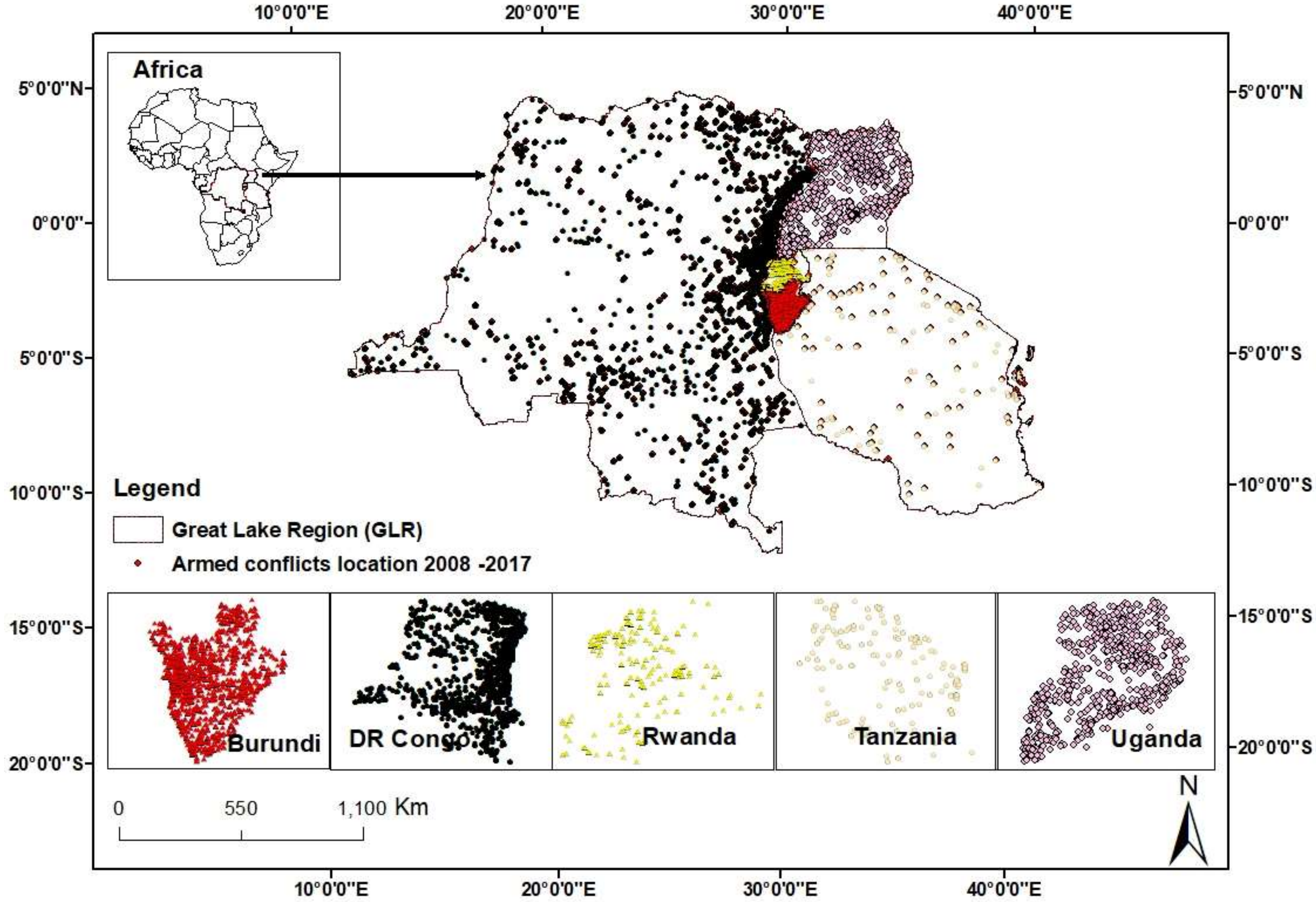

Figure 4.1 Spatial Distribution of armed violent conflicts in countries of the Great Lakes Region from 1998 – 2017.

(Data source: Armed Conflict Location and Event Data Project (ACLED), and the International Peace Information Service (IPIS).

The spatial distribution of armed conflicts in the GLR countries from 1997 - 2017 (Figure 4.1) and by country (inserts) reveal that Burundi has been the country most affected by various types of conflicts in recent years. Overall, the conflicts are concentrated around the borders shared by Uganda, Rwanda, Burundi, and Tanzania with the DRC.

While the previous studies (Hove and Harris, 2019; Alexis, 2019; Congo, 2016; Buhaug and Gates, 2016; Kanyangara, 2016; Basedau and Wegenast, 2009; Autesserre, 2012) have attempted to identify the key factors responsible for these conflicts, including mineral resources, ethnic groups, rebel groups, or political institutions, there is still a need to shed light on several questions. For instance, what are the conflict patterns and trends? Which zones are more vulnerable? Where are the past and existing hotspots? Where are areas at risk of future violent conflicts? What is the role of spatial data in resolving violent conflicts in the GLR? How can GIS contribute to addressing these challenges, support conflict mitigation, and resolution efforts in the region? This chapter explores the answers to these questions.

4.3. Materials and methods

A regional geospatial analytical method including Geocoding, Autocorrelation analysis (Moran's I), Hot spot (Getis-Ord Gi*) analyses were performed to detect the spatial distribution of armed conflicts, conflict clusters and hot spots. Additionally, a Conflict Risk Model (CRM) was developed (Section 4.3.5) in Microsoft Excel using the results of subjective weighting (Wang and Lee, 2009; Quiggin, 2012; Slovic, 2000; Huisman and Rolf, 2009; Samset, 2009) by experts, of selected conflict variables notably rebels density, ethnic group allegiance, political stability and mineral resource occurrence. These variables are the most cited by authors of armed conflicts in the GLR (Alexis, 2019; Congo Research Group, 2018; Congo, 2016; Autesserre, 2012; Mpangala, 2004). The model serves as a tool to predict the areas at risk of future conflicts outbreaks in the GLR region at both a country and regional level (Section 4.4.8 and 4.4.9).

4.3.1. Data sources

A multi-source dataset of x and y locations of conflicts and their attributes in Excel format was downloaded freely online from Armed Conflict Location and Event Data Project (ACLED), 2018 DRC National Census (NC) reports, Congo Research Group (CRG), UN Global Pulse (Uganda Project), and the International Peace Information Service (IPIS). Local and international library archives, especially historical books and maps linked to former European colonies in the GLR were also important sources of data. These international libraries include the Yale University, New York University, Bibliotheque du Moose de l'homme (RCON), Institute Royal Colonial Belge (Olga, 1954; Mertens, 1935) libraries (Bruxelles). Two copies of historical mineral resource maps (for Tanzania and Uganda) were obtained from www.ubos.org, and a combined map for the Congo Belge - Ruanda-Urundi colonial map was obtained via interlibrary loan from L'Institut Royal Colonial Belge or the Belge Royal Colonial Institute (Bruxelles). Additional data was obtained from a questionnaire survey of ten experts in conflicts resolution and peace building from different institutions (academic, local and international organizations).

4.3.2. Data pre-processing

In a GIS platform, data obtained from different sources often presents challenges related to alignment due to different standards, coordinates systems, and formats (Getis, 2007; Cliff and Ord, 1981; Odland, 1988). Generally, this was not the case in this study because data from different sources, were in the same coordinate system (Geographic coordinate system), requiring no further reprojection. During the pre-processing phase, analog historical images containing rebel positions and mineral locations were scanned, imported, georeferenced, transformed, geocoded, and digitized as vector files in ArcMap software. Microsoft excel data (Section 4.3.1) containing the x,y locations of violent attacks in each country were saved in a comma separated values (CSV) table format (Gandy, et al., 2017), to facilitate their importation and display in ArcMap.

4.3.2.1. Georeferencing

Georeferencing of images is a process whereby a dataset (usually a raster layer) relating to a geographical location is assigned proper map coordinates so that it can be referenced to real-world space, allowing it to be processed and integrated in ArcMap with other existing geographic datasets (Giordano et al., 2018; Bajcsy and Alumbaugh, 2003; Scott et al., 2006). The georeferencing process involves identifying a series of ground control points with known x, y coordinates to be used for geocoding the unreferenced raster dataset (Giordano et al., 2018). Control points are locations that can be accurately identified on the unreferenced raster dataset (ESRI, 2019; Oniga et al., 2018) and have corresponding x, y coordinates of the same location in the real world (Martin and Jones, 2015). Generally, an even distribution of multiple control points on the scanned map contributes to georeferencing accuracy. The three scanned maps used in this study, namely, 1) the Congo Belge -Ruanda -Urundi; 2) Uganda, and 3) Tanzania mineral resource analogue maps were georeferenced using this process.

4.3.2.2. Image transformation

Image transformation is the process of correcting the distortions of images resulting from the georeferencing process (Martin and Jones, 2015; Ioannidis et al., 2013). Through GIS (ArcMap), the three scanned maps were transformed or warped to match with the coordinates of the control layer (Martin and Jones, 2015). There are exist different transformation techniques, notably 0, 1st (Affine), 2nd, 3rd, Spline, Adjust and Projective transformations (Gindraux et al., 2017; Martin and Jones, 2015; Mossin, 2013). After georeferencing the images, the resulting distortions were significant, eliminating the use of the 0 and 1st transformations, which are often used when the distortions are insignificant (Martin and Jones, 2015; Hellmann and Fowler, 1999; Hackeloeer et al., 2014 and ESRI, 2018). Since the Spline, Adjust, and Projective transformations are rarely used, this study experimented with the 2nd and 3rd order transformations, and the 3rd order was preferred due to the resulting accuracy (low root mean square error approximately between 0.001 and 0.0025) (Hellmann and Fowler, 1999) (Table 4.1).

4.3.2.3. Geocoding

Goldberg et al. (2007) and Rushton et al. (2006) provide a short definition of geocoding as the process of assigning a geographic code to an image. This definition is derived from the two root words: geo, a Latin word for *earth,* and *coding,* defined as "applying a rule for converting a piece of information into another" (Dueker, 1974:320). Coding the earth provides geographic reference information (for example, street or postal addresses), which can be converted to actual locations on the earth's surface (Rushton, 2006; Hedefalk et al.,2018; Dueker, 1974; Allen and Massey, 1995). Drummond (1995) and Bonner et al. (2003) further explain that Geocoded data is a valid geographic output and maintains that while its input is not necessarily limited to simple postal addresses (Levine and Kim, 2002), the resulting output assigns spatial references to locations.

Another commonly used method of geocoding application is digitizing, vastly used by many organizations to extract digital information from analog materials (Drummond, 1995; Wright, et al., 1997). Digitizing involves both manual and on-screen techniques of tracing geographic data from a georeferenced map (Liu et al., 2011; Mossin, 2013). Traditional manual digitizing involves tracing features from aerial imagery, orthophotographs, or topographical maps mounted on a digitizing tablet using a mouse-like device called a puck (Loveland, 2002; Liu et al., 2011). However, in modern on-screen GIS digitizing, a hard copy map is scanned, imported into a GIS platform where it is georeferenced, and features are traced (digitized) on-screen using a computer mouse and other GIS functions (Elwell, 2009; Fearon et al., 2003; Hill, 2006; Deng et al.,2000; Deshmukh, 2017). The on-screen digitizing method was used in this study to extract data from scanned mineral resources and rebel group spatial distribution maps (Section 4.3.1). The resulting GIS shapefiles were then displayed in GIS ArcMap for further spatial analysis.

Figure 4.2 summarizes the data pre-processing method adopted in this study prior to further spatial analysis within the GIS ArcMap platform. Two major data sources are evident, namely, the scanned historical images related to mineral and rebel groups distribution in the GLR, and excel attribute data containing the x, y locations of rebel groups. These were pre-processed as described in Sections 4.3.1 to 4.3.2, resulting in an integrated overlay of these datasets (output) in a single GIS workspace to enable further analysis.

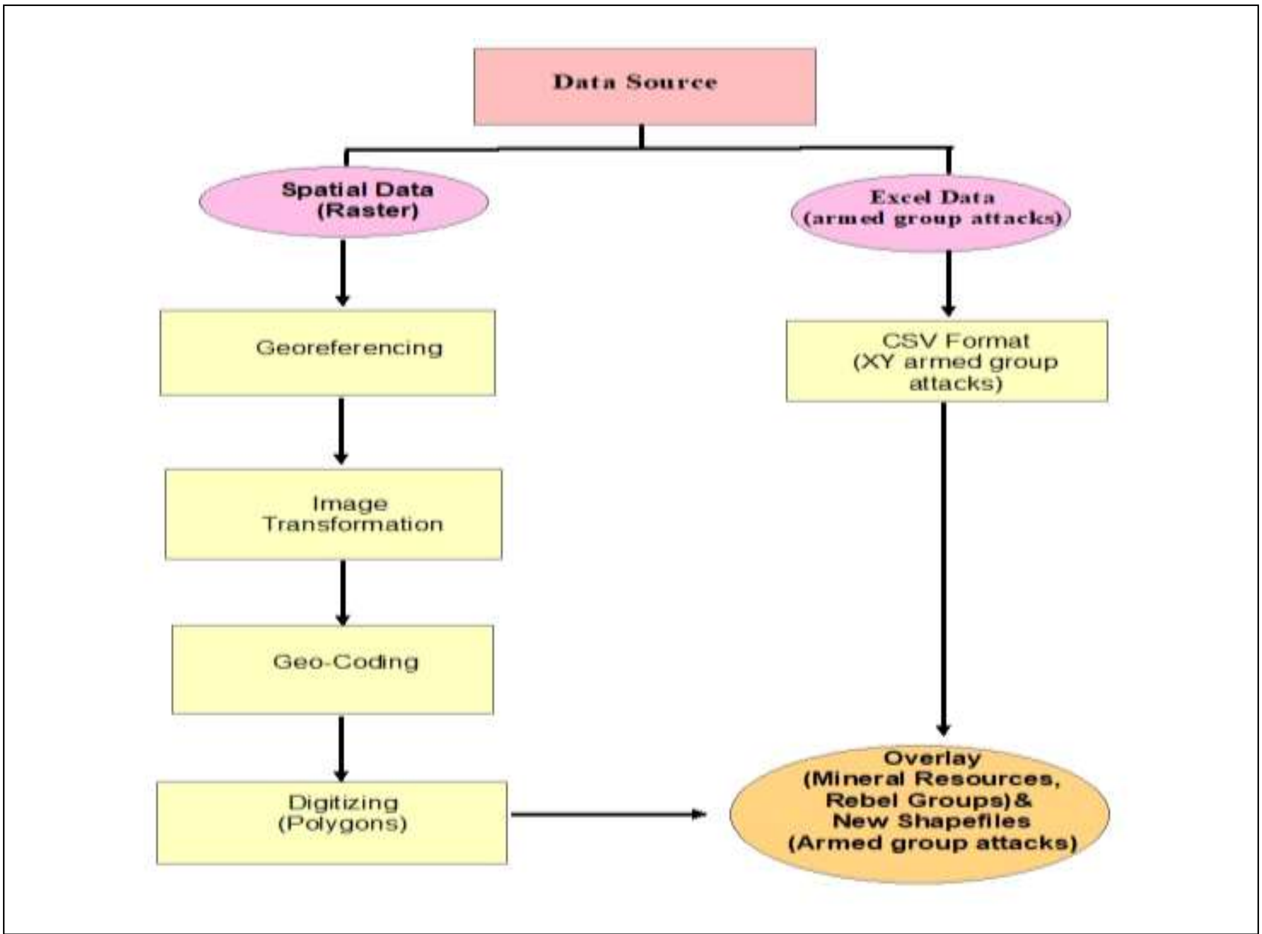

Figure 4. 2 Data Pre-Processing Flow Chart (Rose quartz colour = source of data; Rholite rose = Input-Data format; Yucca yellow = Process, and Mango = Output).

4.3.3. Accuracy Assessment - Root Mean Square Error (RMSE)

Producing a map is not enough, the degree of accuracy is also important to see how well what is on the map correspond with what is on the ground. RMSE values were used to test the accuracy of the control point locations. RMSE is a measure of the difference between locations that are known and locations that have been interpolated or digitized (Louassa et al., 2018, Willmott and Matsuura, 2005; Morad et al., 1996). In the context of this study, it measures the difference between the digitized control point (CP) and their actual locations in the real world or referenced map (Morad et al., 1996; Agüera-Vega et al., 2006). The value retained also describes how accurate the transformation is between the different control points.

There is considerable debate (Willmott and Matsuura, 2005; Burkholder, 1978; Kotz and Johnson, 1988; Marriott, 1990; Hellmann and Fowler, 1999) on how to interpret RMSE. While some authors evoke the idea that values indicating accurate mapping (data analysis) should be less than half of the pixel size of the image being digitize (Willmott and Matsuura, 2005), others argue against such a rigid rule contending that it varies with the nature of the project and the level of accuracy required (Burkholder, 1978, Kotz and Johnson, 1988; Marriott, 1990; Hellmann and Fowler, 1999). A less contesting stance between the two views is the generally accepted position that the closer the RMSE is to zero, the more accurate is the result (Hellmann and Fowler, 1999). In this study, after georeferencing the control points, this less contested view of RMSE was adopted with the 2^{nd} and 3^{rd} order transformations (Section 4.3.2.2), resulting in the selection of the 3rd order transformation due to its lower RMSE values (closer to zero) (Table 4.1).

Table 4. 1 RMSE results of georeferenced and transformed maps

Mineral resource maps	RMSE value (2nd order)	RMSE value (3rd order)
Congo Belge –Rwanda-Urundi	0.00799296	0.00125615
Uganda	0.0090315	0.00257631
Tanzania	0.0209564	0.00184064

4.3.4. Conflicts spatial distribution, clusters, and hot spots

In addition to its ability to create maps from large and complex data sets, GIS has the technological capability to analyze the spatial patterns and trends of features. The spatial statistical analysis is one of the many GIS techniques applied to geographically evaluate where spatial clusters, hot or cold spots occur (Getis, et al.,1996; Asselin, 1995). Different spatial analysis tools were used to understand the general spatial distribution of conflicts through a generalized visualization of conflicts (Figure 4.3), global patterns of conflict clusters using 'Average Nearest Neighbours' (ANN) (Figure 4.5), autocorrelation or Moran's I (Figure 4.6), and Hot spot analysis through Getis-Ord Gi* technique for a period of 20 years with a 10 years interval, ranging from 1998 - 2007 and 2008 - 2017 (Figure 4.8).

4.3.4.1. Spatial distribution of conflicts in the GLR

Geovisualization of spatial data enables the representation and interpretation of the real world through cartographic and geographic methods (GHaedrahmati, et al., 2018; Yasobant et al., 2015). The process of geovisualization allows several conflict indicators to be displayed in a single view (single map) and helps the user to have an improved understanding of the complex relationship between these variables. Previous conflict studies in the GLR contain country-by-country (disjointed) maps on various aspects of conflict, providing this study an opportunity to produce a synthesized generalized regional map of conflicts in the GLR. This was performed using the ACLED conflicts dataset, which was further reorganized into two periods (1998 - 2007 and 2008 - 2017) with a 10 years interval. The x,y CSV conflict points reorganized into two periods (1998 to 2007) and (2008 - 2017), were imported and displayed in ArcMap, providing a generalized geovisualization of violent conflicts in a single map (Section 4.6.1, Figure 4.3 (a) and (b). While the generalized single map does not explain the rate or percentage of change (decrease or increase) in conflicts, further assessment of conflict clusters and Hot spots was performed, and the results are presented in Section 4.7.1 (Table 4.2 and Figure 4.4).

4.3.4.2. Assessment of conflict clusters using Average Nearest Neighbours (ANN)

Clusters of armed violent conflict distribution were performed utlizing the Average Nearest Neighbours (ANN) tool in ArcMap software to see whether conflict occurrences in the GLR are clustered or not (Section 4.7.2, Figure 4.5). The ANN tool calculates the distance between each feature and its nearest neighbours, then computes the average for all nearest neighbour distances (observed average distance) (Moran, 1950; ESRI, 2018; Brasier, 2005). It then compares the computed average distance to a theoretical one (expected average distance) that would be obtained if the points were randomly distributed inside an area (Conley et al., 2005; Brasier, 2005; ESRI, 2018). An ANN of less than 1 represents a clustering of phenomena, while an ANN of more than 1 represents dispersion (ESRI, 2018).

4.3.4.3. Spatial autocorrelation (SA) of conflicts

Moran's I is a commonly used indicator of spatial autocorrelation (SA) and is a further measure of clustering, providing a clue to whether hot spots exist in the data or not (Khatiwada, 2014; Brasier, 2005; Moran, 1950). Unlike ANN, which determines clustering based on distances, Moran's I go further using both feature locations and attributes (in this study, the number of violent conflicts that occurred at each location) to determine whether clustering of high or low values exist in the data and their relationships. Its values range from −1 to 1, where "1" means perfect positive spatial autocorrelation of clustering of (high or low values), while "−1" suggests perfect negative spatial autocorrelation (a checkered pattern), and "0" implies perfect spatial randomness (Tu and Xia, 2008). Moran's, I test Tobler's first law of geography, which states that everything is related to everything else, but near things are more related than distant things (Tobler, 2004; Miller, 2004). If nearby areas are alike (high or low number of conflicts), the SA is positive. Negative spatial autocorrelation applies to neighbouring areas that are no alike (high conflict numbers accompanied by low conflict numbers in their neighborhood), and no spatial autocorrelation exhibits a random and dispersed distribution of conflicts. In addition to being a statistical value (index), Moran's I also produce a z-score and p-value, indicating the significance of the calculated Moran's I statistic (showing the significance of the statistic indicating clustering, non-clustering or randomness) (Khatiwada, 2014; Nyoni, 2017; ESRI, 2016).

The Moran's I is an inferential statistic and is therefore linked to the null hypothesis in spatial statistics, which states that features being analyzed are randomly distributed, and there is no clustering (Khatiwada, 2014; ESRI, 2018). The resulting z-score and p-values allow for the rejection or acceptance of that generally stated null hypothesis. Generally, very low negative or very high positive z-values associated with very low p-values indicate statistically significant clustering resulting in the rejection of the null hypothesis, while higher negative and lower positive z-score associated with higher p-vales indicate statistically significant randomness, resulting in the acceptance of the null hypothesis that feature or events are randomly distributed or are random occurrences (Khatiwada, 2014; ESRI, 2016).

4.3.4.4. Assessment of Conflict Hot spots utilizing Getis-Ord Gi* statistic (Gi*)

The conflict Hot spots was assessed using the Getis-Ord Gi* statistic (Gi*). It is a family of statistics that have several attributes, making them attractive for measuring dependence in spatially distributed variables (Getis and Ord, 1992; ESRI, 2016; Nyoni, 2017). The Getis-Ord GI* function looks at each feature within the context of neighbouring features (Erdogan et al.

2015; Nyoni, 2017). The output of Hot spot analysis tool is the z-score (-2.58 to +2.58) and p-value (± 0.01 to ± 0.10) for each feature. These values represent the statistical significance of the spatial clustering of values, given the conceptualization of spatial relationships and the scale of analysis (Dereli and Erdogan, 2015). A statistically significant positive z-score (≥ 1.96) and small p-value (≤0.05) for a feature indicates a spatial clustering of hot spots, whereas a statistically significant negative z-score (≤ -1.96) and small p-value (≤ 0.05) indicates a spatial clustering of Cold spots (Erdogan et al., 2015; ESRI, 2016). The higher the z-score, the more intense is the clustering (Erdogan et al., 2015).

4.3.5. Creation of a Conflict Risk Model (CRM)

While risk prediction models are common in some disciplines, namely, economics, engineering, or agriculture (Kahneman and Tversky, 2013; Feng and Wang, 2000; Marriott,1990; Yaari, 1987), little has been done in the field of civil wars and conflicts (IEP report, 2017; George, 2016; Starr, 1978), providing an opportunity for this study to develop a Conflict Risk Model (CRM) as a tool to assist in predicting the possibilities of future armed violent conflicts or where probable conflicts or civil wars may occur in the future.

The aim of developing the CRM is to provide a tool or a warning system that may practically assist in mitigating and preventing the occurrence of future conflicts (Mossin, 2007; Wood and Milefsky, 2002; Dietz, 1989) in the GLR. The model was developed in Microsoft Excel using the subjective weighting method of conflict variables (Chen et al., 2001.Carver, 1991; Ayeni, 1997; Janssen and Rietveld, 1990). The subjective weighted method determines the weights of variables solely according to the preferences or judgement of decision-makers (Wang and Lee, 2009; Quiggin, 2012; Slovic, 2000). When using the subjective approach, assessment of variables requires diverse opinions without an expectation that each assessed variable is of equal importance (Wang and Lee, 2009; Quiggin, 2012; Slovic, 2000 and Janssen and Rietveld, 1990), providing a level of confidence of the model’s validity. In this study, the subjective weighting approach was adopted using a survey questionnaire sent to 10 randomly selected experts in conflicts resolution, and peacebuilding, who were requested to rate the four selected conflict variables, based on their subjective expert knowledge (Stephenne et al., 2009; Eastman, 1999; Levins, 1966). Some of these respondents are citizens from countries of the Great Lake Region (Rwanda = 2, Tanzania = 1, Burundi = 1, DRC = 2), and 4 others are from South Africa. Their professions vary from university lecturers, international criminal lawyer and peacebuilding coordinators.

4.3.5.1. Ranking conflict risk variables

Risk ranking is a process of assigning values (numbers or phrases) indicating the level or a score of possible outcomes for any variable (Raleigh et al., 2010; Chen et al., 2003; Hegre, 2011, Bearman, 2016, Bellman and Zadeh, 1970). The subjective weighting method (Table 4.2) was used to rate the conflict risk variables and conflict risk possibilities. Each variable was rated on a scale of 0 to 4, where 0 represents *no conflict risk* posed by a variable; **1** represents a *negligible conflict risk*; **2**, *low conflict risk*; **3**, *moderate conflict risk*, and **4**, *high conflict risk.*

To determine the probability of conflict occurring, the scores were averaged, and the results presented in percentage. The final results (%) were further subjectively ranked at an interval of 20% from very low to very high as follows:

- 0 - 20% = *very low possibility of conflict.*
- 20% - 40% = *low possibility of conflict.*
- 40% - 60% = *moderate possibility of conflict.*
- 60% - 80% = *high possibility of conflict.*
- Greater than 80% = *very high possibility of conflict.*

A sample of the Microsoft Excel model testing the prediction of armed conflict risk is presented in Table 4.2.

Table 4.2 The conflict risk model

Variable | Score no | Risk possibility

	Rebel Density	Minerals Occurrence	Political Instability	Ethnic Identity Allegiances
Input Rating Number	2	2	3	3
Output	Low	Low	Moderate	Moderate
Conflict Percentage (%)				63
Conflict Probability				High possibility of conflict

Table 4.2 exemplifies the prediction of conflict risk for the country of Burundi. Using the selected variables, Rebels density is weighted 2 (low), Minerals occurrence 2 (low), Political instability 3 (Medium), and Ethnic identity allegiance 4 (high). The possibilities of conflicts risk in percentage for Burundi is thus automatically calculated by adding up all the values entered under the four variables (11/16x100), resulting in a high possibility of conflicts (61%) for the next 20 years period (2018-2038). This predictive model can be expressed mathematically in percentage using the conflict risk *equation:*

$$= 6.25 \sum_{k=1}^{4} n_k$$

Where,

- 1 to 4 represents the four variables in the model
- n_k represents the ranks or scores for each variable, and ranks range from 0 to 4
- 6.25 is the constant for converting the average scores to percentage

4.3.6. Prediction of armed conflicts in the GLR at Country and Regional levels

The percentage probability of armed conflict occurring in each country was calculated using the conflict risk equation for a period of 20 years, ranging from 2018-2038. At the regional level, the probability of conflict was determined by averaging all the conflict probability scores (%) for the five countries and the result was interpreted using the conflict probability levels. The use of values outside the rating scale and conflict probability range will result in an invalid or false reading. The created model can be refined and applied in other regions of conflicts other than the GLR.

4.4. Results

4.4.1. Spatial distribution of armed conflicts location in the GLR

Figure 4.3 (a) and (b) presents the results and a holistic understanding of armed violent conflict attacks in the five countries of the GLR for the two study periods of 20 years from 1998 - 2007 and 2008 - 2017. Areas of clustered points on the map show the areas of high concentration of conflicts.

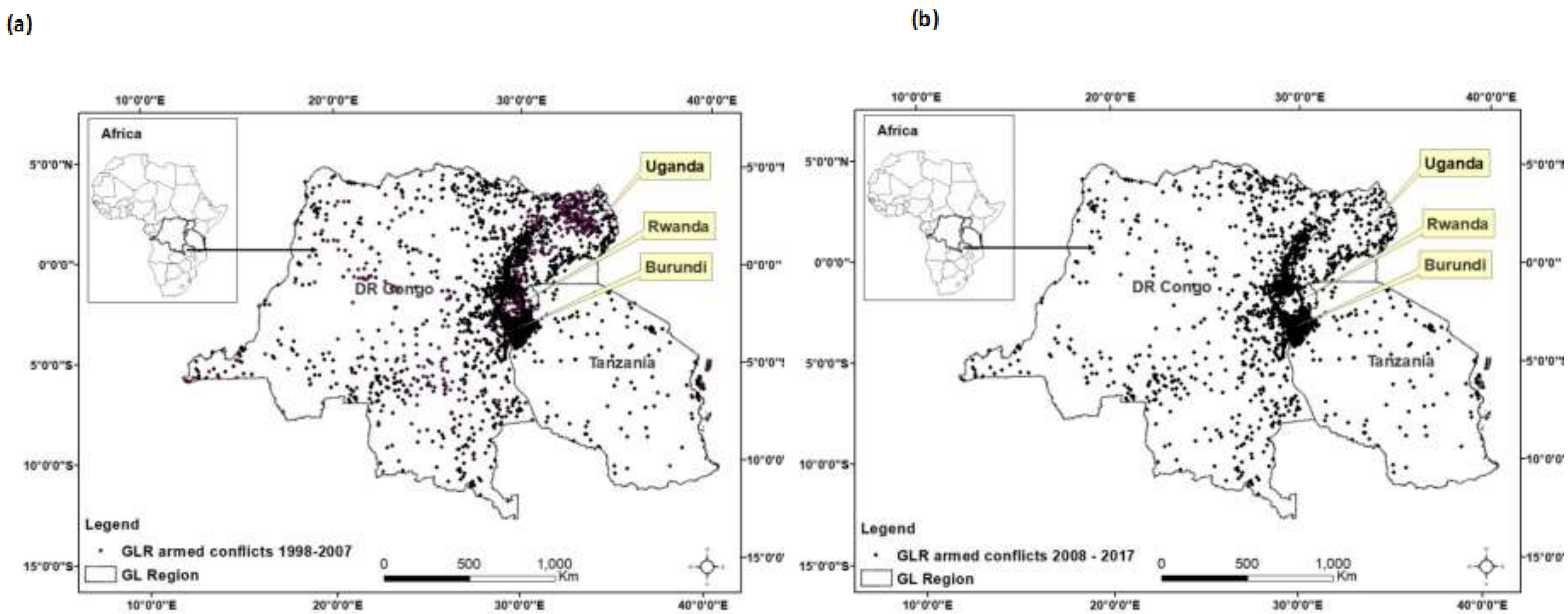

Figure 4.3 (a) A generalized map of armed conflict distribution in the GLR from 1998 – 2007 and (b) 2008 – 2017. (Data source: Armed Conflict Location and Event Data Project (ACLED), Geography Department, University of KwaZulu-Natal, and International Peace Information Service (IPIS)).

The results show that armed violent conflicts were more prevalent in the whole country of Burundi, Eastern region of DRC, North region of Uganda, and less in the country of Rwanda and Tanzania. A comparison of the two study periods (1998 - 2007 and 2008 - 2017) reveal that armed violent conflicts decreased in Uganda and Rwanda. While the generalised map presents an overall distribution of armed conflicts in the whole region during the two study periods, it does not explain why certain countries such as DRC and Burundi experience more armed violent conflicts. Consequently, a further detailed analysis on the spatial distribution of armed conflicts and their trends, including the total number of armed attacks and the rate of change in percentage for each country (Table 4.3 and Figure 4.4) was performed.

The results from comparing the two periods (the Table 4.3 and Figure 4.4) reveals that the DRC has experienced the highest percentage (207%) of increase in conflicts, followed by Burundi (25%) and Tanzania (6%) and the least percentage change was registered by Uganda (-135%) and Rwanda (-3%). While the percentage of change in conflicts has decreased for some of these countries (Uganda and Rwanda), a visual and numerical comparison between the two periods (Table 4.3 and Figure 4.4), still show a slight regional increase in conflicts by 1734 attacks (from 8491 to 10225) between 2008 and 2017.

Table 4. 3 Rate of change in conflicts distribution

Country	1998-2007	2008-2017	Change	Rate of change (%)
Burundi	2313	2742	429	25
DRC	2863	6456	3593	207
Rwanda	228	183	-45	-3
Tanzania	132	239	107	6
Uganda	2945	602	-2343	-135
GLR	**8491**	**10225**	**1741**	**100**

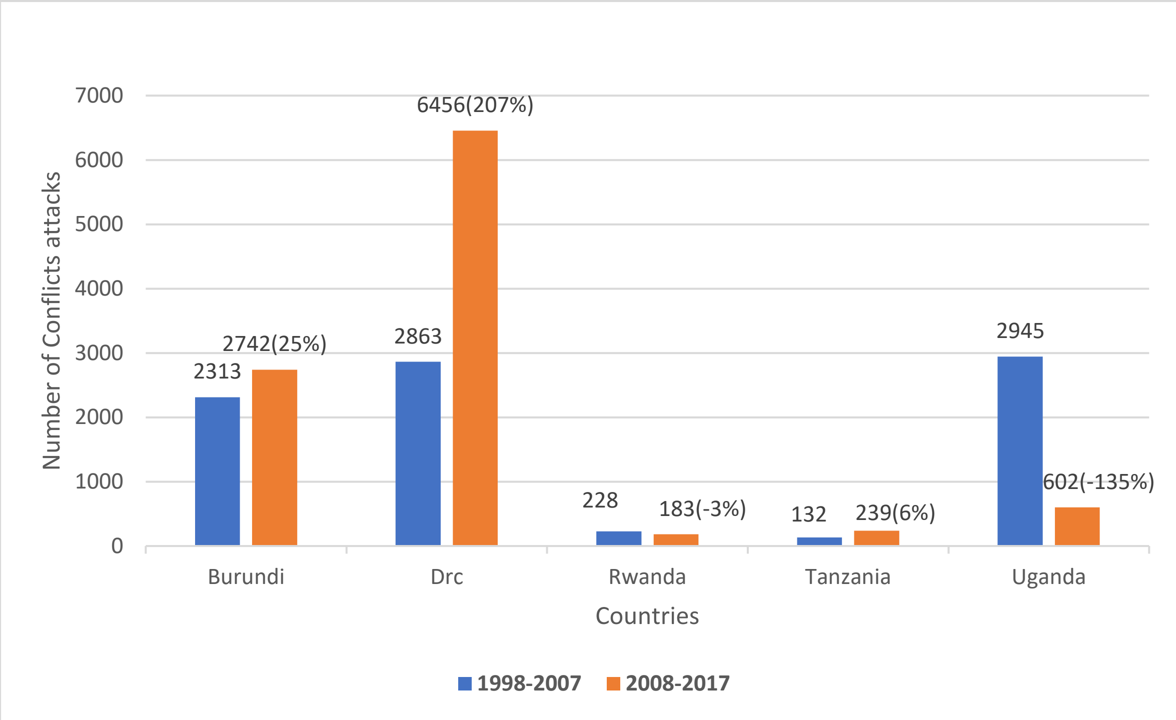

Figure 4. 4 Rate of change (percentage) in armed attacks. (Data source: Armed Conflict Location and Event Data Project (ACLED)).

4.4.2. Conflict clusters

Conflict clusters were determined using the ANN (Section 4.3.4.2, Figure 4.5). To calculate the ANN, knowledge of the study area boundary is required. Therefore, a total area of the GLR was calculated to be 3562513210231 square Kilometres was used to determine the ANN for both periods (1997-2007 and 2008-2017). The ANN results is less than 1 (z-score approximately -161.57 for the 1997-2007 period and -152.45 for the 2008-2017 period), indicating significant clustering of armed violent conflicts at 99% confidence ($p < 0.01$) in some localities of eastern DRC and Uganda (Section 4.5; ESRI, 2016; Figures 4.3a and 4.3b; note the left highlighted rectangles below the two Figures and the accompanying footnote).

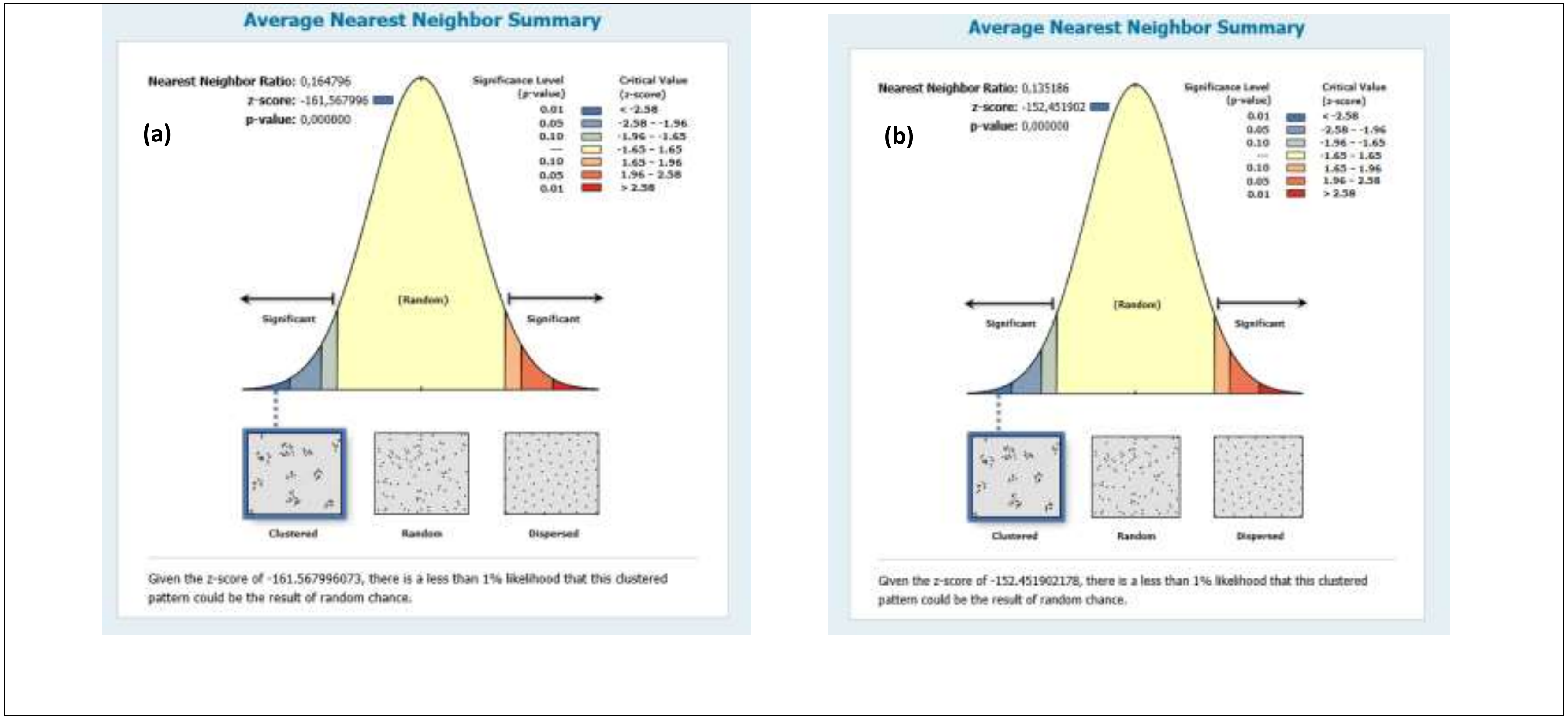

Figure 4. 5 Clustering of armed conflicts in the GLR (a) 1998 - 2007 and (b) 2008 – 2017. (Data source: Armed Conflict Location and Event Data Project (ACLED) and International Peace Information Service (IPIS)).

4.4.3. Determination of Distance Band thresholds using the Incremental Spatial Autocorrelation (ISA) Function

There are several methods for determining the appropriate distance for neighbouring features to be included in the calculation of autocorrelation. These include, among others, the incremental spatial autocorrelation (ISA) method (Nyoni, 2018; ESRI, 2016). The distance band for ISA was calculated from neighbours count in ArcGIS spatial statistical tools and returned three numbers: the minimum, the maximum and the average distance to a specified number of neighbours (ESRI, 2016). The maximum distance is the furthest distance and minimum distance is the closest distance between a feature and its neighbours, while the Average is the distance between all the features and their neighbours. The results reported an average value of 1385 m (1400) and a maximum value of 285189 m (285190) for the 1998 - 2007 period, while the 2008 - 2017 period reported an average distance of 1538 m (1540) and a maximum distance of 178449 m (178450) (Figure 4.6a and 4.6b). To perform Moran's, I Spatial autocorrelation (Section 4.4.3), the resulting maximum distances or distance bands and fixed distance method were used.

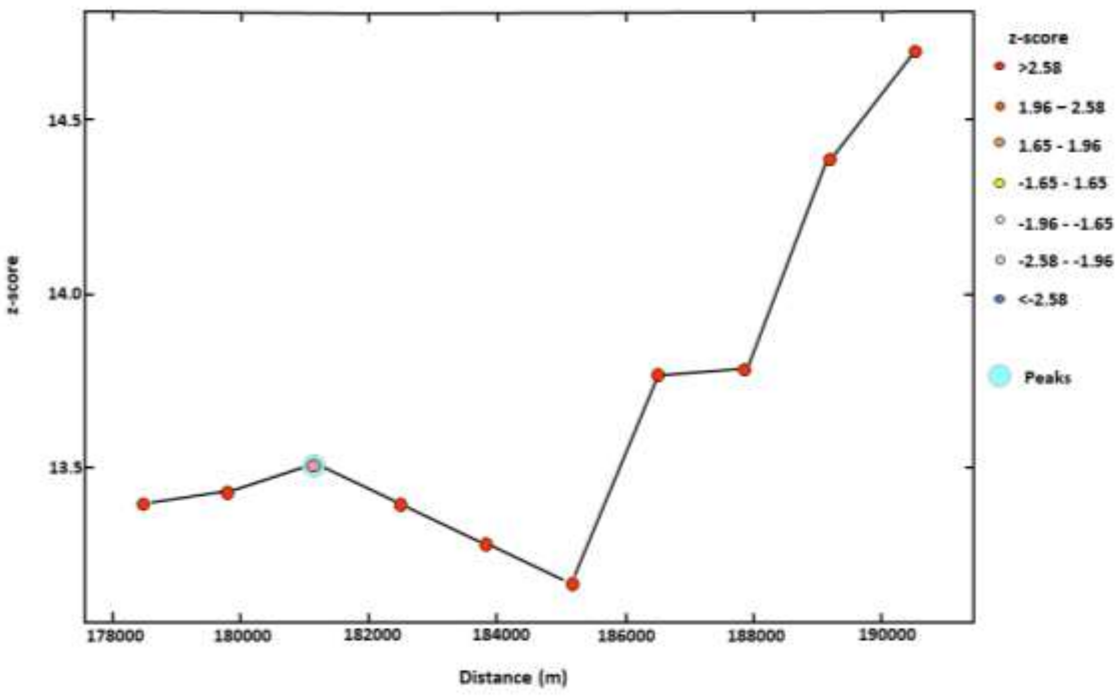

Figure 4. 6 (a) ISA Distance Band values 1998 – 2007. (Data source*:* Armed Conflict Location and Event Data Project (ACLED)).

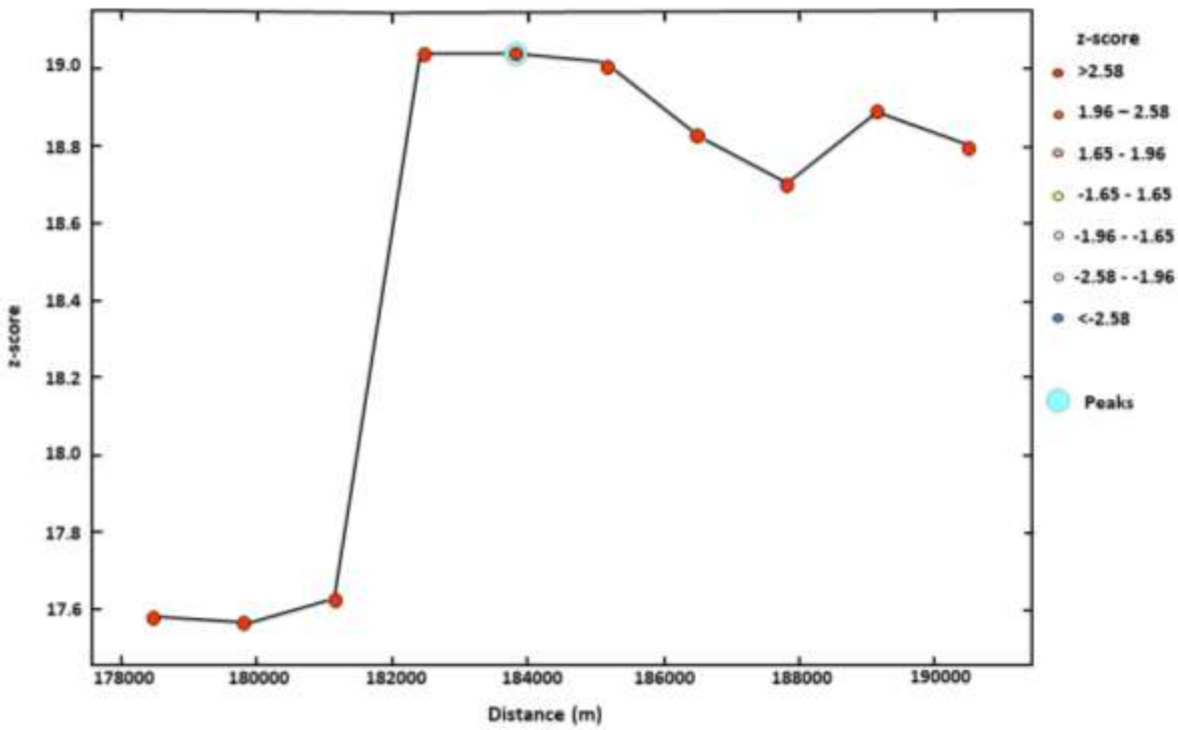

Figure 4. 6 (b) ISA Distance Band values 2008 – 2017. (Data Source*:* Armed Conflict Location and Event Data Project (ACLED)).

4.4.4. Spatial autocorrelation

The Spatial autocorrelation of conflicts is a further measure of clustering. In this study, the resulting autocorrelation z-scores (Standard Deviation) and p-values were 6. 54292623264 (p = 0.00) from 1997 - 2007 and 17. 582161 (p = 0.00) for the 2008-2017 period (Figure 4.7), indicating clustering.

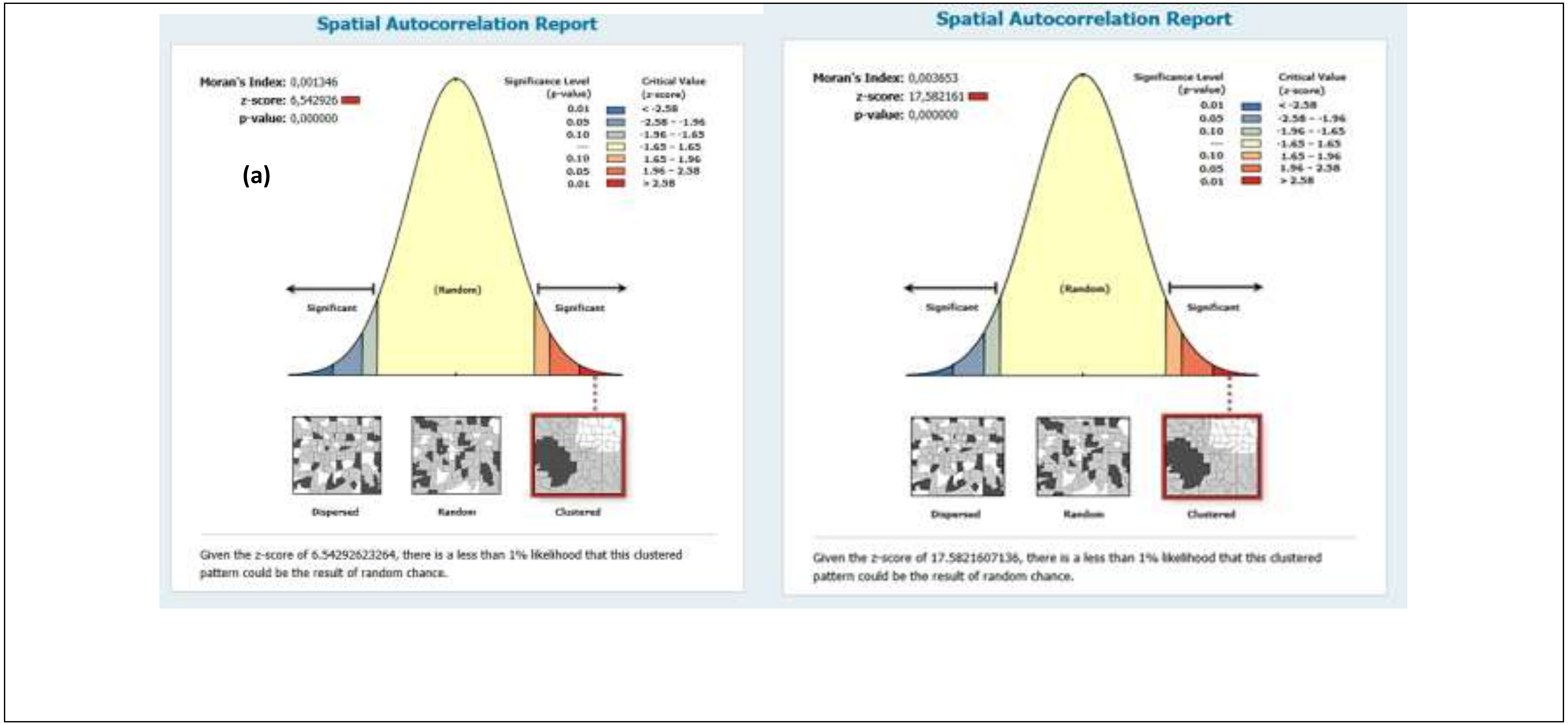

Figure 4. 7 Spatial Autocorrelation of armed conflicts in the GLR (a) 1998 - 2007 and (b) 2008 – 2017.

*(*Data Source: Armed Conflict Location and Event Data Project (ACLED) and International Peace Information Service (IPIS)).

4.4.5. Conflict hot spots

The Getis-Ord GI* hot spot analysis technique (Section 4.3.4.4) was used to determine hot and cold spots of the armed conflicts in the GLR during the two study periods (1998 - 2007 and 2008 - 2017) (Figure 4.8) and understand their spatial pattern and relationship. The results show that during the 1997 - 2008 study period, conflicts hot spots were located mostly along the eastern DRC border (on each side of the border) with Uganda and Burundi, and a few in the north-western and south-western Tanzania (Figure 4.8). The eastern DRC emerged as the area with the highest armed conflicts hot spots at 99% confidence. However, between the 2008 and 2017 study period, there was a slight variation of conflict hot spot patterns. While the north-eastern DRC remained a hot spot, a new hot spot emerged in the south of DRC, and a previous hot spot along the DRC border with Tanzania and Burundi borders became a cold spot.

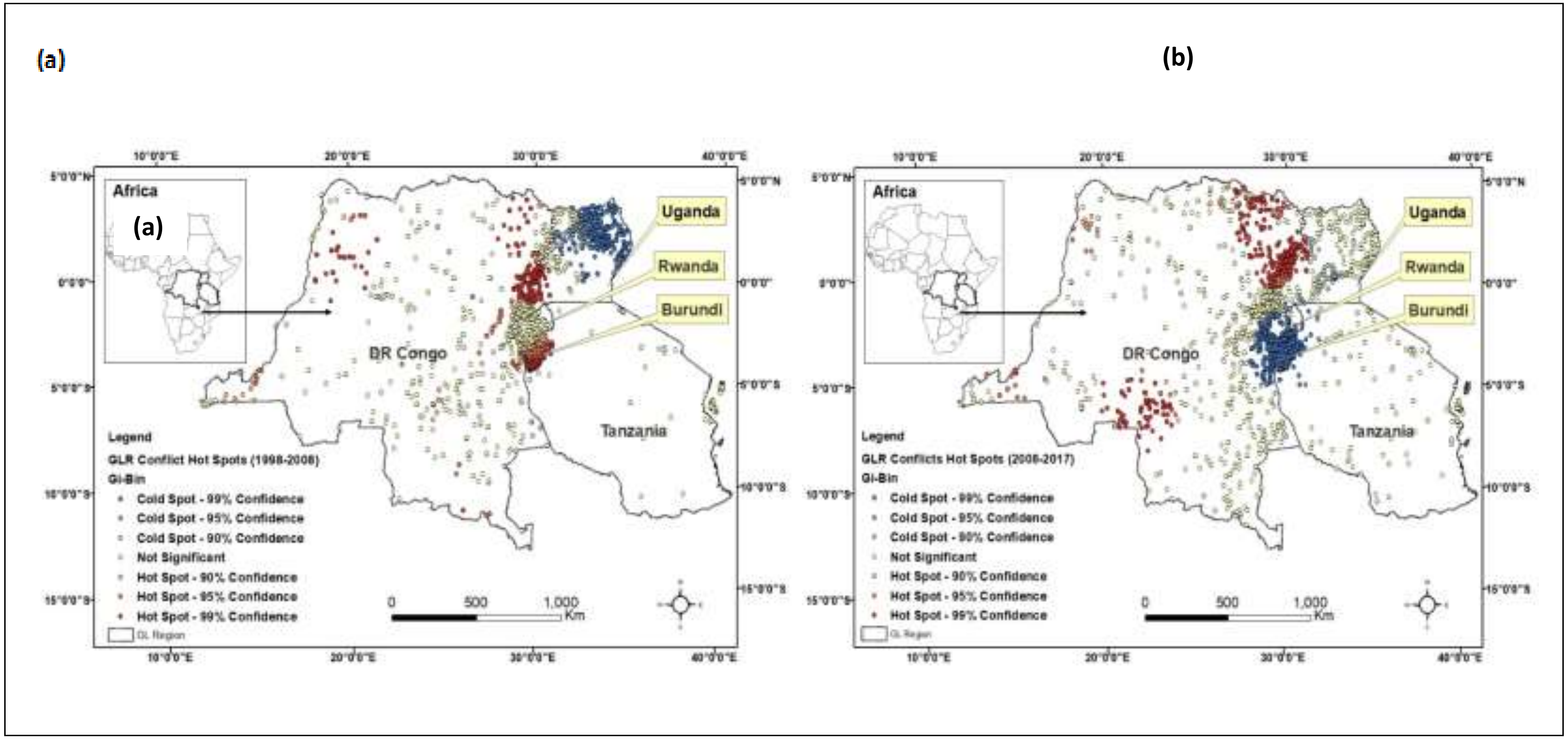

Figure 4. 8 (a) Conflicts Hot and Cold spots 1998 – 2007. **(b)** Conflicts Hot and Cold spots 2008 – 2017.

(Data Source*:* Armed Conflict Location and Event Data Project (ACLED), Geography Department, University of KwaZulu-Natal, and International Peace Information Service (IPIS)).

4.4.6. The spatial distribution of armed rebel groups

Various literature (Congo Research Group, 2018; Buhaug and Gates, 2016; Kanyangara, 2016; Huggins, 2005; July, 1970; Kranigan, 1976; Autesserre, 2012) reported that many armed rebel groups, from different backgrounds, are located in the DRC. Figure 4.9 present the location of 42 rebel groups in eastern DRC, notably the province of Katanga, Kivu (North and South) and Orientale.

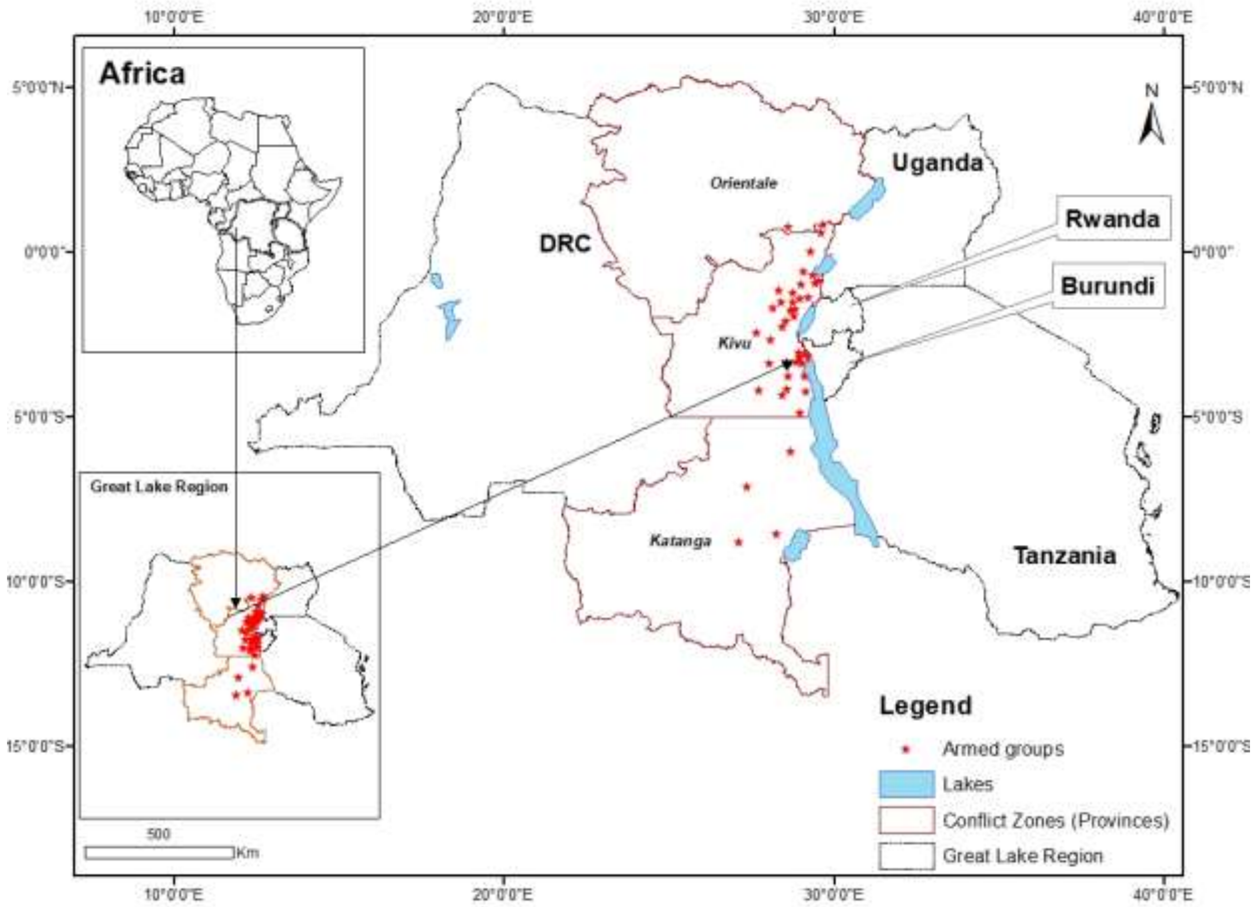

Figure 4. 9 Spatial Distribution of forty-two-armed rebel groups, including 35 in Kivu, 4 in Katanga and 3 in Orientale provinces. (Data source: Geography Department, University of KwaZulu-Natal, and International Peace Information Service (IPIS)).

4.4.7. The spatial distribution of mineral resources

Six main mineral resources type occurring in the GLR, including Copper, Diamonds, Gold, Tin, Iron, and Carbonates were selected and mapped (Figure 4.10) to show their spatial distribution. While these six selected minerals are clustered in the eastern region of DRC, they are generally dotted all over other countries of the GLR (Figure 4.10).

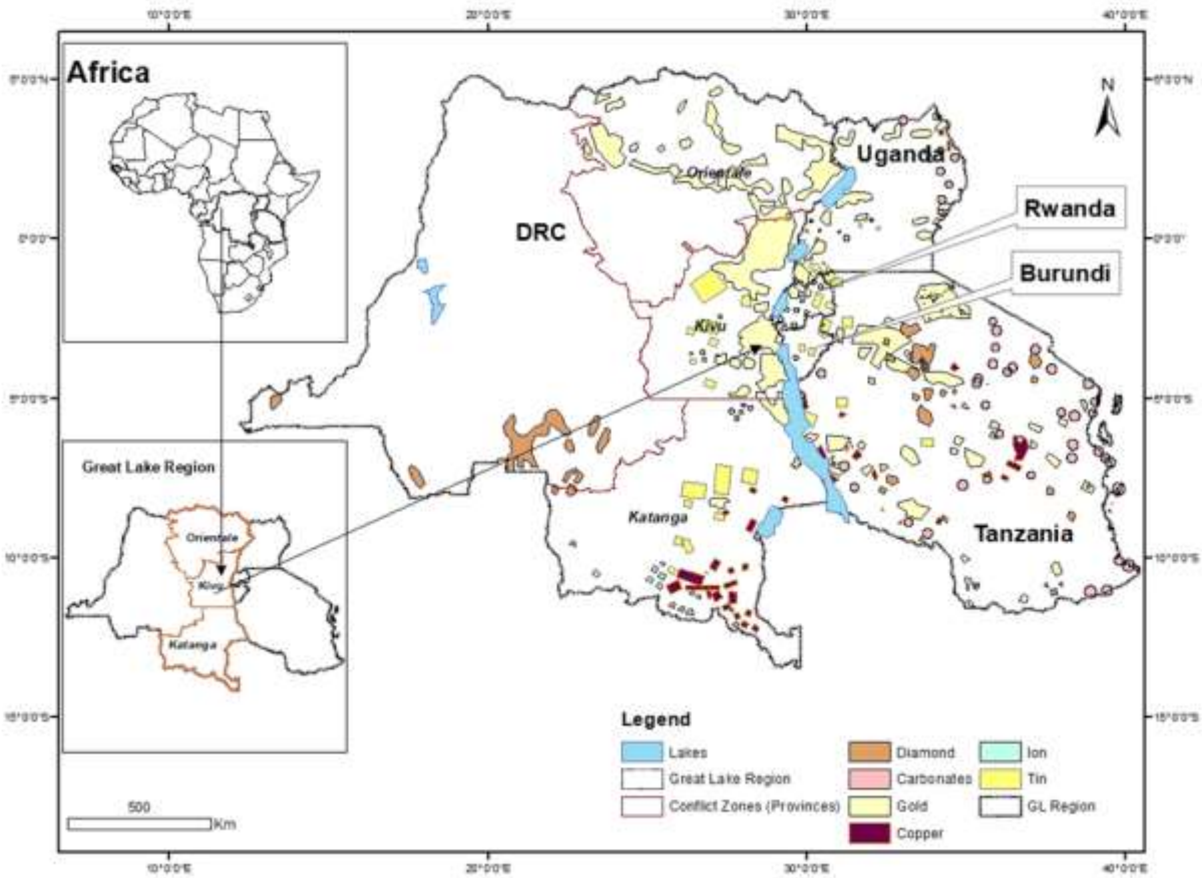

Figure 4. 10 Spatial distribution of six main mineral resources in the five countries of GLR. (Data source*:* Geography Department, University of KwaZulu-Natal, IPIS, CRG, UN Global Pulse (Uganda Project), Yale University, New York University, and L'Institut Royal Colonial Belge library (Bruxelles)).

The question whether there exists any relationship between mineral resources and violent conflict zones has not been well-researched, providing an opportunity for this study to further explore such a relationship. The two maps, including the spatial distribution of rebel armed groups and mineral resources (respectively Figure 4.9&4.10) were overlaid, showing a coexistence (correlation) between the two variables (Figure 4.11).

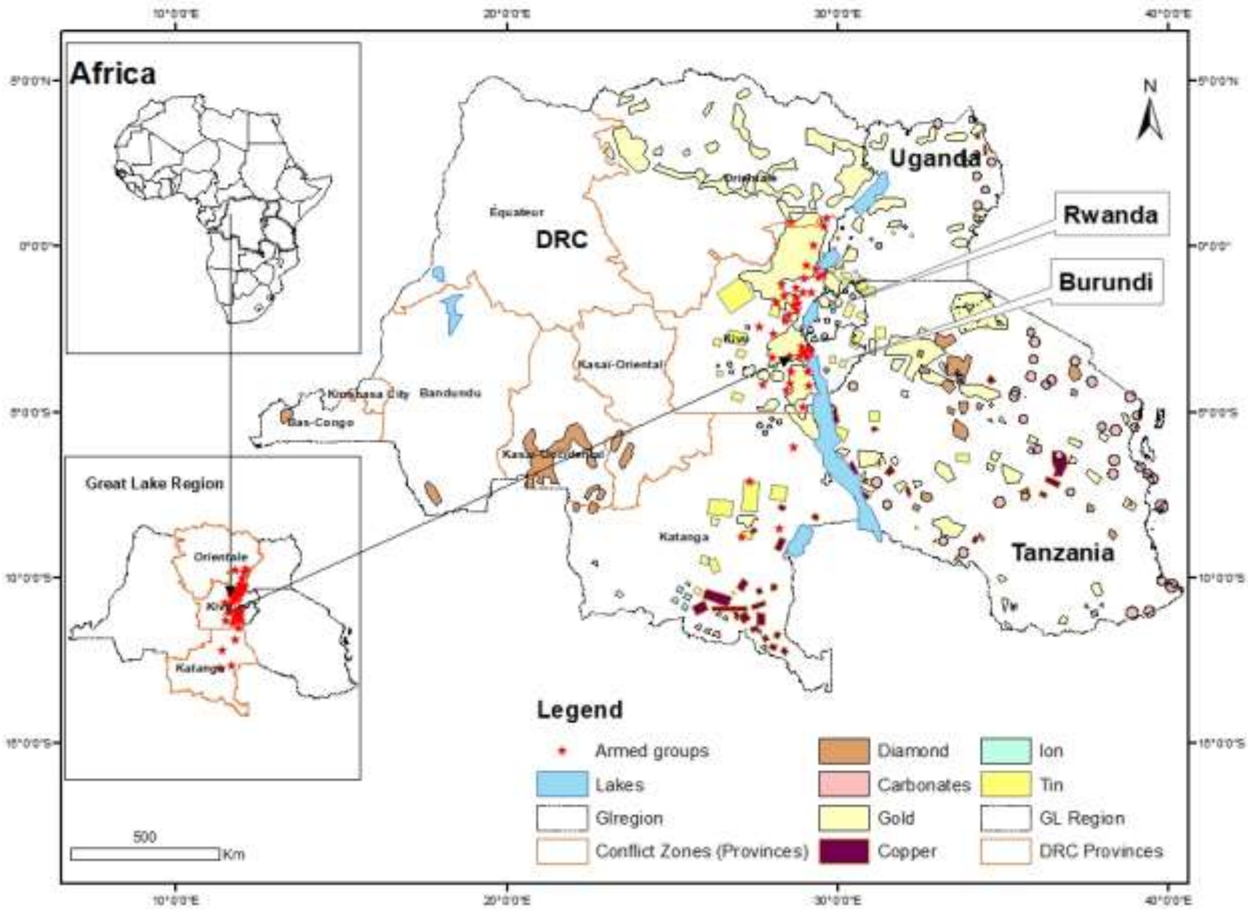

Figure 4. 11 A correlation of armed rebels group and mineral resources maps in the same geographical region of Eastern DRC (Oriental, Kivu, and Katanga provinces).

Data source: Geography Department, University of KwaZulu-Natal, IPIS, CRG, UN Global Pulse (Uganda Project), Yale University, New York University, and L'Institut Royal Colonial Belge library (Bruxelles).

Many rebel groups are located in the Kivu province where most minerals occur, suggesting that mineral resources are a probable causal factor of violent armed conflict in the region.

4.4.8. Prediction of armed conflict at a country level

Average scores of variables predicting the occurrence of armed (Table 4.4), obtained from a survey of 10 expert participants were input into the conflict risk equation resulting in the determination of future conflict risk per country in the GLR. The prediction reveals that DRC has the highest probability of armed conflict (81%) occurring in the future, followed by Burundi (63%), Rwanda and Uganda (56%), while Tanzania is predicted to have the least probability of armed conflict (50%) occurring in the next 20 years, from 2018 - 2038.

Table 4. 4 Predicted average scores of conflict variable per country in the GLR (2018 - 2038)

Variables	Countries				
	Burundi	**DRC**	**Rwanda**	**Tanzania**	**Uganda**
Mineral resource (Occurrence)	2	3	1	2	2
Rebel arm group (Density)	2	4	2	1	2
Population (Ethnic hostilities)	3	3	3	2	2
Government (Political instability)	3	3	3	3	3
Total	10	13	9	8	9
Country average scores (%)	**63**	**81**	**56**	**50**	**56**
Conflict Probabilities	**High**	**Very High**	**Moderate**	**Moderate**	**Moderate**

4.4.9. Prediction of armed conflict risks at regional level

The probability of armed conflicts occurring in the GLR was calculated by averaging the conflict probabilities of all the five countries (Burundi: 63%, DRC: 81%, Rwanda: 56%, Tanzania: 50%, Uganda: 56%), resulting in a 66% (High probability) of armed conflict in the next 20 years (2018 - 2038).

4.5. Discussions

The results derived from this study indicate that the application of GIS to identify and assess the spatial distribution, clusters, hot, and risk spots of armed conflicts can provide a better insight into conflict management in the GLR. While a generalized map (Figures 4.3 a&b), presents an overall spatial distribution of armed conflicts in the GLR from 1998 - 2007, there are some variations for each country. Armed violent conflicts were prevalent in Burundi, eastern region of DRC, north of Uganda, and less in Rwanda and Tanzania. This observation is supported by findings from previous studies, including among others (Steans and Vogel, 2015).

A comparison of results from the two study periods (1998 - 2007 and 2008 - 2017), reveal that there was an increase of armed conflicts from 2008 - 2017 in the eastern region of DRC by 207% and Burundi by 25%, a slight increase in Tanzania by 6%, a sharp decrease in Uganda by -135% and a slight in Rwanda by -3%.

To better understand these variations, conflict clusters (ANN) and hot spot (Getis Stephenne - Ord Gi*) analyses (Lemarchand, 1999; Adamson, 2006; Mulongo, 2010; Rustad et al., 2011), of armed conflicts were further performed for the two periods (1997 - 2007 and 2008 -2017). The results of conflict clusters from 1998-2007 (Figure 4.5a) and 2008-2017 (Figure 4.5b) demonstrate that ANN is less than 1 (approximately -161.57) for the 1998-2007 period and -152.45 for the 2008-2017 period), indicating significant clustering of violent conflicts at 99% confidence ($p < 0.01$) in some localities of the eastern DRC and Uganda. These conflict clusters have been attributed to the presence of mineral resources that attract armed rebels from various ethnic groups seeking economic opportunities (Shyaka, 2006, Greene, and Quick, 2015; Lang, 2009; Bennett, 1982; Pottier, 2002; Mine, 2013; Samset, 2009).

The conflicts hotspots were identified based on the spatial distribution of armed rebel groups and recurring conflicts. The results show that the conflicts hot spots for the study period of 1997 to 2008, were located mostly along the eastern DRC border (on each side of the border) with Uganda and Burundi, and a few in the north-western and south-western Tanzania (Figure 4.8 a). However, from 2008 - 2017, there was a slight variation of conflict hot spot pattern. While the north-eastern DRC remained a hot spot, a new hot spot emerged in the south of DRC, and a previous hot spot along the DRC border with Tanzania and Burundi borders became a cold spot (Figure 4.8b). The reason for the existence of these hot spots in close proximities can be explained by the nearest neighbourhood effect (Getis and Ord, 1995; Fu et al., 2014), and the first law of geography, which states that everything is related to everything else, but near things are more similar than distant things (Tobler, 2004). The application of this law to the resulting pattern of hot spots is further supported by autocorrelation results (Section 4.4.4), indicating clustering of conflicts in the same area (Figure 4.7). Other literature sources, the great man theories on conflicts in the GLR (Lang, 2009; Gimblett, 2002; Bennett, 1982) and the Tutsi-Empire ideology are significant factors that probably contribute to the existence of these hot spots in the GLR (Stanislas ,2014; Chege, 1997; Lemarchand, 1999; Vansina, 1962).

The predictive model for probable future conflicts (Conflict Risk Model or CRM) created in this study is a tool or a warning system that could assist in mitigating and preventing the occurrence of future conflicts (Wood and Milefsky, 2002; Yoffe and Fiske. 2001; Dietz, 1989) in the GLR. Holistically, the results from the CRM analysis have demonstrated the probabilities of high conflict risk (66%) for the next 20 years (2018 - 2038). At the country level, DRC has the highest risk violent conflicts recurrence (81%) in the next 20 years, mainly because it is a country highly rich in mineral resource, consequently hosting a lot of inter and intra-armed label groups from various ethnic groups, profiting those resources (Kanyangara, 2016). On the contrary, Tanzania is predicted to be the least at risk to violent (50%), probably due to its political stability, stringent policies, and non-tolerance of rebel activities (Mpangara, 2004 and Kanyangara, 2016).

4.6. Challenges

Although this chapter has provided useful insights into the spatial patterns and trends of armed conflicts in the GLR, this study was not conducted without challenges. The major challenge was access to spatial data on armed rebel groups, especially at the country level. For instance, except for DRC, where most data was available for its eastern region (Congo Research Group, 2018; Buhaug and Gates, 2016; Kanyangara, 2016; Huggins, 2005; July 1970), there was no data available for other GLR countries (Burundi, Rwanda, Tanzania, and Uganda) on the spatial distribution of armed rebel groups. The inaccessibility of such data raises the question whether there are rebel groups in those countries.

Moreover, where limited data was available (for example, the spatial distribution of mineral resources**),** they existed in hard copy documents, requiring other geospatial pre-processing methods like scanning, georeferencing, and geographic transformation before importing them into a geodatabase. This was further compounded by the fact that most of the hard copy maps were only available in overseas libraries (Belgium-former colonial archives), after lengthy correspondences through international inter-library loan arrangements and at high costs.

Another challenge was presented by policies of some countries of the GLR, where access to some data were prohibited. For example, while all four countries in the GLR allow reports on ethnic groups to be published, one of Rwanda's new policies prohibit reports on ethnic groups or their inclusion on national Identity cards (Carter, 2016; Kanyangara, 2016), making it difficult to perform a comprehensive regional geospatial analysis on ethnic identity and conflicts in the GLR.

Lastly, due to the sensitivity of the topic and volatility of the region characterized by ongoing political instability, armed conflicts, and suspicion of researchers, it was impossible to physically go to these countries and collect data for this study.

4.7. Conclusions and Recommendations

This chapter has explored the application of GIS in conflict resolution and peacebuilding in the GLR, through regional geospatial analysis from 1998 – 2017, and predicts the probabilities of future violent conflict outbreak for the 20 years from 2018 - 2038. A multi-source dataset of x and y locations of conflicts and their attributes in Excel format for the geospatial analysis, were freely collected online from various organizations, mainly Armed Conflict Location and Event

Dataset project (ACLED). Various GIS processes and analyses were employed including geocoding, Average Nearest Neighbours (ANN), autocorrelation (Moran's I), and hot spot (Getis-Ord Gi*) analyses to geovisualize the spatial clusters and hot spot patterns of armed conflicts for a study period of 20 years from 1998 to 2018. From a regional perspective, violent conflicts are prevalent in Burundi, eastern region of DRC, north region of Uganda, and less in Rwanda and Tanzania.

A Comparison of the two study periods from 1998 - 2007 and 2008 - 2017, identified DRC as the country with the highest hot spot of armed conflicts in the past 20 years (1998 - 2017) and remain the highest at risk to conflicts (81%) for the next 20 years from 2018 - 2038, while for the same period Tanzania is predicted to be the least at risk to violent conflicts (50%)

From a theoretical and methodological perspective, this proposed regional spatial model of GIS application to violent conflict resolution could be useful for peacebuilding in the long and persistent violent conflict in the GLR. It sheds light on violent conflict distribution and patterns and thus better informing violent conflict resolution efforts. The limitations of this study offer opportunity for further study, including ground verification of patterns and hot spots in the GLR, assisting countries in the GLR, to develop comprehensive geodatabase and evaluating the socio-economic and environmental impacts of armed violent conflicts in the GLR.

CHAPTER 5

DEVELOPMENT OF A GEODATABASE FOR ARMED VIOLENT CONFLICTS IN THE GREAT LAKE REGION (GLR) OF EAST AND CENTRAL AFRICA

This chapter is based on:

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Abstract

Conflict negotiators, policymakers and peacemakers sometimes find themselves in negotiations with inaccurate, incomplete, or invalid spatial data, breading suspicion among stakeholders, and resulting in inaccurate decisions and unsustainable peace. The initiative to develop a geodatabase for conflicts in the GLR was to provide access to spatial data and offer an opportunity to change the way records are stored, managed, and accessed by different stakeholders in the GLR. Input data, both vector, raster, and tabular data formats from each country of the GLR were obtained online in the form of shapefiles, layers, and coverages. The Environmental Science Research Institute's (ESRI) file geodatabase model was employed using ArcCatalog 10.4 platform in ArcMap software. This model was chosen from among others due to it being the best option for users with limited available funds and its ease of access in comparison to the enterprise geodatabase, which require a long process to get an authorization to connect to the MS SQL server. The development process went through four different phases namely, data acquisition and cleaning, designing a logical model in Microsoft excel, creating a data structure in ArcCatalog and importing data into or populating the geodatabase. The newly created regional geodatabase is made up of three primary feature datasets, including the Living entities, Non-living entities, and Map-Excel table datasets. This new geodatabase intends to serve as a hub for spatial data storage and management, accessible by countries in the GLR, not only during peace negotiations but at any time. Though not very comprehensive at this point, it could be updated and integrated with other data to serve various purposes, including social and economic development.

Keywords: Spatial data, File Geodatabase, Geodatabase creation, Conflict Resolution, Great Lakes Region

5.1. Introduction

Accurate decision making require good information that is derived from quality data (Colonel and Morris, 2018; Foster and Godbole, 2016; Childs, 2009). Data quality refers to "fitness for use" (Cai and Zhu 2015:3) or data that meet requirements for users (Wang & Strong, 1996). Data access, storage, and management is often a challenge in many parts of the world, particularly in Africa including the GLR countries where data access is often seen as a source of political and economic power by those who control it (Harvey and Chrisman, 1998; Kaldor, 2001; Musa et al., 2014). Various literature (Theron, 2017; Harvey and Chrisman, 1998; Leeuwen, 2008) indicates that the characteristics of persistent armed violent conflicts in the GLR countries are strongly regional and attempts to bring peace in the region requires a regionally integrated data and approach. The data for this paper was obtained from online sources including Armed Conflict Location and Event Dataset project (ACLED), National Census (NC) reports, UN Global Pulse (Uganda Project), Geographic Boundary Data (GADM), and International Peace Information Service (IPIS). There are three main types of geodatabases namely, the personal, file, and enterprise geodatabase models. In this study, the file geodatabase model was chosen due to its ability to accommodate users with limited available funds, and its ease of access in comparison to the enterprise geodatabase, which require a long process to get an authorization to connect to MS SQL server. The initiative to develop a new geodatabase made up of conflict datasets in the GLR was to provide access to spatial data and change the way records were stored, managed and accessed by different stakeholders in the region (Yao et al., 2018; Allen and Coffey, 2011; Codd, 1970; Tiler and Arctur, 2004.). In addition to the procedure and steps adopted to develop a geodatabase for the GLR, the challenges relating to its development are also discussed in this paper.

5.2. The Geo-database concept and Conflict Resolution

The concept of a database is a long-existing topic that looks simple and familiar to many users including businesses, economists, and politicians who use a considerable amount of data. However, its definition and explanation remain complex and sometimes challenging to understand (Coronel and Morris, 2018; Foster and Godbole, 2016; Allen and Coffey, 2011; Kennedy, 2009; Childs, 2009). Kennedy (2009) provides a simple definition of a database as data gathered over time, to support the requests of various users. Colonel and Morris (2018) adds that a database is logically coherent collection of meaningful data of the real world. These definitions, though simple have been critiqued by Healey (1991), Musa et al. (2016), Kolb (2016), Allen and Coffey (2011), who argue that they exclude the role of a software system in data management, which is a key component in a database function. Therefore, according to Healey (1991), a database is a collection of one or more data files or tables stored in a structured manner, such that interrelationships which exist between items or sets of data can be utilized by the database management system (DBMS) software for manipulation and retrieval purposes. Allen and Coffey (2011) proceeded to define a DBMS as a database management software package, to manage the integrated collection of database objects such as tables, indexes, queries, and other procedures in a database.

Further to these definitions, Coronel and Morris (2016) adds that a Geodatabase is a version of a database that relates to geographical data including a single or multiple users. While Musa et al. (2014), Healey (1991) call a geodatabase as a GIS database, Coronel and Morris (2018), claim that the prefix 'Geo' comes from the Greek word, meaning 'Earth' and 'Database' which means an 'organized collection of geographic data', hence, a geo-database involves geographical data and a computer system to store and process it. The function of a Geo or GIS database is like the conventional 'database' defined in the previous paragraph; however, the main characteristics that set apart the Geo-database from other databases is its ability to store, manipulate, retrieve, and display the spatial or geographic data (Ullman,1988; Chamberlin et al.,1976). Zeiler (1999:6) presents a different definition to a geodatabase referring to it as an "object-oriented data model" but agrees with other authors (Ullman, 1988; Chamberlin et al.,1976) that it is a database model with extensions for storing, querying and manipulating geographic or spatial data (Healey, 1991). All those definitions and explanations of a geodatabase and its functions are best demonstrated in the ESRI geodatabase model, which is adopted in this study (Section 5.5.3, Figure 5.3).

The spatial data analyses performed using geodatabases can be complex as they involve infinite natural and human environments and processing on different computer platforms and software (Kennedy, 2009 and Healey, 1991). Such geodatabases also provide integrated platforms for simple geospatial analysis, including, among others, spatial data overlays, spatial data queries, and buffer zone creation (Demesouka et al., 2019; Martin 1996; Prakash, 1998; Childs, 2009). For example, to geo-visualise variables related to violent conflict, data layers from a geodatabase can be overlaid in a GIS platform to visualize the area in dispute and the types of resources at stake or populations that might be affected.

Other GIS analyses using data from a geodatabase for violent armed conflict analyses include proximity analysis, modelling risks and vulnerabilities, as well as hots pot analysis to identify areas characterized by the recurrence of violence (Mossin, 2007; Humanitarian Tracker Project, 2014). Data to enable such analysis are contents of a conflict geodatabase and assist conflict resolution practitioners and policymakers to make decisions on conflict resolutions based on the realities on the ground at all levels. This approach may also apply to conflict resolution in the GLR.

Generally, GIS capability in conflict resolution and peacebuilding is aimed at mapping, analyzing, and managing a wide range of geographical information, including a comprehensive range of planning and management functions (Tomlinson, 1974; Xia, 2014; Wood, 2000; Martin, 1996). GIS is utilized for strategic policies and decision-making through Decision Support Systems (DSS) (Xia, 2014; Wood, 2000; Wright, 1997; Heywood, 2006). In the discipline of peacebuilding, GIS has the technological capabilities to facilitate decision-making in conflict resolution talks (Soytong, and Perera, 2014; Tooch, 2005; Wright, Goodchild, and Proctor, 2004). For example, GIS overlays, including remotely sensed imagery, digital terrain models, and other digital data layers, enable the spatial visualization of the area in dispute. This application would include also a multi-criteria analysis of causative factors to determine risks and vulnerabilities and hotspot analysis using kernel density tools to determine areas characterized by the recurrence of violence (Mossin, 2007; Humanitarian Tracker Project, 2014). These functionalities and capabilities of GIS enable all sides in a conflict to have an improved picture of different aspects related to the conflict, enabling informed peace talks and stakeholders' decisions (Longley et al., 1999).

Since the collapse of the Soviet Union, for instance, it has been a host to persistent low-level violence. It is suffering from a multiplicity of challenges that are traditionally associated with conflicts. GIS has been used to "develop a dataset for conflict vulnerability assessment, to generate practical applications to assist in identifying areas where future conflicts might break out and to predict the appropriateness of future aid allocation" (Mossin, 2007:1). The Euclidian distance was used as a tool to determine population proximity to Kyrgyzstan's main rivers and lakes (Mossin, 2007; Humanitarian Tracker Project, 2014), which was then reclassified as being more vulnerable to ethnic conflict. In addition, an aid distribution map was developed based on international aid distribution data for June 2011, compiled by the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA) and the location of all ongoing international aid activities in Kyrgyzstan at the time of that analysis (Humanitarian Tracker Project, 2014).

Israel versus Palestine's persistent violent conflicts is also a good example, where GIS problem-solving capabilities have been used in conflict-related negotiations (Mossin, 2007; Tooch, 2005; Wallach, 2011). The Israeli-Palestinian conflict is one of the most complex and persistent disputes in the world, and it is linked to decades of repeated violence and stalled peace talks on territories like Gaza, Jerusalem and the West Bank (Tooch, 2005; Holbrooke, 1998). The main issues causing the conflicts were Israel's settlement expansions, border demarcations between the two opposing groups, access to natural resources (mainly the Jordan water basin rights), management of the Jerusalem city and other crucial aspects of the prolonged dispute (Tooch, 2005; Wallach, 2011).

Another prominent example of GIS application in conflict resolution includes the use of digital mapping technology in the Dayton peace accord between the Bosnian Serb, Croat, and Muslim ethnic factions in the former country of Yugoslavia (Johnson, 1999; Holbrooke, 1998; Smith, 2001and Yaakup, 1991). Besides diplomatic negotiations, digital mapping was adopted by the peace negotiators and positively contributed to successful negotiations. Besides conflicts, there are various case studies where the application of GIS was successfully used in post-conflict reconstruction. Some examples include the use of GIS for territorial negotiations in Bosnia (Halls, 2008 and Wood, 2000), better aid allocation in Kyrgyzstan (Mossin, 2007), and in Kosovo post-war reconstruction (Soytong, and Perera, 2014; Hetherinngton, 2000; Wentz, 2002; Halls, 2008) and to map areas of need for reconstruction.

5.3. Geodatabase creation of conflicts dataset in the Great Lake Region -a rational

Many reports on conflicts in the GLR (Theron, 2017; Ramadhani et al., 2011 and Wood, 2000) reveal that in the historical past, the GLR has been characterized by persistent violence. These include political instability and a protracted civil war in the DRC, intractable ethnic violence mostly in Burundi, the 1994 Rwanda genocide, and sporadic political violence reportedly in Uganda and Tanzania (Mpangala, 2004; Ramadhani et al., 2011 and Wood, 2000). While these countries share the same geographical boundaries and conflict characteristics, they do not have any integrated regional data framework or a spatial geodatabase. Such a regional geocoded spatial data would assist in the determination of conflict hot spots, and risk zones for future conflicts to inform parties during conflict negotiations and disputes resolutions. This reasoning explains why the authors of this study have chosen the GLR as a pilot project in Africa to create an integrated regional geodatabase in a GIS platform to inform conflict resolution and peacebuilding efforts.

5.4. Methodology

The development process of this file geodatabase of violent armed conflict datasets for the five countries in the GLR went through four different phases including data acquisition and cleaning, designing a logical model in Microsoft excel, creating a data structure in ArcCatalog and importing data into or populating the geodatabase (Colonnel and Morris, 2018; Allen and Coffey, 2011). The construction and completion of the geodatabase was guided by Musa, Idowu & Zemba (2016) and Kennedy's (2009) argument that the implementation of a geodatabase structure does not need to follow a specified order, but that the building steps must be identical with the logical design forms. In their argument, some geodatabase developers create all the domains first and then create all other components followed by subtype, whilst others prefer first to create one feature class, its table, domains, and subtypes.

5.4.1. Geographic data acquisition and cleaning

Input data in the form of shapefiles, and coverages respectively vector (points, lines, and polygons), raster (historical and current images), and tabular (excel spreadsheets) were sourced online. These sources include the Armed Conflict Location, and Event Dataset project (ACLED), countries National Census (NC) reports, UN Global Pulse (Uganda Project), Geographic Boundary Data (GADM), and International Peace Information Service (IPIS).

One of the most important steps in geodatabase development is the provision of accurate and clean data (Colonnel and Morris, 2018; Allen and Coffey, 2011). Data cleaning is one of the crucial steps to prepare data for importation into a geodatabase, especially data from these five countries due to incomplete, inaccessible, and missing spatial references or incompatible coordinated systems (Giordano et al., 2018; Martin and Jones, 2015). For instance, some existing unreferenced historical hard copy maps (natural resources covering the Congo - Belge and Rwanda – Urundi colonial territory) from the former colonial countries (Belgium), required geocoding and georeferencing using GIS techniques. In addition, some sourced data existed in excel spreadsheets formats, also requiring a clean-up and conversion to formats like comma-separated values (CSV) format, to facilitate their display as points in ArcMap software before being loaded into the geodatabase.

5.4.2. Conceptual and logical design

Designing a geodatabase is a crucial step in the development of a geodatabase. This was firstly completed by incorporating some ideas from the literature and views from some stakeholders operating in the region including the Africa Centre for the Constructive Resolution of Disputes (ACCORD), Durban University of Technology (DUT) Department of Conflict resolution and peacebuilding in the GLR, several South African officials and citizens, mostly students and lecturers originating from countries in the GLR. These integrated views significantly contributed to the design of the new geodatabase.

While some authors use the term ‘design’ to mean ‘physical drawing’ (Zeiler, 1999; Mounsey and Tomlinson, 1998), the use of the term ‘design’ in the geodatabase context is a framework to best represent the reality and determine what features need to be included in a new geodatabase (Allen and Coffey, 2011; Kalman, 2004; Zeiler, 1999). Some geodatabase developers use conceptual and logical design steps separately (Allen and Coffey, 2011; Idowu and Zemba, 2016), however this study has combined both. According to Zeiler (1999), these terms in geodatabase development are almost similar in relation to planning and structure but differ slightly. A conceptual design is like a mind map of a geodatabase (Musa et al., 2016) to be created, while the logical design is concerned with critical thinking and a logical geodatabase (Allen and Coffey, 2011; Zeiler, 1999; Musa et al., 2016). For example, while a conceptual design draws more attention on how the schema model of the new geodatabase will look like, a logical design determines what type of geodatabases to choose (personal or multi-user), data source, type of projection, topology or type of features and tabular relationship.

The Environmental Systems Research Institute's (ESRI) geodatabase design form which exist in excel format (Table 5.1) was adopted in this study because it is simple to interpret (Allen and Coffey, 2011; Robert and Thompson, 1992). Several design forms, each representing a new geodatabase name, feature dataset, feature class, field, domain, and subtype components of the newly created geodatabase, were manually completed**.** However only one sample form for each type of components is presented in this report to avoid the overcrowding (Section 5.5.1). These ESRI model forms (Batty, 1990) were freely downloaded and manually completed and served to guide and facilitate the creation of the data structure in ArcCatalog.

5.4.3. Creating a data structure in ArcCatalog

A physical geodatabase design or a data structure in ArcCatalog provides a comprehensive architecture and allows for viewing of the database in its entirety and evaluate how the various aspects of it need to interact (Musa et al., 2016; Mounsey and Tomlinson, 1998). A physical design or creating a data structure was performed in ArcCatalog 10.5 following four stages notably the creation of a geodatabase name, feature dataset and standardization, feature classes, and relationships.

5.4.3.1. Geodatabase name

Assigning a name is very important in the creation of a new geodatabase (Allen and Coffey 2011). It consists of allocating and creating a name or a title of a geodatabase (Allen and Coffey, 2011; Zeiler, 1999; Musa et al., 2016). The name of a geodatabase has to do with an attraction of the audience (users), who need to explore and share data (Zeiler,1999). In this study, a file geodatabase namely, GLRCGDB was created in ArcCatalog 10.5 (Foster and Godbole, 2016; Allen and Coffey, 2011). After creating name of a new geodatabase, the other components notably feature datasets; feature classes and the spatial relationship are attached and created in the newly created name.

5.4.3.2. Feature dataset and data standardization

A feature dataset is defined as a combination of feature classes, having similar characteristics (Foster and Godbole, 2016; Allen and Coffey, 2011; Batty, 1990). When creating a dataset, a dataset name and spatial reference are important elements to consider (Table 5.2). The name of a feature dataset is conventionally written in one word (Allen and Coffey, 2011; ESRI, 2019). The ESRI geodatabase model requires the feature classes to be designed first, followed by filling the logical design forms (Allen and Coffey, 2011). This process allows the accommodation of feature classes with similar topological characteristics in one feature dataset (Allen and Coffey, 2011). Contrary to this, the creation of data structure requires the feature datasets to be created first and thereafter assigning spatial references, which are automatically transferred to new feature classes (Foster and Godbole, 2016; Allen and Coffey, 2011). As the feature classes of similar spatial geometry are grouped and organized within one feature dataset, the spatial reference set up at the dataset level applies to all feature classes in the dataset (Foster and Godbole, 2016; Mossin, 2013; Batty, 1990; Allen and Coffey, 2011, Arctur and Zeiler, 2004). All feature datasets are created through the new name of the newly created geodatabase and must conventionally be in one word (Foster and Godbole, 2016; Allen and Coffey, 2011, Tiler and Arctur, 2004), with an assigned Spatial reference. Once a spatial reference is assigned to a feature dataset, the "coordinate system can be updated" (Zeiler, 1999: 85).

5.4.3.3. Feature classes

A feature is an object that stores its geographic representation and symbols, which is typically a point, line, or polygon, as one of its properties (Foster and Godbole, 2016; Allen and Coffey, 2011; Foster and Godbole, 2016; Batty,1990). In ArcGIS, feature classes are homogeneous collections of common features, each having the similar spatial representation, such as points, lines, or polygons, and a common set of attribute columns (Foster and Godbole, 2016; Batty,1990; Allen and Coffey, 2011), for example, a line feature class representing a road centreline or a polygon representing the mineral resource mining area. In this study, feature classes were created through feature datasets by right clicking on the feature dataset name and following the procedure outlined in Allen and Coffey (2011). Three elements are essentials in the creation of a feature class including the name, spatial reference, and geometry (Table 5.3). As explained in the previous section 5.4.3.2, the spatial reference of a feature class is set up at the feature dataset level (Tiler and Arctur, 2004.).

5.4.3.4. Data integrity rules and relationship classes

When creating a geodatabase, topology and the relationship functionality between datasets or feature classes is also an important element to consider (Bao-li, 2004; Batini and Lenzerini, 1986). Topology allows a geodatabase developer to model spatial relationships between feature classes in a feature dataset (Allen and Coffey, 2011; Bao-li, 2004). Integrity rules among spatial feature datasets, classes or tabular attributes are associated with defining the connectivity rules to keep geodatabase integrity (Foster and Godbole, 2016; Allen and Coffey, 2011; Wise, 2002). Data integrity rules were performed by creating domains and assigning them to the fields in related feature classes (Allen and Coffey, 2011; Tomlinson, 1998; Colonel and Morris, 2018). A domain in a geodatabase is defined as rules in a geodatabase schema that describe the legal values of a field type, enforcing data integrity (Burke, 2018; Allen and Coffey 2011). While there exist two type of domains namely - range and coded domains, depending on functions and type data to use, (Allen and Coffey, 2011; Wise, 2002), this study adopted a coded value domain, indicating different type of mineral resources (Section 5.5.4, Figure 5.4). In addition, to allow updates to be done more efficiently within the classes, a subtype needs to be created. A subtype is a subdivision or a subset of feature in a feature class to facilitate queries from different attributes contained in one feature class (Colonel and Morris, 2018; Wise, 2002). A subtype of ‘MineralGroup’ was created in the MineralResources feature classes as a way to facilitate a query from the two attribute tables of Metal and Fuel (found in the MineralGroup subtype).

The final consideration for this study was to test the functionality and integrity of the newly created geodatabase. Several tests were performed through spatial or attribute queries on various datasets and the results were successful (Section 5.5.3, Figure 5.2 and 5.3)

5.4.4. Importing data into a geodatabase

Data import is an important step in the development of a geodatabase (Burke, 2018; Smith, et al., 2015). Feature classes (shapefiles, raster and tables) on conflicts in the GLR were imported in the new geodatabase (GLRCGDB). These feature classes including five polygons (countries boundary, the spatial distribution of mineral resources, armed rebel groups, ethnic allegiance and great lakes location), one line feature class (road networks), points (armed conflict locations and rebel groups) and a raster class representing a collection of maps. Tables (armed conflict locations) in the form of csv files were also imported into the new geodatabase (GLRCGDB) using the Add data tool and the XY function for determining the longitude and latitude fields as well as the appropriate geodetic datum (in this case WGS84). Thereafter, the tables exported as feature classes.

5.5. Results

5.5.1. Conceptual and logical design of the GLR geodatabase

The conceptual and logical designs created in the initial phase of the GLR's geodatabase (Section 5.4.2) are presented in Tables 5.1 to 5.6). These forms are modified versions of existing ESRI templates which were manually completed according to the unique characteristics of this study including the geodatabase name GLRCGDB (Table 5.1), feature dataset (Table 5.2), feature class (Table 5.3), domain (Table 5.4), subtype (Table 5.5) and relationship class (Table 5.6).

Table 5.1 The new geodatabase

***Geodatabase name**			**GLRCGDB**
Feature dataset name			
Feature classes			
	*Type	Feature class name	Alias
	Poly	Diamond	Diamond sites

***** *Features in Table 5.1 include* ***geodatabase name: GLRCGDB (Great Lake Region Conflict Geodatabase)****; Feature Type: Poly (abbreviation for polygon); Feature class name: Diamond (the name of the feature class); and Alias: Diamond sites (describes the contents of the feature class).*

The table that follows (Table 5.2), represents the feature datasets form. Two feature datasets were designed including LivingConflictEntities (Living Conflict Entities) and NonLivingConflictEntities (Non-Living Conflict Entities). However, to avoid overcrowding and a repetition of similar dataset forms, only a LivingEntities feature dataset form is represented in the table below, the NonLivingConflictEntities is annexed (Appendix 4).

Table 5.2 Feature dataset form: LivingConflictEntities

Geodatabase name			GLRCGDB
***Feature dataset name**			**LivingEntities**
Feature classes			
	*Type	Feature class name	Alias
	Poly	EthnicAllegiance	Regional ethnic allegiances
	Poly	RebelGroup	Armed rebel groups

Features in Table 5.2 include *feature dataset name :LivingConflictEntities(Living Conflict Entities)*; Feature Type: Poly (abbreviation for polygon); Feature class name: MineralResources (the name of the feature class); and Alias: Armed rebel group (describe the contents of the feature class.

Table 5.3 represents the feature classes design form, showing feature classes in the GLRCGDB as polygons (mineral resources, rebel armed group, ethnic allegiance, admin boundary, and the great lakes) and lines (road networks). However, to avoid overcrowding and a repetition of similar feature class forms, only the Mineralresources (mineral resources) feature class form is represented in the table below (Figure 5.3), the other five feature class forms are annexed (Appendix 5).

Table 5.3 Feature classes form

Geodatabase name			GLRCGDB
Feature dataset name			NonLivingEntities
Feature classes			
	*Type	**Feature class name**	Alias
	Poly	***MineralResources**	Mineral resource sites
	Poly	GreatLakes	Main lakes in the region
	Poly	AdminBoundaries	State boundaries
	L	TransportNetwork	Regional roads

Features in Table 5.3 include *feature class name: MineralResources (Mineral Resources)*; Feature Type: Poly (abbreviation for polygon); and L (abbreviation for line) Feature class

name: MineralResources (the name of the feature class); and Alias :Main type occurrence (describe the contents of the feature class).

Table 5.4 represents the domain for the mineral resources feature class and its characteristics. Domain is an important element to keep the integrity of the geodatabase. Mineral types abbreviation (MinTypeAbreviation), were further given specific code values to allow users query the type of minerals according to their market destination (local, international or both)

Table 5.4 Geodatabase domains

Domains worksheet				**Coded values / Range**			
*Domain name	Description	Field type	Domain type	**Code**	**(Min)**	Desc	(Max)
MinTypeAbrevition	**MinType**	**Text**	**Code V /Range**				
Au	Gold			A1		Local-intern	
Co	Cobalt			C2		Intern	
Cu	Copper			C3		Local-intern	
Pb	Lead			P4		Intern	
Ni	Nickel			N5		Intern	
Sn	Tin			S6		Local-intern	
U	Uranium			U7		Local-intern	
Zn	Zinc			Z8		Local	
D	Diamond			D9		Local-intern	
Co	Carbonates			C10		Local	

Features in Table 5.4 include domain** ***name :MinTypeAbreviation (Mineral Type Abbreviation)*;Mineral type (Description);* text (field type), Code V/Range (domain type) :Code (coded value) and Local-Intern, Intern (Description): *Local or international destination, or both.*

Table 5.5, represents the subtype MingroupSubtype, showing two major grouping of minerals notably metals, and fuel, to facilitate their query within the MineralResources feature class. For instance, one user may need to query data from attribute table on petrol and lead. Those are different types of minerals but are grouped in one feature class (mineral resources).

Table 5.5 Subtype worksheet

Subtypes worksheet					
				Preset defauts	
***Subtype name**	**Code**	**Description**	**Field**	**Domain name**	**Default value**
MingroupSubtype	1	Metal	Text	Coded value	
	3	Fuel	Text	Coded value	

Features in Table 5.5 include Subtype name: *MingroupSubtype* (Mineral group Subtype); 1(code); Metal (description); text (field); coded value and defaut value (domain name).

Table 5.6 shows the type of relationships and connectivity rules that were established amongst various components of the geodatabase. For instance, RebelsMineralresources relationship was established to explain the link or relationship that exist between the mineral resources and armed groups location. Contrary to the previous forms (Table 5.1 to 5.5), the relationship form must indicate not only the name of the relationship but the origin (rebels) and destination (mineral resources) of the link as well. Georeferenced information is also mentioned, showing the spatial location of the origin and destination.

Table 5.6 Relationships class

Relationship worksheet					
*Name of the relationship class:		**RebelsMineralResources**			
Origin table/feature class:		**Rebels**			
Destination table/feature class:		**MineralResources**			
Relationship type:		**Simple (peer to peer)**		Composite	
Labels:					
Origin to destination:	**Rebels**				
Destination to origin:	**MineralResources**				
Message propagation:		Forward	Backward	Both	None
Cardinality:	1-1	**1-M**	M-N		
Attributes:	No	Yes - Table name:		**Mineral exploitation**	
				Add to the table worksheet	
		Primary key field		Foreign key name	
Origin table/feature class:		**Label group name**		**Location**	
Destination table/feature class:		**Minerals type**		**Distribution**	

Features in Table 5.6 include the relationship name:* ***RebelsMinerals (Rebels and Minerals);* *MineralResource (origin table); RebelGroup (destination table); simple (peer to peer):Type of relationship; Mineral Exploitation- origin to destination and Rebels – Mineral resources :Labels; 1- M (cardinality): one owner to many, means one rebel group to sell many minerals; yes (attribute); Mineral types (Table name); Rebels group locatione -origin table and Minerals – destination table (Primary key field); Mining (original table) and MineralResources (Destination table) (Foreign key name)****.***

5.5.2. Creating a data structure for the final GLRCGDB

Creation of the data structure, resulted in the final schema with the name of the GLRCGDB (Figures 5.1 and 5.4), followed by the creation of other components including feature datasets and classes, relationship classes, tables, and maps in raster format (Figure 5.1 and Table 5.7). These geodatabase components include five polygons (countries boundary, the spatial distribution of mineral resources, armed rebel groups, ethnic allegiance, and great lakes location), one line feature class (road networks), points (armed conflict locations and rebel groups) and a raster class representing a collection of maps. One connectivity rule was established, illustrating the relationship between attacks by armed rebel groups and mineral resources distribution.

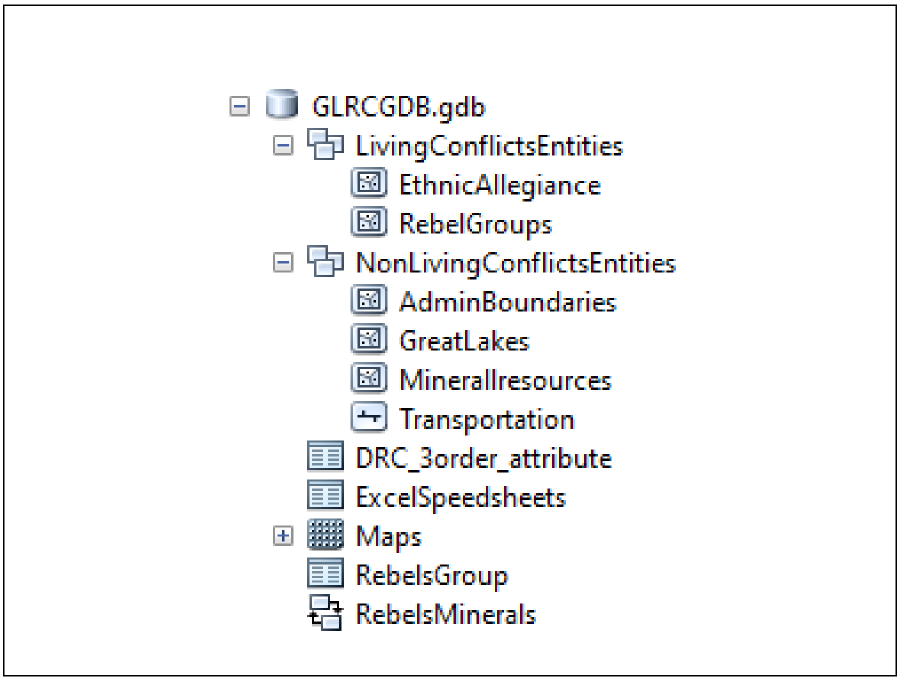

Figure 5.1 The final GLRCGDB schema of the newly created armed violent conflict geodatabase and its components. (Data source: UN Global Pulse (Uganda Project), Geographic Boundary Data (GADM), ACLED Project, IPIS, Bruxelles: Institute Royal Colonial Belge library and ESRI).

5.5.3. Testing the functionality of the new geodatabase

Once all data were imported, functionality of the geodatabase was tested using several queries to validate accuracy of the newly created geodatabase. One of these queries was conducted based on the spatial locations of armed rebel groups in relation to DRC provinces, using ArcMap (Figure 5.2 and 5.3).

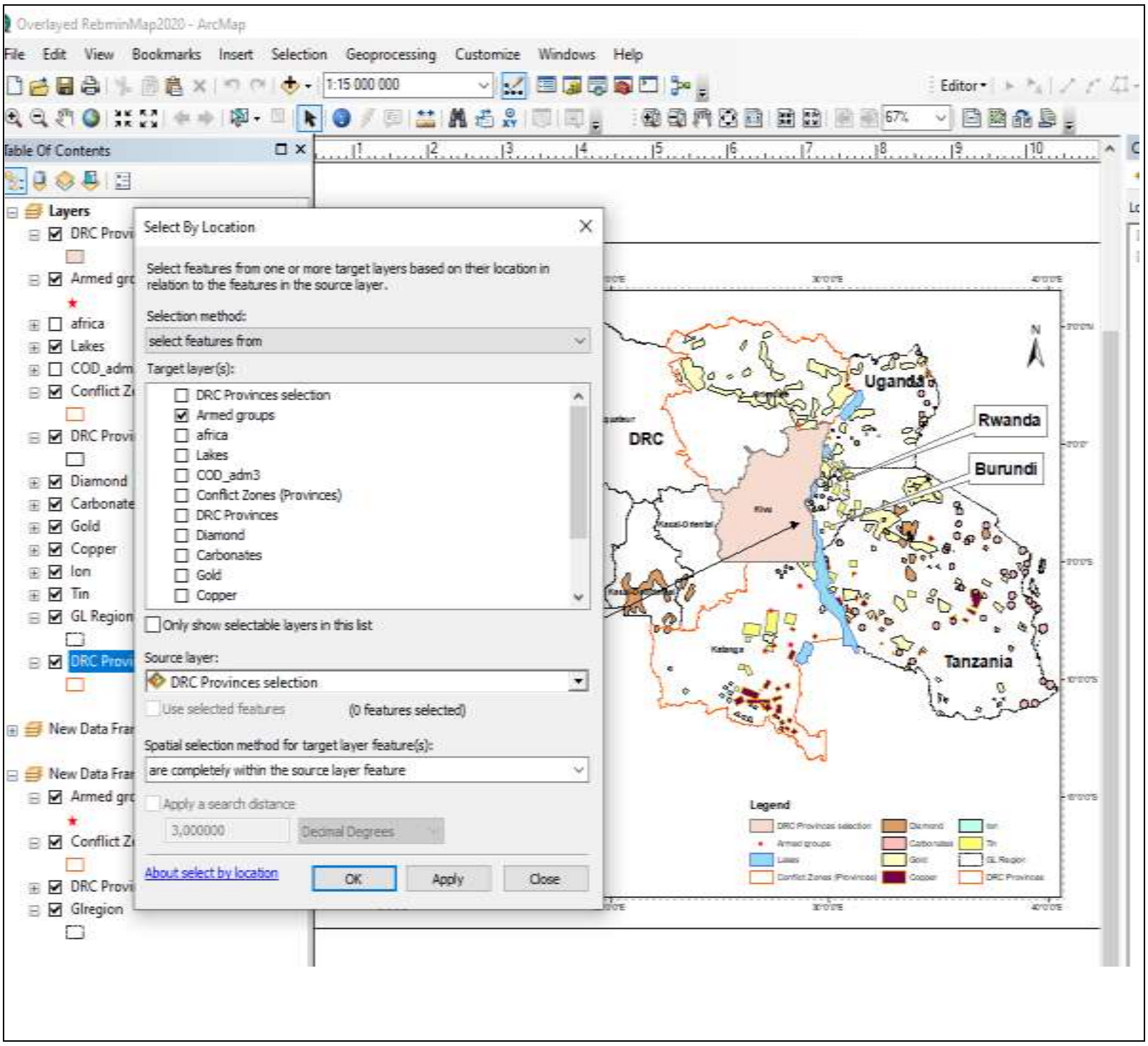

Figure 5.2 An example of a "select by location" query to understand how many armed rebel groups are completely located within the province of Kivu. (Data source*:* GLRCGDB file Geodatabase).

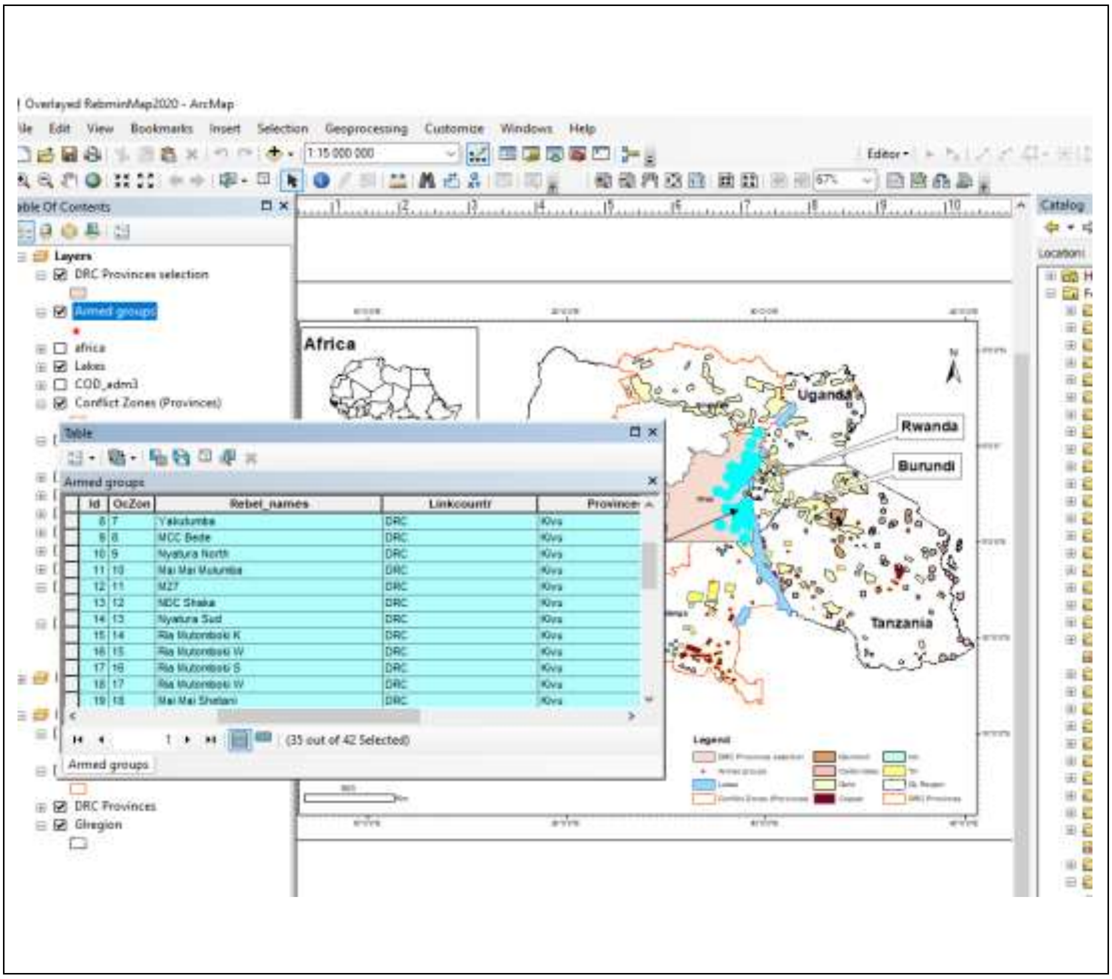

Figure 5.3 The results obtained from the "select by location" query in Figure 5.2. and the results in Figure 5.3. (This results show that 35 armed groups out of 42 groups were selected and located within the Kivu province alone).

5.5.4. GLR Conflicts Geodatabase (GLRCGDB) – A summary of key components

The GLRCGDB is an integrated regional geodatabase for the five countries in the GLR notably Burundi, DRC, Rwanda, Tanzania, and Uganda. It is made up of two main feature datasets including the Living conflict entities and Non-living conflict entities as indicated in a summary Table 5.7 and Figure 5.4. The living conflict entities dataset contains two feature classes, namely armed rebel groups and ethnic allegiance, and the Non-living conflict entities dataset store several feature classes, including state boundaries, mineral resource types, transport network and the great lakes. Each feature class in the dataset has a name, a spatial reference (inherited from the dataset), and a geometry type. The created geodatabase also has individual maps and the comma-separated values (csv) file formats containing tables or spreadsheet data of armed conflict locations, and maps in the raster formats.

Table 5.7 The GLRCGDB - A summary of key features and their characteristics

Geodatabase Name	Feature Dataset	Feature Classes	Type of Data	Field name	Field type	Alias
GLRCGDB	LivingConflEntities	RebelGroup	Poly	ID	Short Integers	Identity number
				Shape	Text	Various forms
				Rebels Name	Text	Group name
				Fight Ideology	Text	The motive
				Spatial Locations	Text	Occupation zones
				Georeference		Spatial coordinates
		EthnicAllegiance	Poly	ID	Short integers	Identity number
				Shape	Text	Various forms
				Ethnic group name	Text	Tribe name
				Spatial location	Text	Sharing boundaries
				Ethnic group affiliation	Text	Political influence
				Georeference	Text	Spatial coordinates
	NonLivingConflEntities	AdminBoundaries	Poly	ID	Short integers	Identity number
				Shape	Text	Various forms
				Country name	Text	Individual county
				Geo-reference	Text	Spatial coordinates
				Country attributes	Text	Attribute data
				Government Stability	Text	Level of Democracy
				Regional Boundaries	Text	Order
		Transportation	Li	Regional	Text	Regional road
				National/Provincial	Text	Provincial road
				Locals	Text	Local transportation
				Length	Short integers	Length in Km
				Name	Text	Local name
		MineralResources	Poly	ID	Short integers	Identity number

		Shape	Text	Various forms
		Region	Text	Admin Boundaries
		Commodity	Text	Use
		Type	Text	Minerals
GreatLakes	Poly	ID	Short Integers	Identity Numbers
		Lake name	Text	Local name
		Size	Short Integers	Liters
		Depth	Short Integers	Liters
		Location	Text	Country name
Excelpreadsheets	Table	ID	Short Integers	Identity Numbers
		Name	Text	Text
Maps	Raster	ID	Short Integers	Map Numbers
		Name	Text	Name

In the table 5.7, the first column indicates the name of the newly created geodatabase GLRCGDB. The second column contains the dataset name, and the third column is the future classes belonging to each feature dataset. The subsequent columns represent the feature type (specifying whether the feature is a line, polygon or point), the field name records the attribute names of each feature, while the field type indicates whether the feature is a text, integer (short or long integer). In addition to specifying the field type, these characteristics plays an important role in geodatabase development, providing data integrity rules. Conventionally, in GIS data creation and geodatabase development, feature datasets and classes are written with one word name and field names are often abbreviated, written with underscores or two words combined (Allen and Coffey, 2011; Foster and Godbole, 2016), thus requiring further clarification in the alias field (description of the field names or feature classes). In addition to these main components and characteristics of the GLRCGDB, it is also held together by relationships and connectivity rules relating tables as simplified in the GLRCGDB (Figure 5.4).

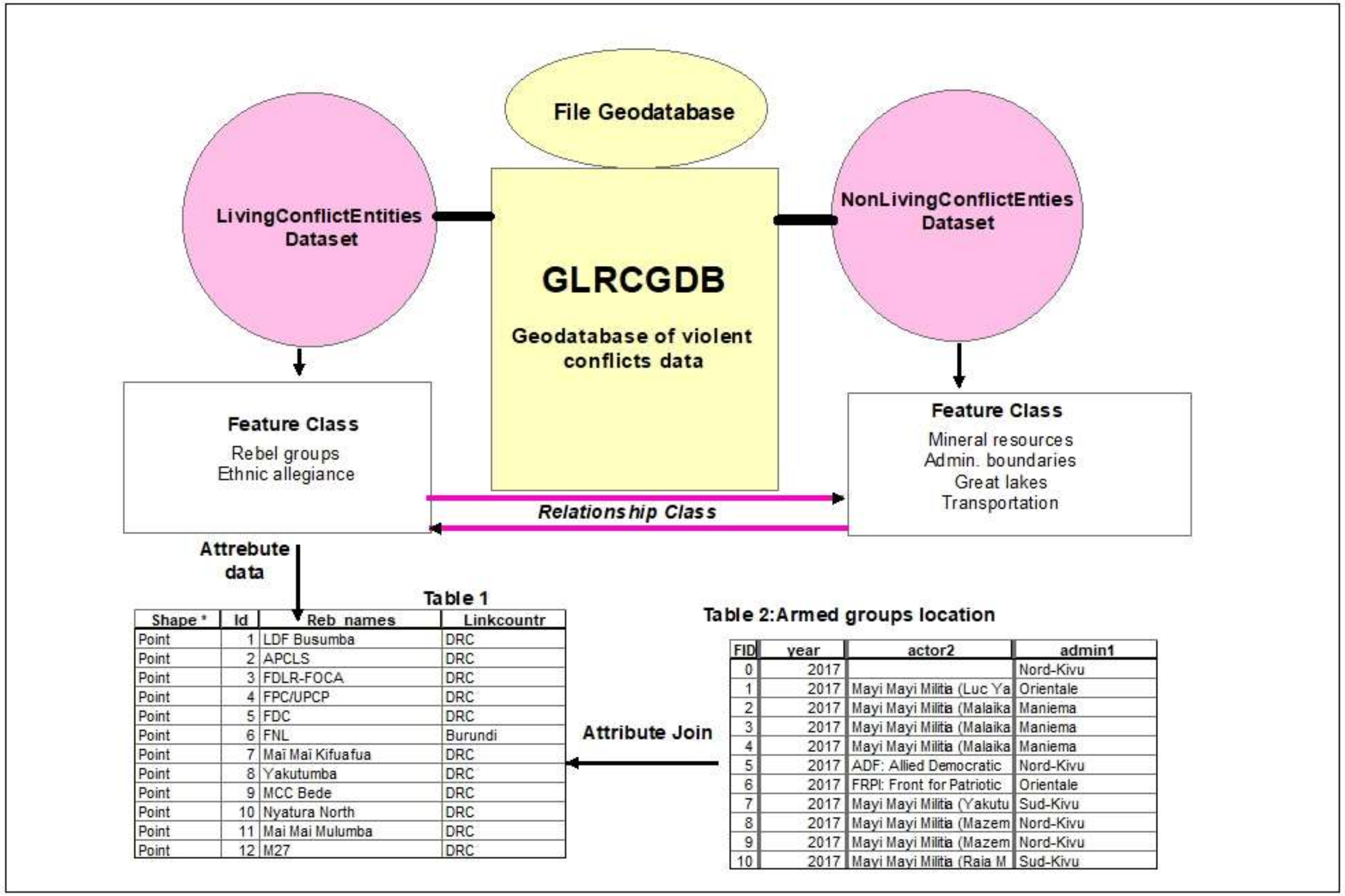

Table 1

Shape *	Id	Reb_names	Linkcountr
Point	1	LDF Busumba	DRC
Point	2	APCLS	DRC
Point	3	FDLR-FOCA	DRC
Point	4	FPC/UPCP	DRC
Point	5	FDC	DRC
Point	6	FNL	Burundi
Point	7	Maï Maï Kifuafua	DRC
Point	8	Yakutumba	DRC
Point	9	MCC Bede	DRC
Point	10	Nyatura North	DRC
Point	11	Mai Mai Mulumba	DRC
Point	12	M27	DRC

Table 2:Armed groups location

FID	year	actor2	admin1
0	2017		Nord-Kivu
1	2017	Mayi Mayi Militia (Luc Ya	Orientale
2	2017	Mayi Mayi Militia (Malaika	Maniema
3	2017	Mayi Mayi Militia (Malaika	Maniema
4	2017	Mayi Mayi Militia (Malaika	Maniema
5	2017	ADF: Allied Democratic	Nord-Kivu
6	2017	FRPI: Front for Patriotic	Orientale
7	2017	Mayi Mayi Militia (Yakutu	Sud-Kivu
8	2017	Mayi Mayi Militia (Mazem	Nord-Kivu
9	2017	Mayi Mayi Militia (Mazem	Nord-Kivu
10	2017	Mayi Mayi Militia (Raia M	Sud-Kivu

Figure 5.4 A summary of the GLRCGDB illustrating its main components (dataset, feature classes and relationship classes).

In Figure 5.4, the key components and relationships are:

- GLRCGDB, a file geodatabase model of armed violent conflicts data in the GLR, containing two main feature datasets namely, the *Living* conflict entities and *Non-living* conflict entities.
- Feature datasets are the highest level of the geodatabase components and form either part of the Living or Non-Living entities.
- Feature datasets are comprised of feature classes (polygons and lines), which have attribute tables and are in turn held together a relationship class (Figure 5.4 in details).
- The relationship is an association between objects or features and controls behaviour of features in a geodatabase when users are performing some queries (Colonel and Morris, 2018; Zeiler, 1999).
- Attribute relationship represents relationships between various tables that are linked together with a common field.

5.6. Discussions

The development of a GIS database or Geodatabase has gained ground in recent years to solve many issues in social sciences including conflicts resolution and peace buildings (Section 5.2). While the traditional model of databases in computer science and business allows for the storage and manipulation of data in a tabular format, it does not account for the complex spatial data or support even the most basic functionality of a Geodatabase (Johnson, 1999; Holbrooke, 1998; Smith, 2001and Yaakup, 1991Tomlinson, 1974; Xia, 2014; Wood, 2000; Martin, 1996). This has given impetus to the creation of an integrated regional geodatabase to serve the five countries of the GLR as a hub for spatial data storage and management, for supporting the peacebuilding efforts in the region. The creation of the geodatabase is intended to contribute towards solving the challenge of data access and sharing among various stakeholders in the GLR and beyond. The absence of spatial data could be another source of persistent violence in the GLR because negotiating parties are not fully equipped with accurate spatial data to inform long-term peace efforts (Manchini, 2013; Holbrooke, 1998; Bisig, 2002; Mossin, 2007). The creation of a regional geodatabase for the five countries in the GLR, bridges the gap created by the absence of an integrated spatial data in the region, contributes to regional collaboration and provides a spatial decision support system for regional stakeholders (Bjorkdahl and Buckley, 2016; Jankowski and Nyerges 2001; Shaw, 2003; Leeuwen, 2008).

A Spatial Decision Support System (SDSS) as provided by the newly created geodatabase, can be defined as an interactive, computer-based system designed to support a user or group of users, to increase its effectiveness in decision making while solving a semi-structured spatial decision problem (Waters, 2018, Leidner and Elam 1995; Kyem, 2006; Janowski and Nyerges, 1997). It supports a user by providing tools to explore the problem in an interactive, and recursive fashion in all phases of the decision-making process (Waters, 2018; Xia, 2014; Wood, 2000). By exploring alternative scenarios, it creates a medium for stakeholders, to exchange views about their values and interests (Janowski and Nyerges 1997; Jordan 2002). However, GIS and a spatial decision support tool like the newly created geodatabase by itself cannot resolve any conflict (Wood, 2000; Martin, 1996 and Prakash, 1998) but rather it is a decision support system, aiding different parties in a conflict to reach an agreement informed by spatial data that has been collected, transformed and analysed (Bouchardy, 2000; Goodchild, 2004; Hardy, 2012). Evidence from many cases of GIS application to conflict resolution such as Kyrgyzstan, Israel-Palestine, and Kosovo has demonstrated that GIS offers considerable scope for application to conflict prevention, resolution, and post-conflict peacebuilding (Manchini, 2013; Holbrooke, 1998; Bisig, 2002; Mossin, 2007).

These case studies provided a foundation for exploring the role of GIS as one of the tools to assist in resolving armed conflicts in the GLR. In GLR where the persistence of conflicts is partly due to unsustainable approaches to conflict resolution and the inadequate or non-recourse to spatial data, the creation of a regional geodatabase will likely contribute towards regional decision making and peacebuilding.

5.7. Challenges

One of the critical challenges in the creation of the GLRCGDB was access to quality spatial data (Musa et al., 2016; Soytong, and Perera, 2014; Tooch, 2005) from some countries of the GLR. Where data was available, accessibility was still a challenge due to national data access policies. For example, while four countries in the GLR allow the publication of reports on ethnic groups, Rwanda's new policies prohibit such reports or their inclusion on national Identity cards (Carter, 2016; Kanyangara, 2016). This made it difficult to include Rwanda's ethnic groups dataset in the newly created geodatabase.

Further to this challenge, in many cases, some data were available as analogue paper images, requiring GIS techniques to geotransform and georeference the data before being imported into the geodatabase. Most of these hard copy maps were obtained from international archives and libraries, mainly in Belgium, and the USA after lengthy correspondences through international inter-library loan arrangements and at high costs. These challenges were further compound by the ongoing political instability and armed conflicts in most countries of the GLR, making it difficult to physically travel to them for data collection. Due to the insecurity, mentioned above, together with the lack of funds (this study was self-funded), it was not possible to physically go to these countries and obtain their views, especially during the logical design stage of the newly created geodatabase.

It is crucial to understand the complex power relations that is involved in GIS representations when developing a geodatabase and to strive at equally representing the interests of various groups in the region. Like many other technologies, GIS appears to have the ability to both marginalize and empower different populations (Elwood, 2002), depending on who owns or uses GIS data and for what purposes within existing socio-political and economic dynamics (Lupton and Mather, 1997; Harris & Weiner, 1998; Elwood, 2002). The power to consult, negotiate, and navigate within the political landscape and to develop a database that would allow both geodatabase developers and partners to work together was not possible due to the unstable political climate in the GLR. While some institutions and individuals were consulted outside of the study area (Section 5.4.2**),** representation of various groups including governments, local and international agencies operating in the region, ethnical and political parties and rebel armed groups, and their interests in the GLRCGDB was another challenge, especially during the designing stage due to the challenges mentioned in the preceding paragraphs. Finally, while the Enterprise Geodatabase would be a better option for dataset to be accessed by all countries in the GLR at the same time, this type of a geodatabase was not used in this study due to the financial inability to acquire ESRI's Enterprise geodatabase license, and the UKZN's licence agreement with ESRI which does not allow students to install the ArcGIS MS SQL server on any student machine.

5.8. Conclusion

The development of an integrated regional geodatabase to assist in efforts towards resolving the persistent armed violent conflicts in the Great Lake Region was the main aim of this study. The newly created GLR's file geodatabase is suitable for users with limited available funds. While it was challenging to integrate various datasets from different sources, the successful creation of this new geodatabase is an important and useful decision support tool for conflict resolution efforts in GLR. This study assumes the position that the absence of spatial data in peace talks is a probable contributing factor among others to the persistent violent conflict in the region. When parties in conflicts are not sure or do not have a common understanding of the issues and their spatial ramifications, resolution efforts could drag on. Therefore, the creation of the GLR conflict geodatabase could contribute by providing spatial data as a tool and decision support for conflict negotiators and peace building in the region, not only for conflict resolution experts but also to grassroots, humanitarians, business, and policymakers. This newly created geodatabase database is intended to serve as a hub for spatial data storage and management, accessible at any time by the five countries in the GLR, not only during peace negotiations. Due to the ongoing nature of the conflicts and challenges discussed in the previous section, there is ample room to improve and update the geodatabase to serve various other social, economic, and environmental purposes.

CHAPTER 6

SYNTHESIS, CONCLUSION, AND RECOMMENDATIONS

6.1. Introduction

Armed violent conflict is a global challenge and negatively impacts on the socio-economic and environmental aspects of many countries, including countries in the Great Lake Regions (GLR), notably Burundi, Democratic Republic of Congo, Rwanda, Uganda, and Tanzania. Over many decades, and more recently, the GLR has experienced persistent armed violent conflicts. These conflicts are dynamic and complex and have common regional interlinked causal factors relating to governance, population (structure and ethnic division), colonial history, and exploitation of natural resources (Chapter 2).

Many global conventional approaches have been employed to address these conflicts and restore peace in the region through negotiations, UN peacekeeping operations (PKO), and peace stabilization, however sustainable peace in the region remains a challenge and elusive. In line with this, some regional approaches in peace talks and peacebuilding, based on regional politico-economic integration and bilateral discussions notably the International Conference of the Great Lake Region (ICGLR), the East African Community (EAC) and the former 'Communauté Economique des Pays des Grands Lacs' (CEPGL), were initiated. Despite these initiatives, conflict resolution and peacebuilding remain unsuccessful in the GLR. Many critics argue that most of these approaches put more emphasis on economic and political aspects using a generalized global approach to resolve local issues and ignore the contribution of local and regional spatial data.

In recent years, the significant increase in spatial data availability and computer technologies, including Geographic Information System (GIS) and Remote Sensing, has enabled new quantitative research methods to analyze the root causes, key drivers of conflicts, and develop predictive models for addressing different types of conflicts resolution. As a result, GIS, in its simplest technological form, has been identified by this study as one of these invaluable tools in conflict analysis and resolution. It assists in the visualization and the management of spatial data (Chapter 4&5), which has been the missing component in past approaches to resolving persistent armed violent conflicts in the GLR. GIS has the capability for data capture, syntheses, overlay, analysis, modelling, and storing spatial data, which can assist in conflict negotiations, policy, and decision-making. However, GIS by itself cannot resolve any conflicts; it is a decision support system that can assist different stakeholders in sustainable peace negotiations. This study aimed at exploring the application of GIS to armed violent conflict resolution in countries of the GLR. This aim (Chapter 1, Section 1.4) has been accomplished through the following six objectives (Chapter 1, Section 1.5).

6.2. Synthesis and Conclusion

6.2.1. Objective 1: To trace the origin and evolution of armed violent conflicts in the GLR

One of the key objectives of this study was to trace and understand the origin and evolution of the persistent armed violent conflicts in the GLR (Chapter 2). While there are controversies and paradoxes related to the origin, evolution, and persistent armed violent conflicts in the GLR, the findings from this study have demonstrated that there is no single factor, but a complex mix of factors that explains the origin and evolution of armed violent conflicts in the region. Most authors describe and cite prominent factors such as ethnic divisions, kingship, colonialism, nationalism, and natural resources as the root causes of the conflicts. However, they fail to capture their evolution over time and the main reason for their persistence in the region (Chapter 2, Section 2.5 & 2.6). The study went beyond the habitual description of these factors and critically analyzed the contribution of each factor to the persistence of armed violent conflicts in the region (Chapter 2, Section 2.6).

Despite the controversy surrounding ethnic division as the most recurring factor in literature, some authors argue that in these countries, ethnicity has reportedly been exploited by political leaders for their ends and is thus not a direct cause of wars and violent conflicts in the region. It is therefore apparent from the discourse of these authors that it would be fallacious to conclude that armed violent conflicts in the GLR are solely caused by ethnic diversity. While the role of African Kingship or Chiefship remains a debateable contributing factor to past violent conflicts in the region, many authors fail to explain why in the modern society (in the absence of traditional kingship and chiefship), violent conflicts is still a significant challenge. Another controversial factor of violent conflict, that has been a subject of debate by authors in the literature, is the role of colonialism and imperialism in Africa. Numerous sources reveal that colonial administrations played a significant role in conflicts through the insemination of divisive ethnic ideology and the creation of artificial borders but does not necessarily contribute to the ongoing armed conflicts in the region. Nationalism has been named as another factor responsible for violent conflicts in the GLR in the 1960s, dividing some countries along ethnic and political lines in the GLR, however, the question arose as to why nationalism has not been a source of persistent conflict in many other countries. Further to the factors discussed above, the abundance of natural resources and their exploitation has also been named among factors of violent conflicts in Africa. However, the availability of mineral resources alone is not enough to justify the persistence of violent conflicts in GLR but a complex mix of factors.

These views on the causal factors of armed violent conflicts in the GLR align with conflict theories viz: the mass–society, relative deprivation, social dominance, leadership, and great man and trait theories discussed in the theoretical framework (Chapter 2, Section 2.3).

Despite the foregoing debate in this section, the position adopted in this study is that which is support by robust literature review indicating that the Hima -Tutsi empire theory – their desire to maintain power probably for life and control the resources in the region is likely the main cause of persistent armed violence in the GLR (Section 2.7).

6.2.2. Objective 2: To review existing literature on the application of GIS to conflict resolution and peacebuilding

The role played by GIS in society, particularly in violent conflicts, is important in many contexts. Besides the use of GIS in the research community to analyze complex issues through modelling and the integration of different data sources, GIS application in the social science community is now gaining momentum for different purposes. The evidence reviewed in this study demonstrates that GIS offers considerable scope for application to violent conflict prevention, resolution, and post-conflict peacebuilding (Chapter 3). The literature review chapter on the application of GIS to armed violent conflict resolution and peacebuilding provided a foundation for exploring the role of GIS as one of the tools to assist in resolving armed violent conflicts in the GLR. The review further scrutinized evidence for the claims made for and against GIS applicability in the prevention, resolution, and post-violent conflict reconstruction. This was accomplished by reviewing its capabilities, opportunities, and challenges to conflict resolution.

The role of GIS, as a spatial decision support system in violent conflict resolution, is evident in the case studies reviewed in this chapter, namely, to prevent conflicts in Kyrgyzstan, Israel-Palestine, and Kosovo (Chapter 3, section 3.5). For instance, the Euclidian distance used as a tool to determine population proximity to Kyrgyzstan's main rivers and lakes, as well as population density around those natural resources in relation to potential conflicts.

Despite the existence of such GIS application to conflict resolution, it was demonstrated that GIS by itself cannot resolve any conflict without quality data and mutual collaboration of parties involved in conflicts. If the two parties in conflict do not mutually agree on the information provided by GIS outputs, and the existing spatial data is of low quality or worst still inaccurate, the use of GIS could even have some negative impacts on the peace negotiations process.

6.2.3. Objective 3: To identify and map the spatial distribution of armed violent conflicts in the GLR

The third objective of this study was to identify and map the spatial distribution of armed violent conflicts in the GLR (Chapter 4). This was achieved by mapping, analysing, and comparing the spatial distribution of armed conflict incidences between two periods of 10 years interval (1997 to 2007 and 2008 to 2017), using ACLED conflicts datasets. The results (Chapter 4, Section 4.4) reveal that armed conflict during these two periods has increased in some of these five countries of the GLR, but mostly in the eastern region of DRC and Burundi (Chapter 4, Section 4.4, Figure 4.3). A detailed analysis revealed that the percentage increase in armed violent conflicts from the two study periods (1997 to 2007 and 2008 to 2017), varied from country to country. For example, the rate of increase was estimated 207% in the eastern region of DRC, 25% in Burundi, 6% in Tanzania a sharp decrease in Uganda by -135% and a slight decrease in Rwanda by -3%.

6.2.4. Objective 4: To assess and map the conflict Clusters and hot spots

The fourth objective of this study was to assess and map the conflicts clusters and hot spots in the GLR region to understand patterns and trends of conflicts in the region. Understanding patterns and trends help in looking for solutions that may be used for better policies and decisions making related to conflict clusters and hot spots. Different spatial analysis tools were used to assess conflict clusters and hot spots in the GLR (Chapter 4, section 4.3). These included assessing the global patterns of conflict clusters using the Average Nearest Neighbours (ANN) (Figure 4.5) and the analysis of hot spots using the Getis-Ord Gi* technique (Figure 4.8).

The results showed that during the 1997-2007 period, conflict hot spots were located mostly along the eastern DRC border (on each side of the border) with Uganda and Burundi, and a few in the north-western and south-western Tanzania (Figure 4.8). However, in the period between 2008 and 2017, there was a slight variation of conflict hot spot pattern. While the north-eastern DRC remained a hotspot, a new hot spot emerged in the south of DRC, and a previous hot spot along the DRC border with Tanzania and Burundi borders became cold spots. Comparing the results from the two different periods (1997 to 2007 and 2008 to 2017), the study revealed that the existence of these hot spots in close proximities can be explained by the nearest neighbourhood effect and the first law of geography, which states that everything is related to everything else, but near things are more similar than distant things (Chapter 4, section 4.5). Furthermore, as revealed from some existing literature and reports in social dominance and great man theories on conflicts in the GLR as discussed in Chapter 2 (section 2.6), the Tutsi-Empire ideology would not be a negligible factor to further justify the existence of these hot spots as a means to control the resources and create a lasting empire in the GLR and extending it to other parts of the African continent.

6.2.5. Objective 5: To develop a Conflict Risk Model

The goal of this objective was to develop a Conflict Risk Model (CRM) that can be used as a tool to predict where future armed violent conflicts may occur in the GLR (Section 4.3.5). The CRM is a mathematical model, involving four main conflict variables, recurring in literature as the main drivers of violent armed conflict in the GLR. These variables are rebel groups, mineral resources, ethnic groups, and political instability (Section 4.3.5.1).

The development of this model assisted in predicting the possibilities of conflict risk both at the country and regional level (Chapter 4, Sections 4.3.6). At a country level, the findings reveal that DRC is the highest at risk (81%) and Tanzania as the least at risk (50%) to violent conflict outbreaks from 2018-2038 (Chapter 4, Sections 4.4.8). According to these findings, the presence of abundant mineral resources appears to be a significant contributory factor to the increase and persistence of violence in DRC and demonstrate that there are more probabilities for the countries with more mineral resources to continue having conflicts in the future.

6.2.6. Objective 6: To develop a Geodatabase of armed violent conflicts in the GLR

This objective has been achieved through the creation of the GLRCGDB. It is an integrated regional and centralized data hub, created using ESRI's file geodatabase model to provide spatial data for the five countries in the region, and serve as a decision support system in peace talks. Despite the superior advantage of the Enterprise geodatabase, it was not used in this study because of licensing and financial cost. The file geodatabase was chosen due to its ability to accommodate users with limited available funds. The development process went through four different phases using GIS ArcCatalog 10.5 platform in ArcMap software. These phases including data acquisition and cleaning, geodatabase conceptual and logical design, creating a data structure in ArcCatalog, and dataset importation into a new geodatabase.

While it was challenging to integrate various data sources in the new geodatabase from these five countries, it is believed that the absence of an integrated spatial database from these countries for peace talks could be one of the probable factors contributing to the persistence of violence in the region. Research shows that when parties in conflicts are not sure or do not have a common understanding of the issues and their spatial ramifications, some of the conflict situations become worse. Therefore, the development of the GLRCGDB provides many opportunities for accessing and sharing spatial data as a useful tool for conflict negotiation and peacebuilding in the region.

6.3. Limitations

The success of this study in demonstrating the application of GIS to armed violent conflict resolution was not accomplished without challenges. Availability and access to quality data and their integration to a common format was a major challenge for this study (Chapter 4 and 5). This issue required other GIS techniques to geo-transformation and georeference some datasets formerly existing in hard copies (jpg images) on the five countries of the GLR, before data extraction, analysis or importing it into the newly created geodatabase. Some of resources that were not available in the local libraries were sourced from international libraries at high cost after lengthy correspondences through international interlibrary loan arrangements (Chapter 4), contributing significantly to the delay of this study. In some of the five countries in the GLR where quality data was available, it was a challenge to access it because of some restrictive policies at a country level, like the new policy in Rwanda that prohibits the inclusion of ethnicity in identity documents or reports. This posed a major challenge for including data on ethnic identity in the findings on conflict hot spots (Chapter 4) and in the GLRCGDB (Chapter 5). Due to lack of funds and security issues to travel to the five countries of the GLR (ongoing political instability, armed conflicts and sensitive data), it was not possible to physically contact all stakeholders in those countries to include their views in the newly created GLRCGDB (Chapter 5).

6.4. Recommendations and directions for future research

6.4.1. Recommendations

1) In order to eradicate the dictatorial spirit of some charismatic leaders in Africa, who use the divine right pretext to justify their long stay in power, this study recommends a radical change of mindset for those self-centered politicians and their leadership to contribute in minimizing the risk of further conflicts outbreak and restore regional peace and security in the region.
2) It is recommended from this research that conflict spatial datasets be included as key components in peace negotiations in the GLR rather than relying wholly on global standards. Governments in the countries of the GLR should invest in the development a robust GIS framework and geodatabase of conflicts dataset at the local level to enable conflict resolution experts, policymakers, and government authorities to proactively

access and update the required data at any time (the newly created geodatabase in this study lays a foundation on which to build).

3) GIS application to the social sciences and the public sector is still new in these some countries including those in the GLR. It is thus recommended that governments in these countries of the GLR intensify the introduction of GIS in schools at all levels from primary to university education, to groom future experts who will create new data, refine and update the newly created geodatabase, and manage a GLR GIS as a decision support system including violent conflict resolution.

6.4.2. Directions for future research

To improve understanding related to the persistent instability in the GLR, prevent the widespread armed violent conflicts and increase the prospect of sustainable peace, not only in the GLR, but on the African continent, the following is recommended for future research:

- *Development of a geodatabase at the individual country level.* In order to address the challenges of spatial data access, wrong format, or the inconsistencies related to data from countries in the GLR, there is a need to have a well-managed individual geodatabase at the country level. The suggested geodatabase will enable local governments and policymakers to access accurate and updated datasets on various aspects such as administrative boundaries, the quantitative and qualitative spatial distribution of natural resources, population distribution, demographic statistics, transportation network, security, or economic datasets. The rationale is that if each country preserves its well-managed geodatabase, the issue of data quality accessibility and availability will be addressed, which in turn will be useful not only during peace negotiations, but also serve various purposes (social, economic, and environmental).
- *The social, economic, and environmental impacts.* This study has identified several negative impacts resulting from armed conflicts in the GLR. Some of these include the division of ethnic groups, mass refugee flows, transnational arms trafficking, and the weakening of national economies. In the GLR and elsewhere, armed violent conflicts also disrupts development programs, discourages investment opportunities, and destroys human and physical capital. Furthermore, armed violence undermines the institutions needed for political and economic reform, redirects resources to non-productive uses, and causes a dramatic deterioration in the quality of life. Therefore, future research should look at the socio, economic, and environmental impacts that

affect the society during and post violence, with a particular focus on sustainable political and economic development reform in the region.

- Considering the short time frame used in this study and the challenges related to all stakeholder inputs to develop a analytical Conflict Risk Model for predicting and mitigating armed violent conflicts in the GLR, there is a need to set aside enough time to develop a robust *conflict risk model* in Africa as a continent. Such a comprehensive conflict risk model should include local, regional, and international perspectives and principles.

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APPENDICES

Appendix 1: Table of Armed rebel groups operating in the three provinces of Eastern part of the DRC

Rebel GrouP Name	Zone No	Country of Origin	Abreviation	Distribution (Region)	Occupe Zone
LDF Busumba	1	DRC	LDF Busumba	Kivu	Masisi
Alliance des Patriotes pour un Congo Libre et Souverain	2	DRC	APCLS	Kivu	Rushuro
Forces démocratiques de libération du Rwanda	3	RDA EX FAR	FDLR -Foca	Kivu	Uvira
Union des Patriotes Congolais pour la Paix	4	DRC	UPCP/FPC	Orientale	Lubero
Front de défense du Congo-Guides	5	DRC	FCP/Guides/MAC	Kivu	Walikale
Forces nationales de libération	6	BRI	FNL	Kivu	Uvira
Maï Maï Kifuafua	7	DRC	N/A	Kivu	Masisi
Maï Maï Yakutumba (PARC)	8	DRC	PARC	Kivu	Fizi
MCC Bede	9	DRC	MCC	Kivu	Uvira
Nyatura-North	10	DRC	FDDH/FRPI	Kivu	Masisi
Mayi-Mayi Mulumba	11	DRC	N/A	Kivu	Fizi
M27	12	DRC	N/A	Kivu	Masisi
Maï Maï Sheka / Nduma Defence of Congo	13	DRC	NDC	Kivu	Masisi
Nyatura-Sud	14	DRC	N/A	Kivu	Ruchuru
Raia Mutomboki-Kalehe	15	DRC	N/A	Kivu	Fizi
Raia Mutomboki-Walikale	16	DRC	N/A	Kivu	Shabunda
Raia Mutomboki-Shabunda	17	DRC	N/A	Kivu	Shabunda
Raia Mutomboki-Walungu	18	DRC	N/A	Kivu	Rushuru
Mayi-Mayi Shetani-Bwira	19	DRC	N/A	Kivu	Fizi
Allied Democratic Forces	20	UGA Lead Islamic	ADF	Kivu	Rushuru
Mayi-Mayi Kapopo	21	DRC	N/A	Kivu	Mwenga
Forces de resistance patriotiques en Ituri	22	DRC	FRPI	Kivu	Kumu
Forces démocratiques de libération du Rwanda	23	RDA	FDLR-RUD	Kivu	Rushuru
Forces démocratiques de libération du Rwanda	24	RDA	FDLR-RUD Urunan	Kivu	Kumu
Maï Maï Morgan	25	DRC	N/A	Orientale	Rubero
Various Local Defence Forces Busumba	26	DRC	LDF	Kivu	Rushuru
Mayi Mai - Kilikisho	27	DRC	N/A	Kivu	Karehe
Mayi Mai - Mayele	28	DRC	MPDC	Kivu	Rushuru
Mayi Mai - Fujo/Nyerere	29	DRC	N/A	Kivu	Uvira
Mayi Mai - Nyakiliba	30	DRC	N/A	Kivu	Uvira
Mayi Mai - Karakara	31	DRC	N/A	Kivu	Uvira
Mayi Mai - Sikatenda/	32	DRC	N/A	Kivu	Fizi
Mayi Mai - Brown	33	DRC	UCCB	Kivu	Uvira
Mai Mai - Mushombe/Irunga	34	DRC	N/A	Kivu	Uvira
Union des Patriotes Congolais pour la Paix	35	DRC	UPCP	Kivu	Kabambale
Mayi Mayi Sikatenda	36	DRC	N/A	Katanga	Fizi
Forces démocratiques de libération du Rwanda	37	RDA	N/A	Kivu	Mwenga
Mayi Mayi Mulumba	38	DRC	N/A	Kivu	Fizi
Kati Katanga	39	DRC	N/A	Kivu	Pweto
Kati Katanga	40	DRC	N/A	Kivu	Manono
Mayi Mayi Simba	41	DRC	N/A	Kivu	Mitwaba
Mayi Mayi Simba	42	DRC	N/A	Kivu	Kalemie
Total	**42**				
	Note:				
	DRC:Democrcratic Republic of Congo				
	RDA:Rwanda				
	UGA:Uganda				
	BDI:Burundi				

Appendix 2: Average scores of conflict variable ranks from a survey of 10 experts

Countries	Variables	Participants											
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Total	Mean
Burundi	Mineral resource (Occurrence)	2	2	2	2	2	2	2	2	1	0	17	**2**
	Rebel arm group (Density)	2	3	2	1	4	2	4	3	1	1	23	**2**
	Population (Ethnic hostilities)	2	2	3	2	4	4	4	3	4	2	30	**3**
	Government (Political instability)	2	3	1	2	3	4	4	3	3	4	29	**3**
Total		8	10	8	7	13	12	14	11	9	7	99	10
DRC	Mineral resource (Occurrence)	4	4	4	4	3	4	4	4	4	2	33	**3**
	Rebel arm group (Density)	4	3	4	4	4	4	4	4	4	3	35	**4**
	Population (Ethnic hostilities)	2	3	2	1	4	4	4	3	3	2	28	**3**
	Government (Political instability)	3	2	2	4	3	4	4	4	2	4	32	**3**
Total		13	5	12	13	14	16	16	15	13	11	128	13
Rwanda	Mineral resource (Occurrence)	2	1	0	1	3	1	3	1	1	1	14	**1**
	Rebel arm group (Density)	1	3	3	1	4	1	3	3	1	0	20	**2**
	Population (Ethnic hostilities)	2	4	4	4	4	3	4	4	4	1	34	**3**
	Government (Political instability)	4	2	3	2	3	3	4	2	3	1	27	**3**
Total		9	10	10	8	14	8	14	10	9	3	95	10
Tanzania	Mineral resource (Occurrence)	2	4	2	3	1	0	2	4	1	1	20	**2**
	Rebel arm group (Density)	3	1	0	4	0	0	2	0	1	1	12	**1**
	Population (Ethnic hostilities)	1	1	0	5	1	0	2	3	1	1	15	**2**
	Government (Political instability)	4	4	2	6	1	0	3	1	2	2	25	**3**
Total		10	10	4	18	3	0	9	8	5	5	72	7
Uganda	Mineral resource (Occurrence)	2	3	1	2	1	1	3	3	1	1	18	**2**
	Rebel arm group (Density)	3	2	3	1	2	1	4	4	2	1	23	**2**
	Population (Ethnic hostilities)	3	1	1	1	2	1	2	3	1	2	17	**2**
	Government (Political instability)	3	3	3	1	2	3	4	3	3	3	28	**3**
Total		11	9	8	5	7	6	13	13	7	7	86	9

Appendix 3: Feature dataset – Non-Living Conflict Entities

Geodatabase name			GLRCGDB
Feature dataset name			**NonLivingEntities**
Feature classes			
	Type	Feature class name	Alias
	Poly	MineralResources	Mineral resources sites
	Poly	GreatLakes	Main lakes in the region
	Poly	AdminBoundaries	State boundaries
	L	TransportNetwork	Regional linkages

***Features in Appendix 3 include *feature dataset name: NonLivingConflictEntities(NonLiving Conflict Entities)*;Feature Type: Poly (abbreviation for polygon); Feature class name: MineralResources (the name of the feature class);: and Alias :Armed rebel group (describe the contents of the feature class.*

Appendix 4: Feature Class1- Mineral Resources

Geodatabase name			GLRCGDB
Feature dataset name			NonLivingConflictEntities
Feature classes			
	*Type	**Feature class name**	Alias
	Poly	**MineralResources**	Main type occurrence

***Features in Appendix 4 include feature class name: MineralResources (Mineral Resources)*; *Feature Type: Poly (abbreviation for polygon); and Alias: Main type occurrence (describe the contents of the feature class).*

Appendix 5: Feature Class 2- GreatLakes

Geodatabase name			GLRCGDB
Feature dataset name			NonLivingConflictEntities
Feature classes			
	*Type	**Feature class name**	Alias
	Poly	**GreatLakes**	Main lakes in the region

Features in Appendix 5 include* ***feature class name: **GreatLakes *(*Great Lakes*)***; Feature Type: Poly (abbreviation for polygon); and Alias:* Main lakes in the region *(describe the contents of the feature class).*

Appendix 6: Feature Class 3 – Admin Boundaries

Geodatabase name			GLRCGDB
Feature dataset name			NonLivingConflictEntities
Feature classes			
	*Type	**Feature class name**	Alias
	Poly	**AdminBoundaries**	State boundaries

*****_Features in Appendix 6 include **feature class name :**_ **AdminBoundaries (AdminBoundaries)**_; Feature Type: Poly (abbreviation for polygon); and L (abbreviation for line) Feature class name: MineralResources (the name of the feature class); and Alias :_ State boundaries _(describe the contents of the feature class)._

Appendix 7: Feature Class 4 – Transport Network

Geodatabase name			GLRCGDB
Feature dataset name			NonLivingEntities
Feature classes			
	*Type	**Feature class name**	Alias
	L	**TransportNetwork**	Regional road linkages

Features in Appendix 7 include* feature class name: TransportNetwork (Transport Network); Feature Type: L (abbreviation for polygon); and Line (abbreviation for line) and Alias:* Regional road linkages *(describe the contents of the feature class).*