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The Geography of Conflict Diamonds: The Case of Sierra Leone

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Abstract. In the early 1990s, Sierra Leone entered into nearly 10 years of civil war. The ease of accessibility to the country's diamonds is said to have provided the funding needed to sustain the insurgency over the years. According to Le Billon, the spatial dispersion of a resource is a major defining feature of a war. Using geographic information systems to create a realistic landscape and theory to ground agent behavior, an agent-based model is developed to explore Le Billon's claim. Different scenarios are explored as the diamond mines are made secure and the mining areas are moved from rural areas to the capital. It is found that unexpected consequences can come from minimally increasing security when the mining sites are in rural regions, potentially displacing conflict rather than removing it. On the other hand, minimal security may be sufficient to prevent conflict when resources are found in the city.

Keywords: Agent-based modeling · Geographic information systems · Civil war · Conflict

1 Introduction

In the early 1990s, Sierra Leone, a small country on the western coast of Africa, entered into nearly 10 years of civil war. Sparked by an abusive government and fueled by an illicit diamond market, the decade-long war killed an estimated 70,000 and displaced another 2.6 million people [1]. It is said that the primary driver of the war was the country's most abundant and valued resource, diamonds [2]. While the resource has resulted in growth in other countries such as Botswana, Sierra Leone has experienced some of the highest levels of poverty in the world. Unlike the diamond mines of Botswana, however, the alluvial diamond mines of Sierra Leone cover widespread areas in remote parts of the country where mining areas cannot be easily fenced and security is minimal [3].

Le Billon [4] argued that the spatial dispersion of a resource is a major defining feature of a war, impacting the type of conflict that may emerge. An agent-based model (ABM) was developed of the resource-driven conflict to explore

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Le Billon's [4] theory. Some of the earliest ABMs of rebellion include Axelrod's [7] model of new political actors and Epstein's [8] civil violence model. More recent ABM's have explored in-group dynamics and ethnic salience (e.g., [9–11]). While the ABM presented here shares similarities with prior ABMs that have explored income, resources, and identity as drivers of conflict, it also introduces some key differences. Utilizing geographic information systems (GIS) and socioeconomic data of the country, a landscape and population that better represent the actual setting being modeled is created while the behavior of agents draws from theory. Different scenarios are run as the diamond mines are made more secure and the mining areas are moved to the capital. It is found that unexpected consequences can come from minimally increasing security over the diamond mines in rural regions. For instance, while minimal increases in government control stopped rebel activity in the south, it displaced the conflict to a district in the north, which had not seen violence in prior runs of the model.

2 Background

Theorists have pointed to opportunity, along with motivation and group identity, as indicators of war (e.g., [5,6]). Opportunity can come in the form of financing, the availability of recruits, and the ability to garner these resources with relative ease, which can be due to factors such as geography, economics, and availability. Others have focused on the financing of war through "lootable" resources (e.g., [6]). Le Billon [4], while agreeing that lootable resources are a factor in conflict, argues further that the spatial dispersion of a resource is a major defining feature of a war, impacting the type and duration of rebellion.

According to Le Billon [4], conflict characteristics are affected by two geographic factors: (1) the location of resources as they relate to the country's center (proximate versus distant) and (2) the concentration of resources (point versus diffuse). Distant resources (i.e., in remote areas) are easier for rebel forces to capture and control, while proximate resources are easier to secure and are less likely to be captured (e.g., coffee). Diffuse resources are widespread over large geographic areas, making the resource more difficult to secure (e.g., alluvial diamonds). Point resources, however, are concentrated in small geographic areas and typically require mechanized extraction (e.g., kimberlite diamonds) making them easier to secure and less likely to be exploited [4]. Assuming an environment that is ripe for conflict, the geographic features of a resource can influence the type of conflict. This relationship is illustrated in Table 1.

3 Model Development

An ABM was developed in MASON [12] to explore the role of geography in the resource-driven war. GIS data was utilized to create the modeling landscape, while socioeconomic data provided initial agent attributes. Due to the localized nature of social processes, including civil violence, ABM combined with GIS is ideal for modeling the unique environment of Sierra Leone and the long-lasting

Table 1. The relationship between the resource dispersion and conflict type [4].

Concentration/Relation to center	Diffuse Widely spread with minimal control	Point Concentrated in small areas
Distant Located in remote territories	Warlordism	Secession
Proximate Close to center of power	Rioting / mass rebellion	State control or coup

conflict it endured. For brevity, a high-level overview of the model is presented here. The detailed model description using the Overview, Design Concepts, and Details (ODD) protocol [13], the source code, and data to run the model can be downloaded from https://www.openabm.org/model/4955/. The model's initialization process is discussed in Sect. 3.1; the agents' behavior is discussed in Sect. 3.2; and the model's outputs are reviewed in Sect. 3.3.

3.1 Model Initialization

The modeling world encompasses the country of Sierra Leone, an area of approximately 71,740 km^2. Each run of the simulation begins by reading in the spatial dataset and building the environment using data from the Global Administrative Areas database [14], the Oak Ridge National Laboratory [15], the Peace Research Institute Oslo [16], and OpenStreetMap [17]. The agent population is created using data from the Republic of Sierra Leone 1985 and 2004 Population and Household Census [19] and the Oak Ridge National Laboratory [15], while socioeconomic data, which provided information on age distribution, income levels, and employment statistics, came from the Republic of Sierra Leone 2004 Population and Housing Census [22,23] and Statistics Sierra Leone's Annual Statistical Digest [18]. Due to the computational constraints of modeling the complete population of Sierra Leone (approximately 4.9 million), the population within each parcel is reclassified to equal one percent of the total population. Model runs performed at varying populations yielded similar qualitative results. Note that households are not explicitly modeled here. The idea of a household is used only to ensure that agents can be assigned an income even if unemployed. Table 2 summarizes the input parameters used in the model.

The model proceeds in one-month increments. While the decision to join the rebellion may occur in a short time period (hours or even minutes), there is a lag of weeks or even months between the time someone makes that decision (or is forced to make that decision) and the time they are actually ready for combat [24]. In addition, the war lasted years. From a modeling perspective, we are interested in capturing the dynamics of the conflict over the years, not days or hours. We also need to consider the balance between spatial and temporal computational resources. The modeling world is the entire country of Sierra Leone and simulates the dynamics of a war as it spreads a country.

Table 2. Input parameters and variables.

Parameter	Range	Default value	Reference
Agents			
Initial number of agents	1–4.9 million	49,000	[15, 19]
Percentage of population in the initial opposition group	0–1	0.005	[2]
Age	Grouped in age ranges	0–6, 7–17 18–64	[23]
Income level	1–3	1–3	[18]
Employment status	1–4	1–4	[22]
Vision	0–370	25	Authors estimation
Likelihood to mine if food poor	0–1	0.01	[5, 6]
Likelihood to mine if total poor	0–1	0.05	[5, 6]
Rebel threshold if adult and not a miner	0–1	0.1	[5, 6]
Rebel threshold if adult miner	0–1	0.01	[5, 6]
Rebel threshold if minor	0–1	0.01	[5, 6]
Parcels			
Distance to diamond mines	0–1	0–1	[14, 16]
Remoteness	0–1	0–1	[17, 25]
Government control over mines	0–1	0	[26]
Maximum parcel risk	0–1	0–1	Authors estimation

3.2 Agent Behavior

The PECS (Physical conditions, Emotional state, Cognitive capabilities, and Social status) framework is a cognitive architecture that provides a flexible framework to model human behavior [20]. Using PECS to implement agent behavior, Fig. 1 provides details on the specific motives (i.e., needs) and the set of potential actions available to the agent. The Intensity Analyzer is responsible for determining the action-guiding motive from the set of possible motives. Two sub-models discussed here – the Needs Model and the Opportunity Model – are incorporated into the Intensity Analyzer to determine agent behavior.[1]

The Needs Model. As illustrated in Fig. 1, agents can have three motives: (1) the need for basic necessities such as food and shelter, (2) the need for security of employment, housing, and financials, and (3) the need to maintain the home. These motives represent the two most fundamental levels from Maslow's [21] hierarchy of needs.[2] Agents meet these needs through a household income, whether from employment in the formal market, employment in the illicit diamond market, or employment of a "household" member. While

[1] A third sub-model, the Identity Model, activates the identity of the agent based on the outcome of the Needs and Opportunity Models. A detailed description of this sub-model is provided in the ODD, which can be downloaded from https://www.openabm.org/model/4955/.

[2] While the Needs Model is responsible for determining the agents' motive, and as such, could be called the "Motives Model", it was instead named after the humanistic needs theory for which it draws from to highlight the application of theory.

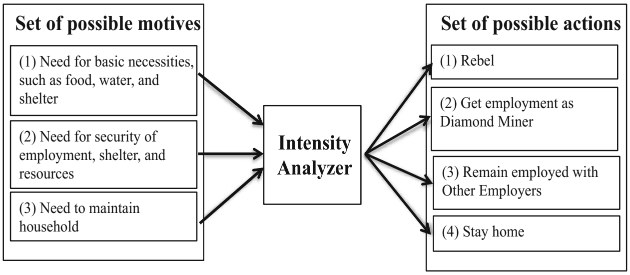


Fig. 1. Motives and actions via the Intensity Analyzer (adapted from [20]).

the Needs Model determines the action-guiding motive, the Opportunity Model helps determine the final goal and, subsequently, the final action the agent will take.

The Opportunity Model. Drawing from opportunity-based theories, which have stressed such factors as the accessibility to resources, the geographic concentration of rebels, and economic factors, agents in the model require opportunity to join the illicit mining industry or to rebel. The first factor of opportunity is the accessibility to resources. This is driven by three criteria: the presence of diamond mines, the remoteness of the area, and the level of government control (or security) surrounding the resource [4]. The second factor is economic in nature. We use a simple likelihood to mine variable to model this, where the lower income brackets are the most vulnerable to joining the conflict. The final factor is the concentration of rebels within an agent's "vision". The more geographically concentrated the rebels, the easier it is to overcome challenges of collective action and to mobilize. In the model, if the first two factors of opportunity are met, then there exists the opportunity to mine in the illicit market. If the third factor is also met, then there exists the opportunity to rebel. In the case of those agents forced to rebel, however, economic factors are not considered, as these cases were largely children abducted and violently coerced to join the conflict [1].

The Action Sequence. An agent can perform one of three activities at each time step: mine, rebel, or do nothing. If an agent stays home or works in the formal market, the agent will do nothing (agents "going to work" is not explicitly modeled). If the agent joins the illicit diamond market, that agent will leave its current employer and will join the diamond mining industry. If the agent's income level was zero, it is increased to one. An agent who becomes a rebel, on the other hand, does not work for any employer, as the agent is either being forced to rebel or is seeking to take control of a mining area for purposes beyond that of the average independent miner.

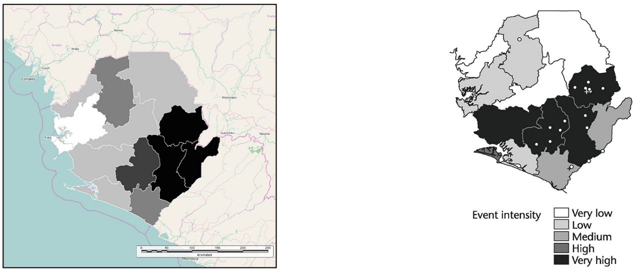
Agents that are miners or rebels will move on the modeling landscape. These agents need to be near the diamond mines, but at the same time it is assumed that they will want to move to a location that will minimize its potential level of risk as much as possible. Utilizing cost surfaces developed to create the initial landscape, an agent will move to a parcel within its vision that is closer to the diamond mines but more remote than its current location. The agent will continue to move until it cannot find any parcel within its vision that would be better (i.e., closer to the mines and more remote) than its current location.

3.3 Model Output

The model exports a set of comparative statistics, including the number of agents by a set of labor attributes and income levels. Statistics are collected at the district-level by time step so that changes in the conflict's dynamics can be assessed across time and geographic location. The spatial dynamics of the conflict as it evolves across time are observed through the interface during model runs.

4 Simulation Results

This section describes the model results. First, sensitivity testing was performed to ensure the model was working as intended and to establish qualitative agreement of model results to empirical data of the conflict. To determine initial default parameter values, the model was calibrated by adjusting parameter settings and selecting values based on observed visual results that most closely replicated the actual conflict from a qualitative perspective. Figure 2 shows average intensity levels of rebel activity. Because the model does not simulate events, intensity here is a function of that proportion of the total population that rebelled.



(a) (b)

Fig. 2. A visual comparison of model results to actual events. a: Average model results using default parameter values. b: Actual event intensity [26].

Next, two experiments were performed to explore Le Billon's [4] theory. As discussed in Sect. 2, Le Billon [4] examined four types of conflicts and the environmental factors required for each to emerge. To explore this theory, two experiments were performed: (1) an experiment where resources are distant and government control (i.e., security) is varied, and (2) an experiment where resources are moved closer to the country's center and government control is varied (all other parameter values are set to the default values shown in Table 2).

The Impact of the Spatial Dispersion of a Resource on Conflict Type When Resources are Distant. To explore the potential impact on a conflict between having distant, diffuse resources, which is associated with conflicts of warlordism, and distant, point resources, which is associated with secession attempts, government control is varied in increments of 0.05 and the diamond mines, whose relation to the "center" of the country is already distant, are maintained at their current locations. Government control of zero represents the minimum securities typically found with diffuse resources while government control of one represents the increased security over point resources.

Figure 3 illustrates the spatial dynamics of rebel intensity as government control is increased. Results shown are the average rebel intensity during year 10 of the conflict. Figure 3a–b show that at lower levels of government control, the resulting violence was widespread with some regions experiencing very high levels of rebel activity. In this case, the resulting spatial dynamics of the violence was similar to the actual areas where conflict was the most intense. Because of the geographic similarities between the real-world case of warlordism in Sierra Leone and model results, the model output supports the theory that distant, diffuse resources are associated with conflicts of warlordism. As expected, Fig. 3c–d show that with increasing government control, the intensity of rebels and the geographic spread of the violence decreased. There are a few unexpected results, however. For instance, while minimal increases in government control were enough at times to stop rebel activity in the south, the conflict looked to be displaced to a district in the north. As government control was increased systematically to simulate a resource situation going from diffuse to point, rebellion occurred in smaller, more contained areas, often on the boundaries of the country. Given these spatial dynamics and the unique geographical location and size of the conflict, a situation of secession may be feasible.

The Impact of the Spatial Dispersion of a Resource on Conflict Type When Resources are Proximate. Freetown is the country's capital, most populated city, and main financial center [27]. Freetown can thus be considered the "center" of Sierra Leone. In this second experiment, the diamond mines are moved to Freetown and results are observed as government control is varied from zero to one at increments of 0.05. Figure 4 shows the spatial dynamics of rebel intensity as government control is increased. Results shown are the average rebel intensity during year 10 of the conflict.

Environments with proximate, diffuse resources are associated with conflicts of mass rebellion or riots near the center of power. When government control is low, this experiment seeks to simulate this environment, as shown in Fig. 4a. While rebel activity emerged in the model, it was largely contained to the capital and its surrounding areas. Although the resources were placed in Freetown,

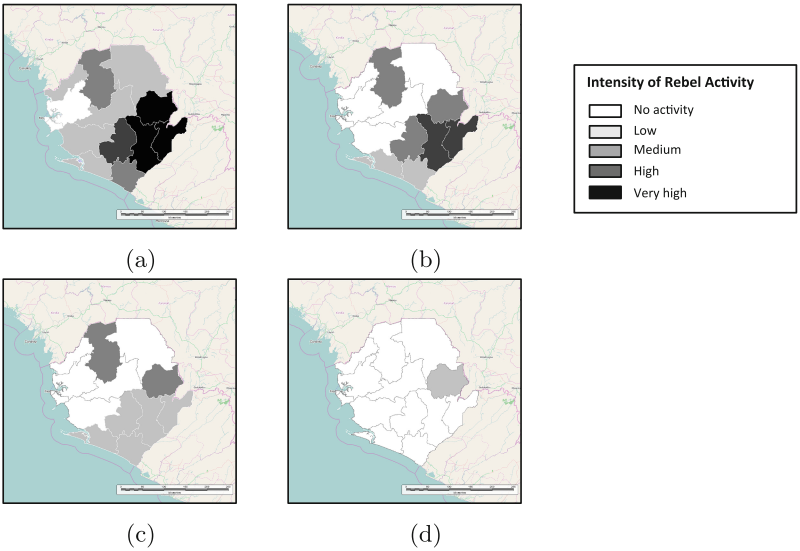


Fig. 3. Average model results in year 10 when resources are distant. a: Government control is 0.0. b: Government control is 0.2. c: Government control is 0.4. d: Government control is 0.6.

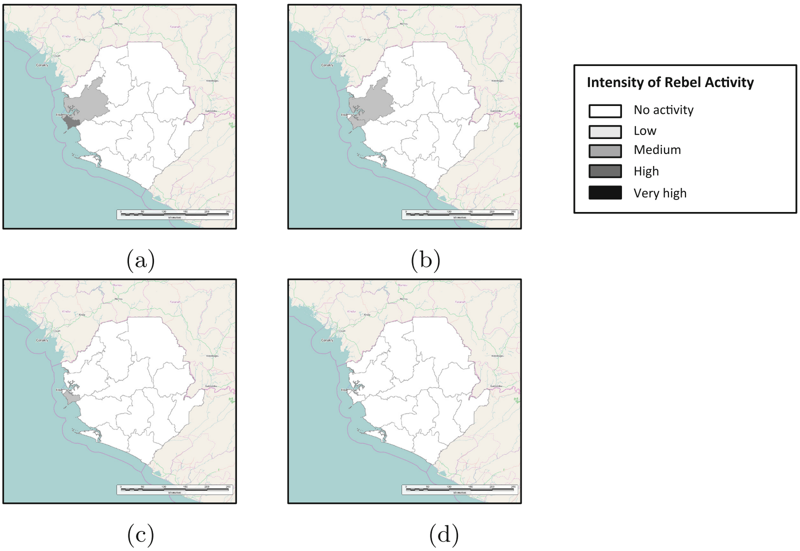


Fig. 4. Average model results in year 10 when resources are proximate. a: Government control is 0.0. b: Government control is 0.25. c: Government control is 0.35. d: Government control is 0.45.

which is located in the district of Western Area Urban, its neighboring district (Western Area Rural) actually experienced higher levels of rebel activity (see Fig. 4a–b). Given the geographic location of rebel activity and the spread of the violence in the model at low levels of government control, these results provide support to the idea that diffuse, proximate resources are associated with rebellion. From Fig. 4, we find that only minimal increases in government control are required to rapidly drop the intensity of rebel activity, supporting the idea that proximate resources are easier for the government to control. As government control was maximized, an environment with proximate, point resources is modeled, as shown in Fig. 4c–d. These types of resources are associated with conflicts of state control or coups. A coup would occur in the country's center of political power, however, at relatively low government control levels (0.25 and above), no rebel activity ensues in the capital. Thus, we cannot support or reject the notion that proximate, point resources are associated with coups.

5 Conclusion

Since diamonds were discovered in Sierra Leone, the government has been unable to control the activity and provide residents with the benefits of having the resource [27]. Through the interplay of ABM and GIS, the model presented explores Le Billon's [4] theory and the impact that the unique environmental and socioeconomic attributes of a region and its population can have on the onset of conflict. The resulting intensity and spatial characteristics of conflict in the model provided support to Le Billon's [4] theory that the spatial dispersion of a resource can lead to warlordism, secession, and mass rebellion. However, the model did not implement the necessary detail to support Le Billon's [4] claim that proximate, point resources lead to a coup. Furthermore, in future work, agent movement could be empirically calibrated to the displacement levels of the population. Nevertheless, by applying simple behavior we were able to explore theory and test "what if" scenarios. When an environment is ripe for conflict, this type of model could potentially provide insight into the locations most prone to conflict and the characteristics of a conflict. Different conflict types may require unique intervention strategies [28], an important consideration for policy.

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