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An Agent-Based Modellingand Simulation of Conflict between Fulani Herdsmen and Indigenous Farmers of Barkin-Ladi L.G.A. Of Plateau State

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ABSTRACT: *In this paper, an agent-based model (ABM) is proposed using Netlogo to analyse the spatially explicit interaction between Fulani herders and the indigenous farmers of Barkin-LadiL.G.A. of Plateau State, Nigeria. The simulation is described by following the ODD (Object, Design and Details) protocol. The proposed ABM simulates interactions and conflict between Fulani herders with indigenous farmers over the use of land resources. The ABM also simulates cattle rustling and conflict between herder agents and farmer agents in the area. The ABM consists of three kinds of agents: herders, farmers and cattle rustlers. The ABMmodelled how socio-ecological interactions have resulted into conflicts between the Fulani herdsmen and the indigenous Berom farmers in the area. The developed ABM also incorporates the activities of cattle rustlers who are involve in the theft of cows belonging to the herders. Results from simulation analysis depicts that the ABM is robust to the wide range of unknown parameters when the model is implemented with the rich data set from field study, remote sensing and literature.*

KEYWORDS:*Herders, Indigenous farmers, Cattle rustlers, Netlogo, Agent based modelling, Parcel, Resources, Simulation and Barkin-Ladi L.G.A.*

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I. INTRODUCTION

Agent based modelling *(ABM)* is a foundation modelling system, where everyindependentbody, such as an animal or individual person, is articulated asa collection of parameters and behaviour rules Takuya et al. [1].Meretsky [2] asserts that agent-based technique is increasingly applied for understanding and modelling complex human environmental interaction. The employment of *ABM* on pastoral scheme of sub Saharan Africa has been investigated by various researchers. To declare few of these investigators on pastoral systems sub Saharan Africa, Macopiyoet al.[3]investigated the application of a geographic information system(*GIS)* based *ABM* to investigate herder movement in northern Kenya and Southern Ethiopia. Kusnar and Sedimeyer [4] discovered*NOMAD* which models the ongoing tribaldisagreement in Darfur region of South Sudan, stressing the significanceof herder farmer associationthroughout environmental adversity. Bah et al. [5] discoveredan involvement based on*ABM*to model a struggle on natural resources and the right to use of water in the Sahel among diverse pastoral groups.

The foremostlimitation to the application of *ABM* to socio-ecologicalsystems has been inadequateexperimental information to model real-world complexity [6][7]. In this paper, we employ abroadvariety of data on indigenous farmers, Fulani herders, cattle rustlers, peoples and communities of Barkin-Ladi*L.G.A.* to develop our simulation model, together withinterrogative based surveys of demographic and socio-economicfeatures of all households contained in the study region, along data on human beings killed, plants\crops destroyed and animals rustled.

The Fulani herders, before 1970 had lived affectionately, communally co-existing with the indigenous farmers and people of Barkin-Ladi*L.G.A.* The basis of the conflict started over resources essential for survival. The violence between the two groups is because each group is struggling to survive on the same resource called the 'green of the land'. The Fulani herders in Barkin-Ladihave established asophisticated social coalitionstructure to deal with differentecological and social challenges such as drought, flood and cattle rustling. Devoid of sufficient resources (i.e. the small carrying capacity of the land) to grow plants and to graze animals, this new socio-ecological system hasextremelybeen characterized by conflicts [8]. Fulani herdsmen relation with their ethnic group allows them to share scarce resources in time of need and to cooperate in time of conflict. The Fulani herders share common resource among themselves since they belong to the same ethnic group and compete with the indigenous farmers of the area.

In this study we depict the model based on a spatially-explicit*ABM*to understand interactions between indigenous farmers andtheir natural environment as well as the interaction between Fulani herdsmen and the indigenous people in Barkin-Ladi area that has led to the ongoing violence in the area. We seek inparticular to simulate the interplay between subsistence agriculture, livestock grazing, cattle rustling, attacks on communities of indigenous farmers, destruction of farm yield of the indigenous farmers and their impact on indigenous populations, landscape and cattle population through bottom-up modelling framework. While ourmodel is implemented through rich dataset from fieldwork, geographic information system and literature review, a broad sensitivity analysis is alsocreated to demonstrate how robust simulation results are to a small number ofunknown parameters.

This paper presents a holistic agent-based modelling (*ABM*) framework to modelled the spatially explicit interaction of Fulani herdsmen and the indigenous Berom farmers, people and communities of Barkin-Ladi L.G.A. The computer programming environment employed to achieve this explicit spatial *ABM* framework is 'Netlogo'. In section 2 of this paper, we treat the modelling approach and method, while section 3 presents the evaluation of the model. The remaining sections of 4, 5and 6 presents results, discussion and conclusion respectively.

II. MODELLING APPROACH AND METHOD

2.1 Description of the study area

Dung-Gwom and Dung [9] asserts that the study area, Barkin-Ladi*L.G.A*(also called Gwol) is located 9032'00"N and 8054'00"E, is about 50 Km on the Jos-Mangu highway as illustrated in Figure 1. The area is located on the Jos Plateau with an averageheight of 1,200 meters above sea level. The area is characterized of a hugecoverage of basement complex rocks and several volcanic rocks. The rocks include huge deposit of minerals such as TinandColumbite which have been tapped on commercial quantity since the commencement of the lastcentury. Most of the mineral ores being alluvial deposits and open cast mining was the main method oftapping of the ores [10]. With the growth of hydro electricity supply fromKura Falls in the 1920s, Barkin-Ladi became a major area of mechanised tin mining on the Jos Plateau.The Barkin-Ladi main town became a flourishing small town since becoming a local government headquarters(third-tier/level of government in Nigeria) in 1976. From 1976, the population has improvedrapidly, from 22,720 (*NPC, 1991*) to 45,428 in 2006 and now estimated at 71,626 (2016), with a growth rateof 4.7%.With the collapse of tin mining activities from the mid-1970s and the withdrawal of foreign miningcompanies, the economy of the town was transformed from being dependant on the tin industry toagriculture (the mining ponds provided water for dry season farming and livestock), trading and commerce as well as serviceindustries [11][12]. In the past three or four decades, therefore, theinformal economy has been the major source of employment and driver of the local economy.

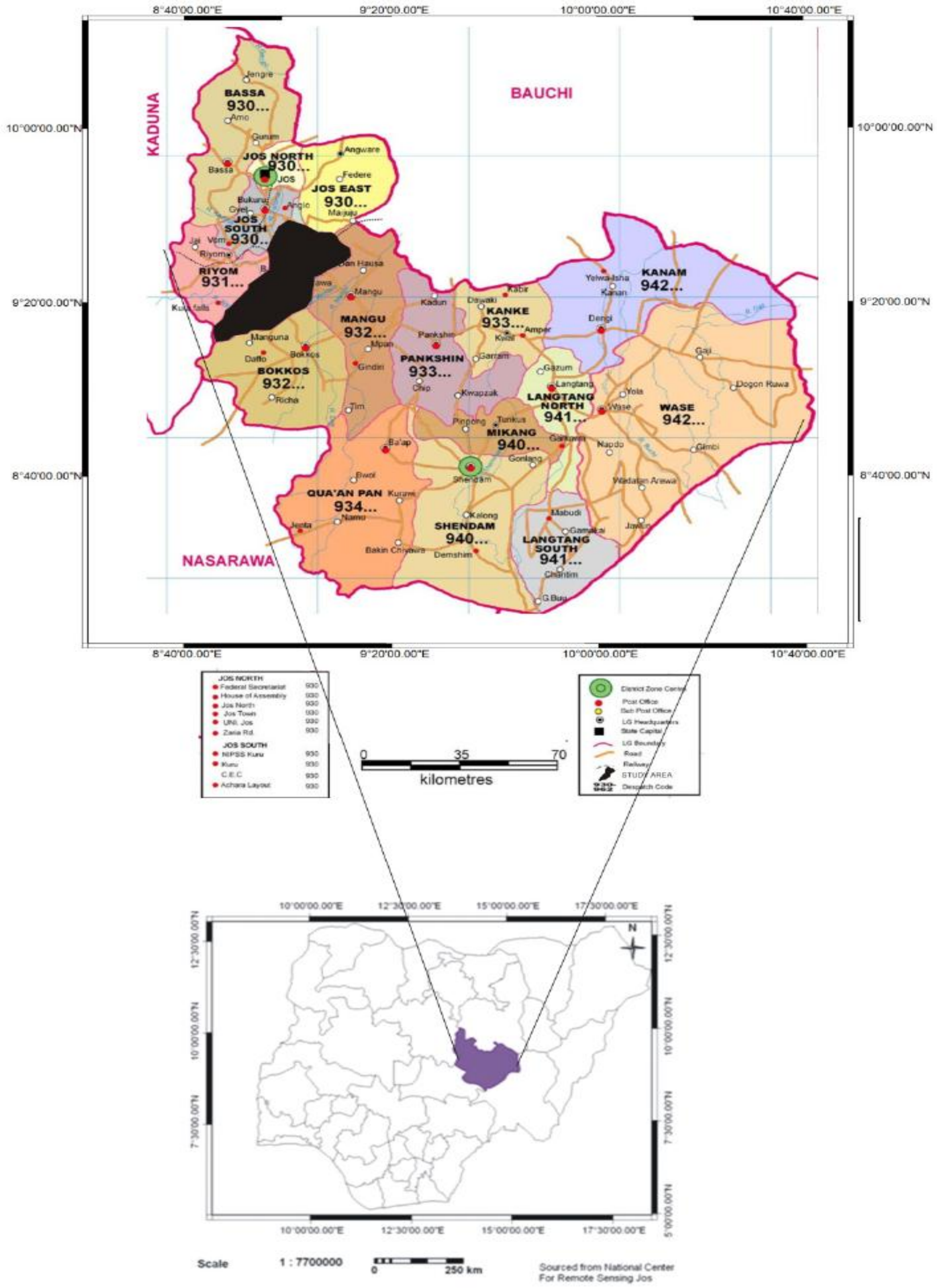

Figure 1: Map of Nigeria showing Plateau State and Barkin-Ladi L.G.A

2.2. The agent-based model

We develop our modelby using Netlogo;the programming environment specialized for spatially explicit*ABM*[13]. The simulation model is described by following the *ODD* (Object, Design and Details) protocol [14].Our agent-based model (*ABM*) simulates interactionsand conflict between Fulani herders withindigenous farmers over the use of landresources. Themodel also simulates cattle rustling and conflict between herders and indigenous people in the study area. The model largely centres on the apprehensionbetween different Fulani herder groups with indigenous farmers over the exploitation ofthe regular grazing land and water resources as well as theemergence of conflict related to their use and the emergence of conflict related to cattle rustling.The model consists of three kinds of agents: herders, farmers and cattle rustlers as illustrated in Figure 2. Since Fulani herders are in the centre ofthis model, their behaviour is represented in significantlygreater detail. Each herder is represented as a singleagent with combined characteristics of the herder's family, and the herd animals.

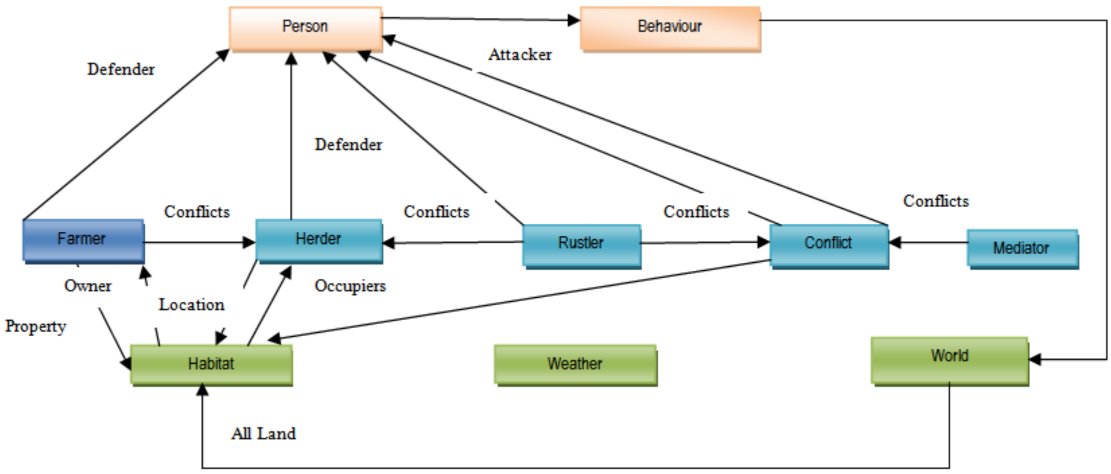

Figure 2: ***ODD*** **Diagram of Herder, Farmer and Cattle Rustler Agents**

Herders own a herd of cattle and small ruminants that are led to where the seasons take them, between qualitypastures and waterholes, from one camp to another. In response to the variability in space and time of the primaryresources, herders have adopted a strategy based on mobility (Figure 2). In Barkin-Ladiarea, all herders are a part of the Fulani ethnic group. Figure 2 also depicts how the different activities performed by herders are linked to the farmers and cattle rustlers.

2.2.2 Farmer

Indigenous farmers own three or more plots of farmland which they farm in the rainyseason. Their activities consist of preparing their fields starting with clearing and ridging. They start planting about 2 weeks after the first rains in order to be able to carry outmonitoring and weeding throughout the raining season. The raining seasons last for about 6- 7 months beginning from April to October. The farmers begin harvesting, sorting and collecting the crops in November to December when the harmattan winds have dried the crops. In the dry season the farmers market the products and residue from their fields while some of the farmers clear their farmlands in preparation of dry season cultivation (Figure 2).The farmer category is predominantly the Berom ethnic group. The farmer agent whose practices involves clearing of farmlands, planting of crops, weeding of the cultivated farmland already germinated with planted crops and harvesting of ripe crops is represented by the following equations.

$$C_{clearing} = 5.4\beta \frac{c_{clearing}}{s} \quad (1)$$

$$P_{plant} = 4.75\beta \frac{p_{planting}}{s} \quad (2)$$

$$W_{weeding} = 4.50\beta \frac{w_{weeding}}{s} \quad (3)$$

$$H_{harvesting} = 5.9\beta \frac{h_{harvesting}}{s} \quad (4)$$

where s is the size of the cell in hectare. $C_{clearing}$ is the number of farmer agents employed percell from clearing,$P_{planting}$ is from plantingseeds,$W_{weeding}$ is from weeding and $H_{harvesting}$ is from harvesting the crops. $c_{clearing}$ is thetime required to clear one hectare of forest, which is typically 400hours.$w_{weeding}$ signify how longweeding a one-hectare plot takein hours, which is typically 180 hoursper hectare with hand weeding [15]. We assume that planting, $p_{planting}$, and harvesting,$h_{harvesting}$, take 12 hours each for onehectare [16] [17].

2.2.3. Cattle rustlers

Cattle rustlers are agents that are responsible for the stealing of the Fulani herder's cows and other animals. In Barkin-Ladi,cattle rustlers are part of the Fulani and Berom ethnic groups. The rustlers will steal the cows and convey the cows to other parts of the state or another state within the country to sell. Each cattle rustler in a village rustles within the village territory, where there exist field-based animal locations. In the model, rustling consists of three stages: searching, stealing and selling. During the searching stage, a rustler agent moves within the territory randomly, changing its direction stochastically up to 180^0at every step. A step is a movement from one cell to another. For each movement from one cell to another by a rustler is given by the equation

$$C_{walk} = 3.2\beta h_{walk} \quad (5)$$

where β is the distance covered in km and h_{walk} is the number of hours required to walk through a cell.h_{walk} depends on the size of the cells and the walking speed is assumed to be 3 km per hour. If a rustler agent enters the cell where animals are located, the rustler agent selectively steal cows with more than 1040 kg in weight at a given rustling success rate. If no animal weighing more than 1040 kg is located within a cell, a rustler agent selects the next largest available animals to rustle. Larger animals are preferred as they contain a larger amount of meat and have a higher fat-protein ratio, hence selling at a very high price. A rustler agent continues rustling ifthe number of animals rustled is below the requirementthreshold, or until the total number of rustling trips reaches the predetermined maximum rustling trips. During each rustling trip, a rustler can have rustled up to ten animals, up to a total weight of 10400 kg. For each rustling trip, a herder agent loses some animals. The foregoing process is represented by the equation

$$C_{steal} = 3.6\beta h_{steal} \quad (6)$$

The time required for rustling, $h_{rustled}$ is assumed to be 1 minute per animal.

2.2.3.1 Animal meta-population dynamics due to cattle population change and dispersal

We incorporate 20 out of 237 rustled animals based on herders affected by the highest rustling frequencies. These twenty cattle represent 76% of the total number of cattle rustled. Cattle population change is simulated by a logistic function with carrying capacity and intrinsic population growth rate:

$$\frac{dN_{ij,t}}{dt} = r_i N_{ij,t-1} \frac{N_{ij,t-1}}{(k_{ij} - N_{ij,t-1})} \quad (7)$$

where $N_{ij,t}$ represents the number of animals in the habitat$i$in the habitat j at the time step t, k_{ij} is the carrying capacity of animals in the habitat $j$for the cattle i, and r_i is intrinsic animal population decrease rate for cattle i due to rustling. We set the time step as a year and usethe rate as annual animal population decrease due to rustling. A carrying capacity is assigned to each habitat, which is defined as a set of contiguous cells of the same land cover type (forest, grassland or water). The carrying animal capacity of each habitat is calculated based on the maximum animal population density and the area size of habitat patches:

$$K_{ij} = d_i A_j \quad (8)$$

whereA_j is the size of a habitat j and $d_i$is the population density for species i. Maximum animal population density is estimated from our database by taking the highest density estimates among 104 transects[18][19].

III. MODEL EVALUATION

We evaluate our simulation model in two ways. The first verification is between herders and farmers, while the second verification is between herders and rustlers. In the first verification, herders share the general resource if they are of the same Fulani ethnic group and compete with the indigenous farmers since they are of a different ethnic group. The land resource always is limited and, in such circumstance, the Fulani herders engage in conflict with the indigenous farmers. The conflict can escalate byinvolving other herders within the Fulani ethnic group from other localities within and outside the country whoshare the trouble through collaboration to enhance theirpace of continued existence.

The keymodelloops comprise of herder agentsacclimatizing to the seasonally steeringtransformations in thegrazing surroundings. Seasonal modifications in weather, inthe variety of the quantity of rainfall, decide thepresentcondition of any given habitat according to thathabitat's highestrichness. Each time step is equivalentto a day and the herder agent's employ its presenthabitat toattach to this time increase. As theenvironment permits, herder agents keep away indigenous farmers to move from habitat to habitat to cultivate their land and water to maintain their habitats especially in the dry season. This phenomenon has the capability of creating conflict between the herders and the farmers. In another development, habitatre-growth occurs but at a much slower rate than theherders' grazing reaps from them. This has thepossibility to drive herders into farmers land for the period of such predicament. For example, if a herder agent's physical condition attainsthe distressedphaseowing to the need of feasible graze landor water, herder agents will then take the nearby habitatwith available resources not considering the presence of a farmer agent. It is these infringingactions that areregarded as conflict and the results of all the conflictsare established by the end of each day.

Conflict is analysed by checking herder movement anddetecting of occurrence of trespassing incident. Weconsider an incident as a combat (or opportunity forcombat) between a herder and either another herder ora farmer. Conflict is modelled as two agents in the samehabitat at the end of the movement part of a time step. Conflict(s) can grow over time and potentially involvemultiple herders and farmers. Consequences of anincident depend on participants. When it is betweentwo herders of the same clan, the incident is resolvedpeacefully by averaging hunger and thirst valuesbetween both herders helping one and hurting other.When the conflict is between herders of different clans, the defender's herd size is reduced by damage ratio (aparameter) while the attacker's herd is increased bythose animals. In the meantime, the attacker's hungeris also reduced based on the captured resources.However, both the attacker and defender thirst are notchanged. In farmer and herder situation, farmer isaffected by conflict through the destruction of the farmers' yield by the herders and the farmers in cases of reprisal attacks also kill the cows of the Fulani herder agents which results to herder's herd size isreduced by a damage ratio percentage.

The second verification is the conflict between herder agents and cattle rustler agents. Escalation of conflict occurs only between herders and cattle rustlers who steal the animals of the herders to go and sell for monetary gains. The herder agents believed that rustlers always moved around with all kinds of firearms such as AK-47 guns and rocket launchers, making it virtually unattainable for an ordinary herdsman to confront them. Olaniyan and Yahaya [20] assert that rustling activities in Nigeria have resulted in the theft of a huge number of cows, deaths of people and destruction of property. Daily reports across the northern region have confirmed that cattle rustlings have significantly contributed to the increasing security challenges facing the Nigerian state and seem to have become big business involving the herders, big time syndicates, and heavily armed bandits.

In the event of the theft of cows by rustling that continues over a specifiednumber of steps, which is when the duration reaches a specified number ofsteps, escalation of conflict is initiated. In this case, herder agents will invade the indigenous farmers to unleashed horror on the farmer's agents killing and injuring so many farmer agents. The primary aim of the herderagents is to wreak havoc, attack defenceless communities, leaving behind completely destroyed arable farmlands and corpses of residents.

3.1. Description of the Experiment

To illustrate the robustness and fidelity of the model in relation to real world phenomena, we have limited our experiments to the relationship between the number of habitats, the total population and the level of dominance of one of the ethnic groups. The ethnic groups in the area in this case are the Fulani ethnic group and the indigenous Berom ethnic farmers. We perform a series of experiments to explore the robustness and fidelity of the model. This procedure is achieved by varying the number of habitats of land in six steps between 50-300. The experiment focused on the linkages between land reductions due to increase in population and conflict. The carrying capacity of a parcel is the number of farmers and the quantity of livestock that the habitat can support without being damaged and it is expressed in hectares. We have established a minimum surface area of a field entity at one hectare, or $10{,}000m^2$.

In the first experiment, we introduce a small number of herders in the habitats which corresponds to a category whose herd size represents a viability threshold for family farms. Also, a small number of farmers is introduced here in the parcel which corresponds to a category whose yields represents a viability threshold for family farms. Small number of cattle rustlers is also introduced here. In the first experiment the frequency of conflict is one of every 15 years. In the second experiment, we introduce a medium size number of herders in the habitat, a medium of farmers in the habitat and a medium number of cattle rustlers. The frequency of conflict between herder agents and farmer agents as well as between agents and cattle rustlers to three of every 15 years with 20% reduction in space due to increase population of farmers, herders and livestock within a particular habitat. In the third experiment, we introduce a large number of herders and farmers within a particular habitat. Also, a large number of cattle rustlers within a habitat is also introduced. We also increase the intensity of conflicts to a 50% reduction in space within a habitat of each 15-year cycle. For each of these experiments, we conduct five 100 years runs. We start the first run being the experiment with a small number of herder agents, farmer agents and a small number of cattle rustler agents. In this case, the number of herder agents is 100, the number of farmer agents is 200 and the number of cattle rustler agents is 10. In the second run being the second experiment with a medium number of herders, farmers and cattle rustler agents, we used 200 herders, 300 farmers and 20 rustlers. In the third run being the third experiment with a large number of herder agents, farmer agents and cattle rustler agent, we used 300 for herder agent, 400 for farmer agents and 30 for cattle rustler agents. For each of these experiments we conduct five 100-year runs.

IV. RESULTS

4.1 Herder-Farmer conflict and carrying capacity

The base run has no conflict occurrence. It begins with 100 herders, 200 farmers and 10 cattle rustlers. The number increases steadily in the first 120 months (10 years) until the population reaches the environmental carrying capacity imposed by limited vegetation, water and conflict. Occurrences of conflict separated by long time periods give better opportunity for recovery than when conflict occurrence is separated by short-periods or in sequence. However, when the intensity of conflict increases, surviving farmers and herders comes in question as shown in the Figures 3, 4 and 5.

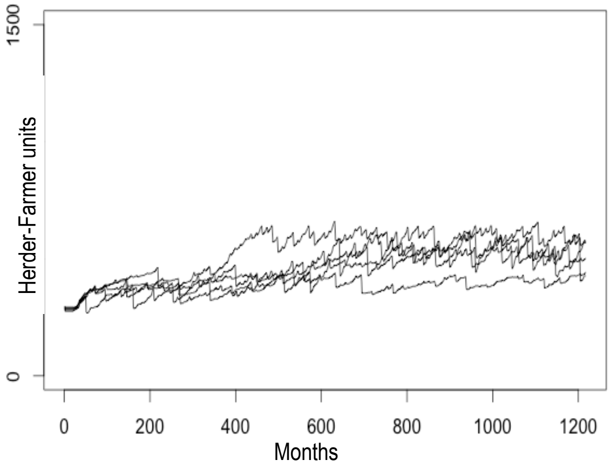

Figure 3: Population at the based with 0% Parcel Reduction

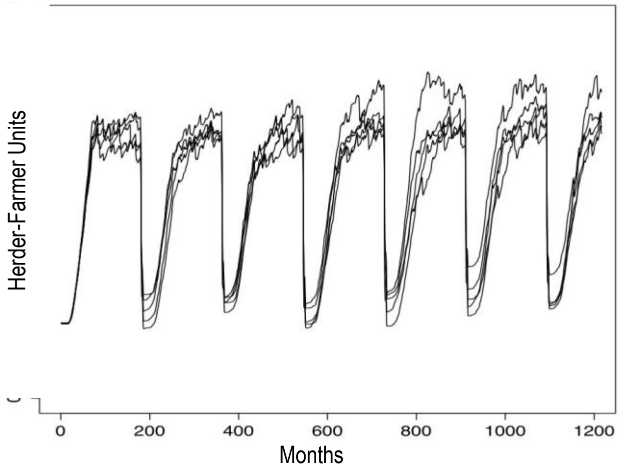

Figure 4: Population with 20% Parcel Reduction in

Every 15 years for the last 5 consecutive Years

4.2. Herder-Cattle rustler conflicts

The impact of the damaged of crop yields of farmer agents and the theft of cows by cattle rustler agents causes a significant change on the level of conflict in the system. In the base run with no

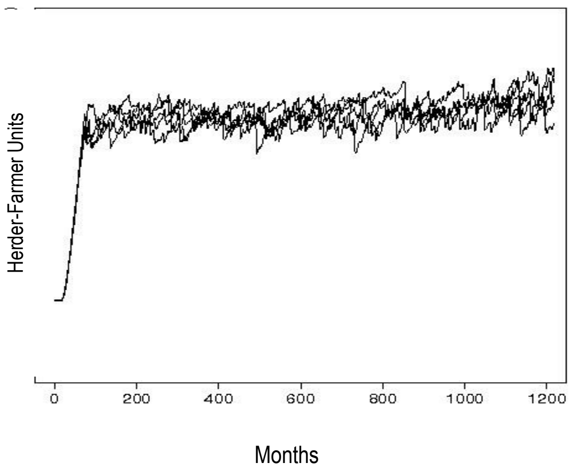

Figure 5: Population with 50% Parcel Reduction in Every 15 Years

reduction in space, more sporadic conflict was observed. However, as the theft of cows occurs in subsequent experiments, significant level of conflict occurred between farmers and herders sequel to the recovery stage where herder agents dwell within the habitats with their livestock. Figures 6-8 further illustrates the foregoing assertions.

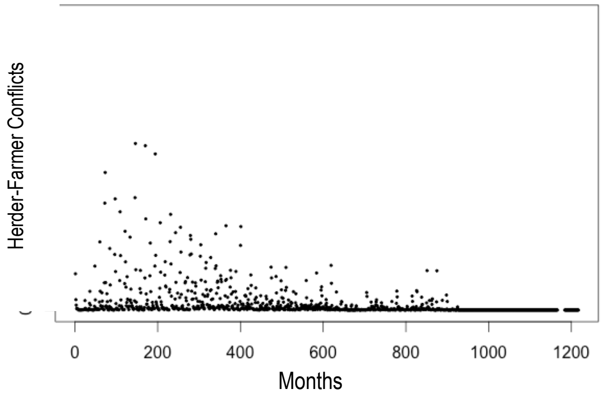

Figure 6: Conflict with 0% Parcel Reduction

V. DISCUSSION

In this paper, our simulations depict the effectiveness of *ABM* in understanding the interactions and dynamics of complex systems. We have modelled interactions of social and ecological systems for indigenous peoples and their lands with the interaction of Fulani herdsmen and their livestock on the

indigenous people's lands. We also incorporate the activities of cattle rustlers who are involve in rustling the cows of the herders as illustrated in Figures 9-11. We modelled how these socio-ecological interactions have resulted into conflicts between the Fulani herdsmen and the indigenous farmers. These conflicts have emerged as a major security challenge in Nigeria and it has consequences for the socio-economic, political, cultural and psychological spheres of society. At the economic level, it constitutes a major threat to the livelihood of herders and those who depend on cows for survival as well as the indigenous farmers since they also depend on their crops for survival. At the socio-political levels, these conflicts have resulted in death, loss, and the destruction of lives and properties, thereby disturbing peace and security.

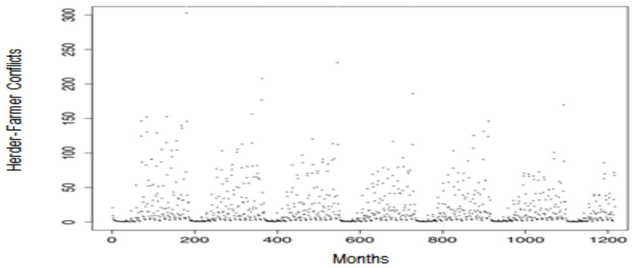

Figure 7:Conflicts with 20% Parcel Reduction in Every 15 Years for the last 5 consecutive Years

Years for the last 5 consecutive Years

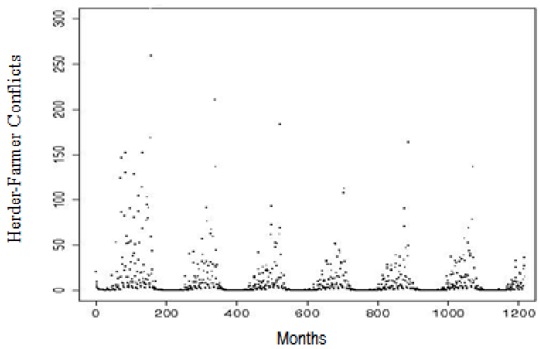

Figure 8: Conflicts with 50% Parcel Reduction in Every 15 Years

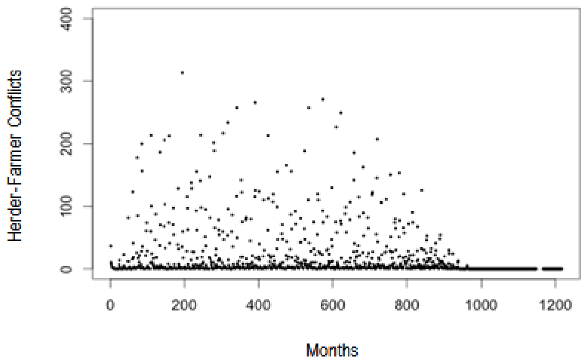

Figure 9: Conflict with 10 Cattle Rustler Agents Involve in the Theft of Cows

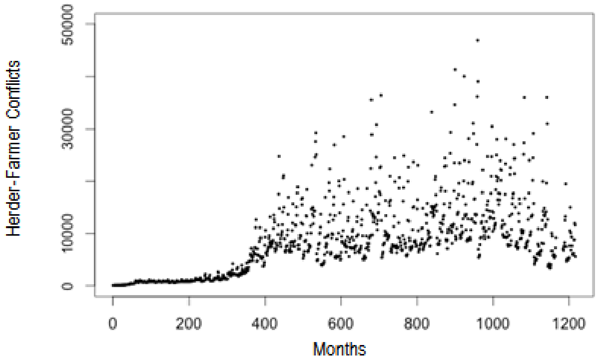

Figure 10: Conflict with 20 Cattle Rustler Agents involve in the Theft of Cows

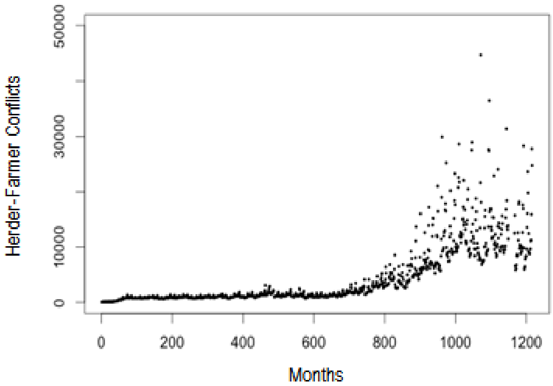

Figure 11: Conflicts with 30 Cattle Rustler Agents involve in the Theft of Cows

VI. CONCLUSION

The outcomes emerging from our experiments permit us to foresee the possibilities that *ABMs* offer in event scenarios for overseeingcollective space and resources. The growth of such a tool is very important because it is a crucial step in fashioning a frequent and affiliated approach to agro-ecological systems and socio-economic systems for the sustainable running of space, resources and conflicts.

Outcomes from simulations analysis also revealed that our model is robust to the extensive ranges of unknown parameters, when the model is executed with the affluent data set from field study, remote sensing and literature. Human and livestock population in an indigenous communityinfluences overall environmental condition in the area. Our model illustrates the potential to examine the sustainability of indigenous communities and their lands with a more holistic framework that integrates major feedbacks for maintaining sustainable livelihoods and lands. Even though we considered a very simple behaviour in our model, we can draw conclusions concerning behaviour representation in modelling and simulation.

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