European Journal of Geography

Volume 12, Issue 2, pp. 052 - 073

Article Info
Accepted: 30/09/2021
Corresponding Author: * kurwakumiree@tut.ac.za
DOI: https://doi.org/10.48088/ejg.e.kur.12.2.052.073

Global Perspectives
Research Article

Informal cadastres as enabling tools for disaster risk management

Edward **KURWAKUMIRE**[1*],
Shelter **KUZHAZHA**[2] &
Paul **MUCHECHETERE**[3]

[1] Tshwane University of Technology, South Africa
[2] IIE MSA, South Africa
[3] Midlands State University, Zimbabwe

Keywords

Disaster Resilience, Disaster Risk Management, Land Tenure, Informal Cadastre, Informal Settlements, Informal Tenure, Social Tenure Domain Model

Abstract

Disaster Risk Management requires up-to-date land information availed through the cadastre. Informal settlements are often located in disaster prone areas. Having up-to-date land information about these informal settlements is one step towards disaster preparedness and building community resilience in the highway towards sustainable development. This study designs conceptual models using unified modelling language (UML) for an informal cadastre for recording land information pertinent to disaster risk management based on a South African case study. The results demonstrate that land tenure relationships in informal settlements can be mapped using the Social Tenure Domain Model (STDM). The importance of disaster information is that it provides communities with information to tackle disasters and improve in their capabilities to handle them. With such information, the disaster risk can be minimised. This study is aligned to Sustainable Development Goals (SDGs) 1 and 3. The linkage between spatial data, disaster resilience and the SDGs is explored.

The publication of the European Journal of Geography (EJG) is based on the European Association of Geographers' goal to make European Geography a worldwide reference and standard. Thus, the scope of the EJG is to publish original and innovative papers that will substantially improve, in a theoretical, conceptual or empirical way the quality of research, learning, teaching and applying geography, as well as in promoting the significance of geography as a discipline. Submissions are encouraged to have a European dimension. The European Journal of Geography is a peer-reviewed open access journal and is published quarterly.

1. INTRODUCTION

The ever-increasing urban population is resulting in a rise in demand for affordable housing (Safarabadi et al., 2015). All citizens have a right to adequate housing and against eviction from their places of residence according to Chapter 2: Section 26(1) and Section 26(3) of the Constitution of the Republic of South Africa (RSA, 1996). Un-Habitat concurs that housing is a basic need and should be available to all (Un-Habitat, 2011). While this protects the public, this presents a dilemma of informal settlement growth that continues to escalate in South Africa (Huchzermeyer, 2006). The increase in slums is partly dependent on failure to provide adequate housing by local governments and increasing poverty (Hofmann et al, 2015; Safarabadi et al., 2015) and inherited inequalities regarding access to economic resources (Huchzermeyer and Karam, 2006) and urban sprawl. Urban sprawl focuses on land transformation activities occurring on the periphery of urban areas or in the peri-urban areas (Wadduwage and Millington, 2019). Uncontrolled urbanization has resulted in multiple problems in many cities worldwide that include substandard living conditions, waste management, water, air and noise pollution (Tamilenthi and Baskaran, 2013). Unprecedented urbanisation coupled with a refugee crisis can impact negatively on the ability for municipalities to manage economic growth, social welfare and service delivery in their cities (Teoman, 2018) and often leads to the formation of slums. Population growth is resulting in degradation of the environment and increased desertification (Jahantab et al, 2017).

Informal settlements are a growing phenomenon worldwide (Safarabadi et al., 2015). They normally serve low-income residents but often bring about multiple negative effects on the environment. In some countries informal settlements are mostly concentrated in the urban periphery. In South Africa's context, the sprawling mostly happens inland than in the peri-urban spaces due to specific factors such as: proximity to work opportunities, distance to work, distance to amenities, distance to existing infrastructure and availability of a water source such as a river among others.

The low-quality material that is used to construct houses and structures in informal settlements such as galvanized zinc sheets and wooden boards reflect poverty and unequal access to economic resources. These building materials offer the least protection from the weather elements and natural disasters that strike because of climate change. Informal settlements house the majority of the poor and low-income earners. This group of people is exposed to poverty and is at high risk of contracting diseases by nature of the environment they dwell in warehouses are cramped together (see figure 1) to cater for the high population density. The proximity of houses and therefore people increase the transference of diseases and disasters such as fire from one household to another and one property to another respectively. There lacks proper infrastructure such as paved roads, water and sanitation before informal settlements upgrades have been affected, and normally after several service delivery protests. Local governments should design effective policies for managing informal settlements. The improvement of quality of life and living standards of all citizens should be the priority of any municipality (Nyussupova et al., 2017).

Informal settlements can be identified or detected through analysing high resolution multi-temporal aerial photography and satellite imagery as such images can be analysed to detect urban changes (Tamilenthi and Baskaran, 2013). The patterns of houses and roofing material often makes it easy to identify them on a true colour photograph (see figure 1). On multispectral satellite imagery, image classification has to be carried out to identify and quantify the extent of informal settlements through assessment of land use and land cover change. Multi-temporal remote sensing imagery enable land use change detection to be executed in a timely and cost-effective manner

(Tamilenthi and Baskaran, 2013). Remote sensing imagery is used in quantifying land use change in India using Landsat TM imagery by (Vishwakarma et al, 2016). Figure 3 demonstrates land use and land cover change in Booysens, Pretoria due to the mushrooming and expansion on an informal settlement over a number of years resulting in a once vegetated area now occupied by households. Land use describes mankind's activities on land (Vishwakarma et al, 2016).

Figure 1. Image of Informal Settlement

Source: Google Earth (25.722032°S 28.119801°E)

These informal settlements are often located in restricted open spaces such as wetlands and flood plains which are disaster risk prone areas (Doberstein and Stager, 2013; Napier and Margot, 2002; McCallin et al, 2015) and sometimes on mountain sides where there is risk of house being washed away during storms. The most prominent disasters are due to floods and fire. Typical examples include flooding in Cape Town (Somdyala, 2019) and Durban (Singh, 2019); and fire outbreaks in Alexandra (Ngqakamba, 2019) that has resulted in loss of lives and property. Present day, natural disasters such as floods are occurring with increasing frequency and intensity (Bello and Aina, 2014; Kurwakumire et al, 2019) and result in loss of life and devastated livelihoods (Sawada and Takasaki, 2017) with poverty eventually the resulting by-product. Disasters impact negatively on vulnerable communities in informal settlements (Tas et al, 2013) where less formal and often weak land tenure arrangements exist (McCallin et al, 2015). Informal settlement dwellers are often evicted by municipalities from their places of residence (Shatkin, 2004) due to their insecure land rights.

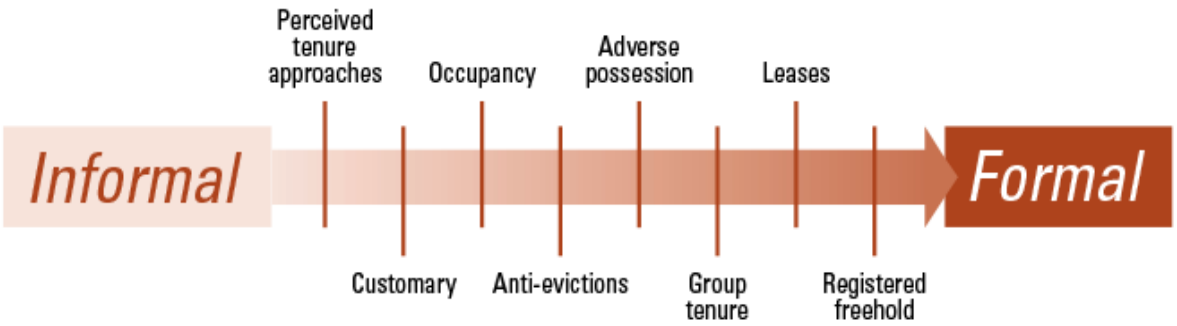
These areas seldom lack adequate land information (Lengoiboni et al, 2019) for use in disaster resilience activities (Unger et al, 2019) and effecting interventions for improving living conditions (Hofmann et al, 2008) such as sanitation (Hasan, 2006; McFarlane, 2008), clean water and roads. As informal settlements fall under the informal land rights, there often does not exist methods for documenting rights as is the case with some customary tenure systems (Kurwakumire, 2013, Sylia et al, 2018, Lengoiboni et al, 2019). This is partly due to informal settlements being considered as illegal or extra-legal by virtue of their position in the continuum of land rights (see figure 2) and lack of recognition by statutes (Whittal, 2014; Mutisya and Yarime, 2011) and municipal systems (Shatkin, 2004) and weak security of tenure (Hurskainen and Pellikka, 2004).

This is in the wake of different parts of the world being in the information society and technology for gathering land information is becoming cheaper and widely available.

Spatial data such as maps are increasingly becoming available in digital form enabling remote access by users through smart devices (Evangelidis et al 2018). Maps are important for decision making as they provide spatial identity. Maps are important tools for making decisions and policy interventions for informal settlements. Cadastral maps, in this case, depict the location and extend of each household in the informal settlement and other socio-economic data can be added as layers to each land parcel identified and defined. Cadastral maps are the base layer in land information systems and spatial data infrastructures. Such infrastructures are necessary for ensuring efficient access to spatial information.

Geographical Information Systems (GIS) can be used to map electrical assets using high-resolution satellite imagery (Rai and Singh, 2016). In the same manner, it can be employed in mapping households and their nature for the cadastre for disaster management. Information that can be modelled include wall types and roof covers for buildings, municipal services, and public infrastructure. In this study, satellite imagery is used in mapping boundaries. The application of satellite images in boundary mapping is detailed in (Lemmen et al, 2009). In other studies, GIS has been used for mapping and analysing urban ecosystem services (Nedkov et al, 2018) and in monitoring of epidemics for example leptospirosis in (Ferreira and Marujo-Ferreira, 2019). Similarly, GIS can be employed in modelling the spread of water borne diseases such as cholera, dysentery and malaria based on socio-economic information that is recorded, stored, and managed in an informal cadastre. This information is useful in controlling and containing the spread of the pandemics through allocating necessary interventions in the identified hotspots. In the period 2020 to 2021 there has been wide use of GIS in monitoring the spread of the Covid19 pandemic and to direct government policy in mitigating its impacts.

Figure 2. Continuum of Land Rights Model



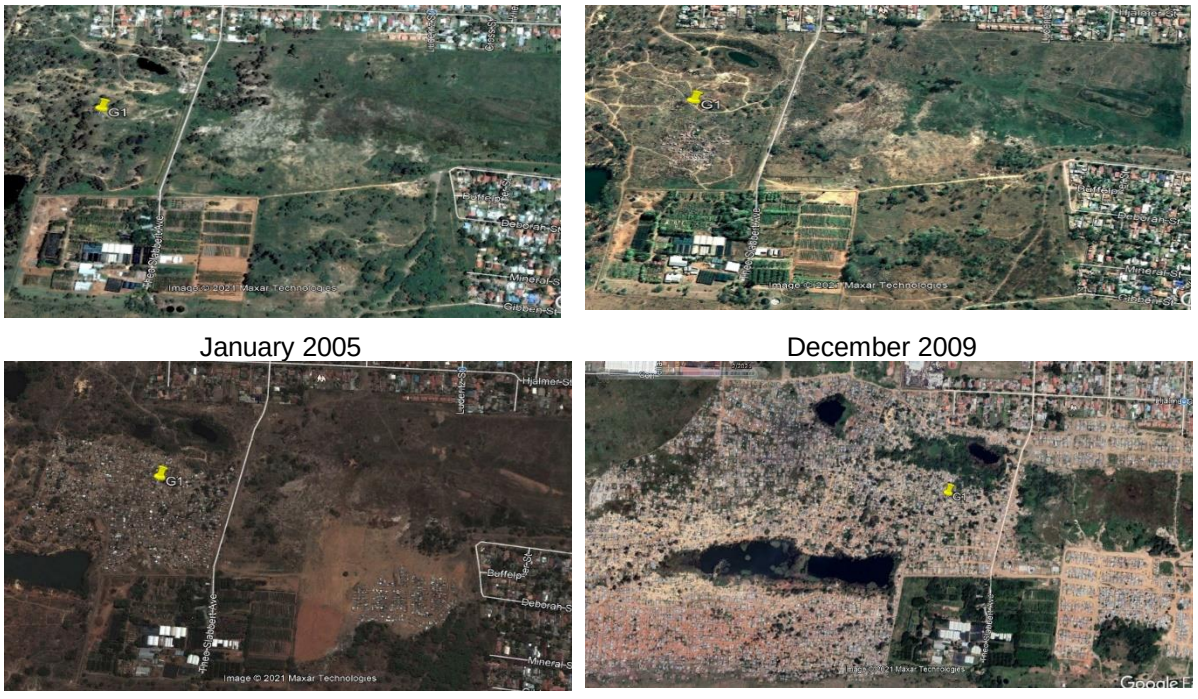
Source: Un-Habitat, 2011

Informal settlements imply that such areas are under informal tenure in which rights to land are not formally recognized (Augustinus 2010; Whittal 2014). Informal land rights fall under the continuum of rights (UN- Habitat 2018) and can be represented using the social tenure domain model (Augustinus 2010; Lemmen et al, 2007; Lemmen 2010). Normally no policies about attaining the sustainable development goals exist in these areas. Interventions are often affected on need and non-permanent basis, for example, after the surprise strike of a natural disaster or disease outbreak. Informal settlements are beyond the scope of the spatial development framework of the city yet in reality, they coexist with other planned suburbs. Spatial data plays an important role in targeting interventions (Craglia and Johnston, 2004), improving service delivery

(Passalent et al, 2013) and designing and implementation of policies (Scott and Rajabifard, 2017) that can aid in achieving a sustainable future in informal settlements.

Currently informal settlements have little or no land information available as they are not formally recognized by municipalities. The inhabitants of informal settlements are more vulnerable to disaster risk such as floods (Doberstein and Stager, 2013; Tas et al, 2013; Abunyewah, 2018) by virtue of their existence on unplanned urban spaces or restricted places by virtue of their environmental characteristics. Without adequate land information, authorities are not able to effect rapid decision making (Hurskainen and Pellikka, 2004) and respond to disasters, hence the need to record land information (Unger et al, 2019) about informal settlements and their dwellers. Informal settlements also introduce land use and cover change that result in deforestation (see figure 3) and sometimes land degradation. Land use change detection can be used to identify urban sprawl. This is achieved through classifying and analysing satellite imagery taken over different years (Gonzalez Gonzalez, 2017). Within land administration literature there has been a drive towards formalizing informal tenure including the recording of land rights (Kurwakumire, 2013; Whittal 2014). This has often been achieved through land titling in some developing countries.

Figure 3. Land cover change between 2005 and 2021 due to Informal Settlement growth



Source: Google Earth

The Social Tenure Domain Model (STDM) was developed to aid developing countries with little or no spatial coverage, customary tenure and informal settlements in recording land rights (Lemmen, et al 2007). The purpose of the STDM is to model all land rights regardless of their position in the continuum of land rights or their level of legitimacy and or legality (Lemmen et al, 2007; Lemmen, 2010). The official recording of land rights is an initial step to ensure equality and access to economic resources

which can reduce poverty (Mendola and Simtowe, 2015) in accordance with sustainable development goal 1. This process can be combined with the collection of disaster risk planning to assist with disaster response and management tasks. The disasters include pandemics that may spread in informal settlements. A focus towards achieving the sustainable development goals would see informal settlement dwellers improving on their economic potential thus reducing poverty and living in healthier environments. Land registration and titling can result in the establishment of land markets (Deininger and Binswanger, 1999; Galiani and Schargrodsky, 2010) that attract other forms of investments.

The sustainable development goals (SDGs) bring attention towards poverty eradication and improving the quality of life of citizens through several interventions to include access to health, education and decent homes (Nyussupova et al., 2017). The sustainable development goals can provide direction of policy for informal settlements with the guidance of available land information. In order to improve management of socio-economic development in an area, it is crucial to map, visualise and monitor socio-geographical using geographical indicators (Nyussupova et al., 2017). There has been inadequate research about the development of cadastres for informal settlements and furthermore the linkage towards disaster risk management and attainment of the sustainable development goals. The aim of this paper is to design conceptual models for an informal cadastre for collecting, storing and managing informal settlement cadastral and disaster risk information for the purposes of attaining sustainable development goals 1 and 3. A framework showing the linkage between the informal cadastre, disaster management and sustainable development is discussed.

2. RELATED WORK

This section discusses prior literature on issues and vulnerabilities faced by informal settlement inhabitants, sustainable development and cadastres.

2.1 Informal Settlements

Informal settlements face challenges of disease and other epidemics by nature of the locations they exist, often wetlands in South Africa and seldom inadequate sanitation (Taing et al, 2013) and water reticulation infrastructure. When there is above average rainfall, these areas flood and bring with them several diseases. When there are actual floods, informal settlement dwellers have higher risk to loosing property and becoming homeless. Their houses are very closely located (Hofmann et al, 2015) and in most cases made of timber in the interior which increases the risks of fire. Fires start due to overloading of electricity transformers as dwellers make illegal connections of electricity to their houses. The lack of piped water, proper sanitation and refuse collection brings a wide array of diseases. Grass is not cut, adding mosquitos and possibility of malaria to possible outbreaks. There are no health centers within the settlements. Other challenges include crime and environmental degradation (Onyekachi, 2014) and a wide array of diseases (David et al, 2007). The lack of cadastral data and address data makes it a challenge if not impossible for emergency services such as ambulances to promptly react to emergencies. If all these vulnerabilities and their magnitudes are mapped, authorities can in principle develop interventions and strategies for eradication in the event of actual outbreaks. This requires spatial data of the settlements so that post disaster strategies can be effected.

2.2 Sustainable Development

Sustainable development is about exploitation of resources in manner than ensures survival of future generations. It can be extended to the design and implementation of policies, strategies and interventions in a manner that solves problems for a relatively long time. Informal settlements face many challenges in form of disaster risks and vulnerabilities which require sustainable solutions. Informal settlements need to build community resilience which enables them to manage, cope and recover in the event of disasters striking (Adger et al, 2005). Informal settlements have grown partly due to the failure by governments to provide adequate affordable housing and inequity in access to economic resources (Huchzermeyer and Karam, 2006; Hofmann et al, 2015). The attainment of sustainable development is linked to the achievement of the sustainable development goals. This study is aligned with SDGs 1 and 3. To achieve these goals, there is need to up-to-date land information complimented by disaster risk information that is spatially referenced. This spatial data will aid all agencies interested in effecting interventions in targeting them where they are needed most and in designing the relevant policy instruments (Scott and Rajabifard, 2017). Accurate spatial data plays an important role in targeting interventions (Craglia and Johnston, 2004) when conducting problem solving. Spatial Data Infrastructures (SDIs) provide linkage to geographic information by different users (Otero and Torres, 2017).

2.3 Cadastres and Land Registration

A cadastre is an official record of land information based on the land parcel and normally exists in areas of formal tenure such as freehold. Cadastral data is the most important component in the cadastre as it depicts boundaries of all land parcels. A land parcel can be associated with land use activities and ownership (FIG, 1995). The cadastral layer links a person to a particular geographical location in space (Henssen, 1995). In the context of this study, the cadastral layer defines the boundaries of each land parcel in the informal settlement as well as the end of the whole informal settlement. The cadastre plays and important role in improving land administration and management.

2.3.1 Boundary Mapping

There are two types of boundaries that are considered in cadastral surveying: Fixed and General Boundaries. Fixed boundaries are accurate delimitations determined by high precision surveying instruments such as Total Stations and Global Navigation Satellite System positioning equipment. With these instruments, sub-centimeter accuracy for positioning of boundary beacons is achieved. Monuments placed in the position of beacons to mark boundaries are often 12mm iron pegs in concrete. Fixed boundaries are stored as coordinates available in a survey diagram of the property in question. General boundaries on the other hand are often less accurate but relatively inexpensive to map. They use natural features and, in most cases, manmade fences to depict boundaries. A hedge for example, can be used as a boundary between two properties or a tree can be used as a beacon for a corner point. The challenge with general boundaries is that they are not always fixed as for example, hedges grow on either side of properties and the actual boundary line eventually shifts. General boundaries are not stored as coordinates but are based on the knowledge of the property owners and the community locals (Kurwakumire and Chaminama, 2012). To speed up land registration, satellite images (see Figure 1) can be used to extract general

boundaries. Satellite images provide a pro-poor and low cost method of surveying cadastral boundaries as opposed to the expensive conventional approaches of fixed boundaries (van der Molen, 2005; Lemmen et al, 2009). The traced boundaries need to be confirmed by neighboring parties in a participatory land registration approach (Kurwakumire, 2013).

2.3.2 Continuum of Land Rights

The continuum of land rights (see figure 2) classifies land tenure arrangements from formal to informal which translates to most secure to least secure (Un-Habitat, 2011; Whittal, 2014). Formal tenure arrangements are properly registered and documented at the cadastral and deeds offices and are based on fixed boundaries and have supporting legislation. Informal land rights are largely undocumented (Lengoiboni et al, 2019; Morales et al, 2019), and employ general boundaries which are often unmeasured. In some cases, municipalities do not recognize the rights, as they are considered 'illegal' or in other terminology 'extra-legal'. Citizens with weak tenure arrangements are often the most vulnerable to disaster risk (Tas et al, 2013; Abunyewah, 2018). They have high risk of extended poverty due to their likelihood of being evicted by city authorities from their homes, when they are already poor.

2.4 Land Information Infrastructure Design

While there is wide research in developing cadastral information systems which are also referred to land information infrastructures, there is wide consensus about restraining from reinventing the wheel when designing systems. This has seen the development of frameworks and conceptual schemas for designing land information infrastructures such as the core cadastral domain model (van Oosterom et al, 2006), social tenure domain model (Lemmen et al., 2007; Lemmen, 2010) and the land administration domain model (Tjia and Coetzee, 2013; Lemmen et al, 2015). The other aim of these models was to provide sustainable solutions to land administration challenges faced particularly by the developing world. These conceptual schema can be adapted to suit different contexts and country tenure arrangements as there is no one-size-fits-all system in land information infrastructures. The social tenure domain model was specifically developed to map and register rights for less formal tenure arrangements (Augustinus, 2010; Lemmen, 2010). It covers communal areas and informal settlements hence its application in this study. The social tenure domain model has been successfully applied in mapping family tenure in Trinidad and Tobago by (Griffith-Charles, 2011).

2.5 Highlights

Informal settlements fall on the informal section of the continuum of rights model. This means they are characterized by insecure and undocumented rights which translate normally to absence of land information and formal cadastres. Informal settlement dwellers face high risks of disasters such as floods and fires with great exposure to epidemics due to inadequate sanitation and refuse collection and sometimes lack of clean drinking water. To reduce vulnerabilities, there is need to build community resilience. The first step is to collect and present cadastral and disaster risk information about the informal settlements. This information is then used for managing disasters, targeting interventions, and designing sustainable development policy frameworks. The social tenure domain model can be used to map the land rights as it

was designed for mapping less formal tenure arrangements. Informal settlements employ general boundaries which can be extracted from satellite images to generate the cadastral layer.

3. CASE STUDY AND METHODOLOGY

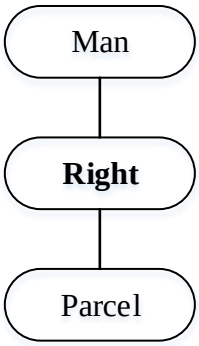
The case study adopted for this article is Gomorrah informal settlement in Pretoria, South Africa shown in figures 1 and 4, located in a disaster risk area. A lost cost method is adopted which employs open-source software for mapping boundaries. Property boundaries are determined through digitizing Google Earth imagery using AutoCAD software.

Figure 4: Gomorrah Informal Settlement

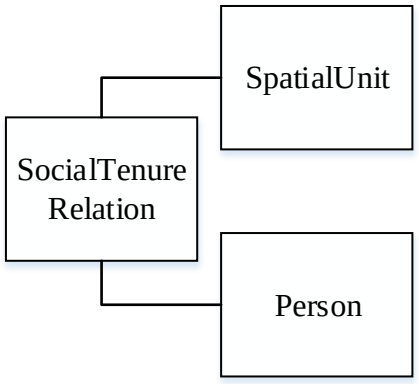
Gomorrah Informal Settlement, Pretoria (Source: Google Earth)

New Land Claim in Gomorrah Informal Settlement [Photograph taken on 5 August 2019 at location (-25.722422, 28.126570)]

Figure 5: Land Tenure Models



Subject-Object-Right Model (Henssen, 1995)



STDM (Lemmen, 2007; Augustinus, 2010)

The database modelling or conceptual schema is done using Unified Modelling Language. The recording of land rights is done based on the subject-object-right model for land tenure in (Henssen, 1995) which is the core of the STDM presented in (Lemmen et al, 2007) and applied in (Griffith-Charles, 2011). An informal approach to registering land rights is recommended as informal settlements are normally considered as illegal settlements (Whittal, 2014; Mutisya and Yarime, 2011) and formal methods of recording rights that require boundary surveys are often too expensive hence the presentation of a pro poor rights registration method (van der Molen, 2005; Augustinus, 2010; Lemmen,

2010; Kurwakumire, 2013) for documenting land information in informal settlements in this study.

4. RESULTS

4.1 Low Cost Boundary Mapping for Informal Settlements

Fixed boundary surveys are among the most expensive aspects of land rights registration (Kurwakumire and Chaminama, 2012) and often their costs are beyond the reach of the poor (van der Molen, 2005). Informal settlements are of a social nature as their creation results from the need to solve a societal problem of inadequate housing delivery, poverty and inequality in access to economic resources. In the creation of informal settlements, neighbors agree on their plot boundaries on the ground and use fences to denote their boundaries (see figures 1 and 7). These general boundaries where digitized used AutoCAD resulting in the diagram presented as figure 6. The same applies to land held under customary tenure (Kurwakumire, 2013; Lengoiboni et al, 2019). Since boundary surveys are expensive (van der Molen, 2005; Kurwakumire and Chaminama, 2012) and informal settlements are considered as illegal settlements (Mutisya and Yarime, 2011), boundary extraction from freely available google earth imagery is utilized to design the cadastral layer. Boundaries have been extracted from satellite imagery in (Lemmen et al, 2009). A GPS coordinate for the centroid of the parcel is extracted and used for navigation and network analysis functions. The WGS84 UTM Zone 35S : EPSG:32735 projection with parameters { Extent: 24.00, -80.00, 30.00, 0.00; Proj4: +proj=utm +zone=35 +south +datum=WGS84 +units=m +no_defs} was employed with the ground control points (see Figure 6).

4.2 Abstract Schema for Informal Cadastre

This study presents an informal cadastre in the sense that the area under study is under informal tenure and the settlement has not been sanctioned by the municipality. Such areas fall under social tenure and thus can be documented and modelled (Lemmen et al, 2007; Lemmen, 2010) using a database approach. This cadastre is the basis for gathering information that can be used in disaster risk management. A cadastral layer for a portion of the area under study is depicted in Figure 5. While this exercise can be done using satellite imagery, there is still need to confirm some boundaries through fieldwork since boundary marking features are not always visible from the images. Unified modelling language (UML) is used in developing the preliminary conceptual schema of the informal cadastre presented in figure 7 showing the relationship between the plot (spatial unit), land rights (social tenure relation) and the person or subject as illustrated in (Lemmen et al, 2007). UML has been used in modelling cadastral systems in (Kurwakumire, 2013; Tjia and Coetzee 2013; van Oosterom et al. 2006; Griffith-Charles 2011). The spatial unit is the informally subdivided plot comprising the plot and buildings. The primary identifier is the parcelid. Stand numbers (standNo) are allocated incrementally and can have a prefix or suffix linked to the name or section of the informal settlement for easy identification. Street names can be assigned by informal settlement dwellers of a particular street.

Figure 6: Extracted Cadastral Layer for Gomorrah Informal Settlement

Image Assessment:

1. Unpaved mud roads
2. Majority of structures constructed using metal sheets
3. No electricity power lines
4. Area covered = 100 X 50 metres
5. Maximum (X,Y) = (612380m,7154650m)
6. Minimum (X,Y) = (612280m,7154600m)

Ground Control Points:

	Northing	Easting
G1	7154650.42 m S	612296.58 m E
G2	7154645.30 m S	612376.06 m E
G3	7154604.38 m S	612371.63 m E
G4	7154620.71 m S	612286.75 m E

The land use code relates to the primary activity on the plot which can be residential, business, non – governmental organisation and day care. Business covers small grocery shops, car washes, barbers and saloons in the informal settlement. Under non-government organisations, a clinic may be set up to facilitate immunization of children.

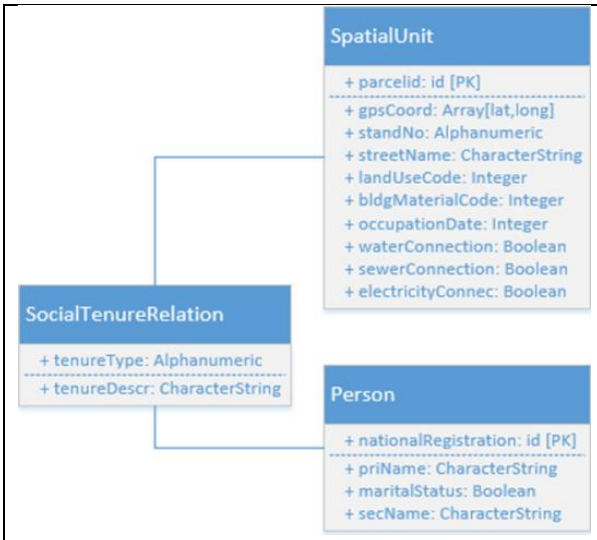
The social tenure relation represents the actual rights that the informal settlement dwellers have even though they are on the informal side of the continuum of rights. The rights are mainly for plot owner and rental assigned as informalPlotOwner and informalPlotRental respectively. The person is the natural or non-natural person who is holding rights to the plot or property within a given plot (Lemmen et al, 2007) in accordance with the social tenure domain model. The natural person is an individual or family who have rights to a plot or section of the property in a plot in the informal settlement. The non-natural person represents the non-governmental organisations who try to aid informal settlement dwellers especially in the areas of health and day care centres.

5. TOWARDS A COMPREHENSIVE CONCEPTUAL SCHEMA

The model based on the subject-object-rights that translates to ‘person - spatial unit - social tenure relation’ (see figure 7) and based on the land tenure model by (Henssen 1995) provides a limited view of land rights. Figure 7 however, provides value addition through presenting a social tenure situation for informal settlements. This provides a basis for recording land information based on a database approach. In this section the model presented in figure 7 is expanded to incorporate aspects in the social

tenure domain model and new classes related to disaster management (see figures 8, 9 and 10).

Figure 7: Abstract Conceptual Schema for Informal Settlement Land Rights

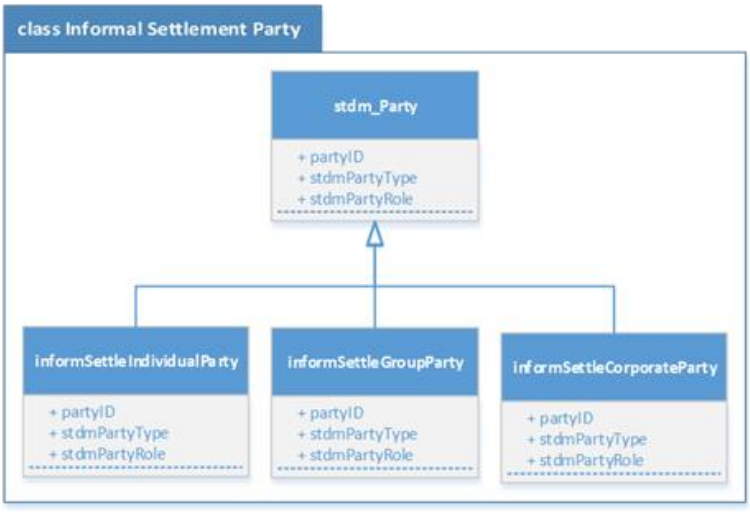


STDM Adaptation for Informal Settlements [Adapted from (Lemmen et al. 2007; Henssen 1995)]

Houses or Structures in Gomorrah Informal Settlement [Photograph taken on 5 August 2019]

Restricted open space in a flood plain adjacent to Gomorrah Informal Settlement [Photograph taken 5 August 2019 at location (-25.721516, 28.126665)]

Figure 8: Informal Settlement Party Class – Modified from (Griffith-Charles 2011)



The informal settlement party class (see figure 8) describes the different kinds of owners, which are individual, group, multiple group and corporate. Individual refers to one person registering occupancy to the property while groups are families. Multiple groups relates to a situation where there are many families on a single property. Each family in this case, each family possesses a share of the total rights including the rights

of passage. This is the case when the owner constructs additional structures for rental purposes or the property is used exhaustively for rental purposes. This class is an expansion of the person class in Figure 7.

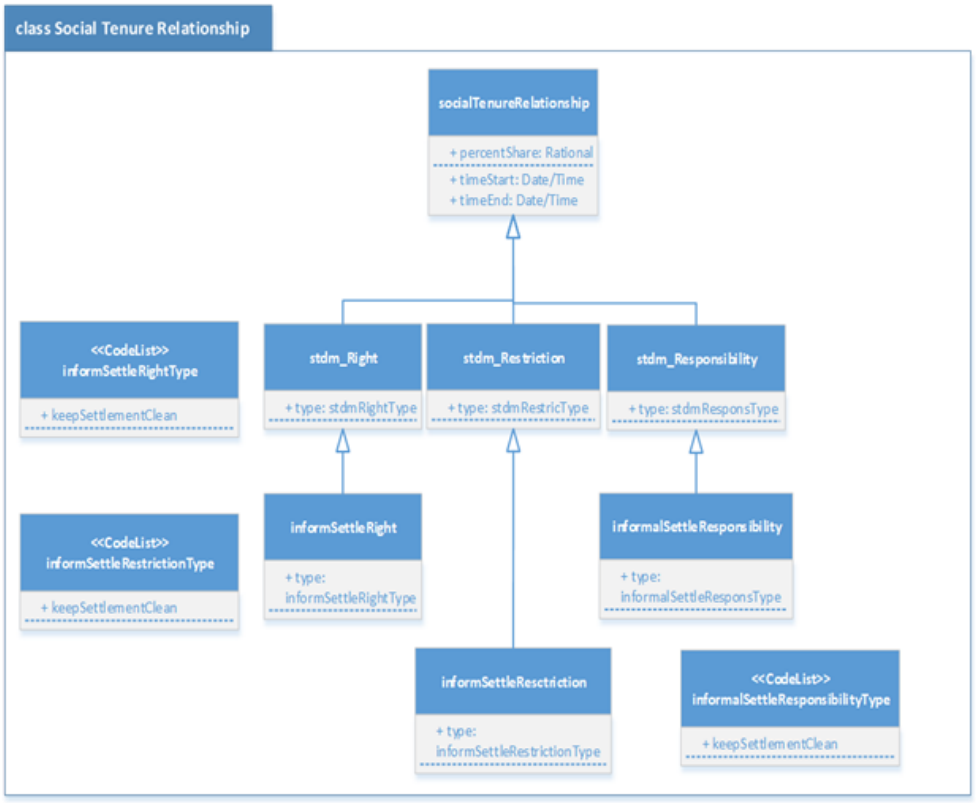
Table 1. Restrictions Class

Restrictions Class	
Attribute	**Options**
restricType	30m buffer from existing properties
	No construction on wetlands
	No construction biodiversity areas
	No construction in parks
	No construction over utility pipes
	No construction in electricity servitudes
	Existing road buffers
	No firewood harvesting

Table 2. Responsibilities Class

Responsibilities Class	
Attribute	**Options**
responType	Settlement cleanliness
	Infrastructure vandalism
	Air pollution

Figure 9: Social Tenure Relationship Class – Modified from (Griffith-Charles 2011)



The social tenure relationship class (see figure 9) is an expansion of the social tenure relation class in figure 7. Social tenure relationships are time dependent as land changes hands with time. The specialisations from the social tenure relationships are the rights (stdm_Right), restrictions (stdm_Restrictions) and responsibilities (stdm_Responsibilities) sub-classes. The rights class map the different ways in which land can be held and registered in informal settlements to include occupancy and rental. Restrictions (see table 1) depict regulations that informal settlement dwellers should abide to such as building lines from existing roads, servitudes from electricity power

lines and distance from existing planned neighborhoods. Responsibilities (table 2) include keeping the settlement clean which is not always adhered to. Restrictions and responsibilities are modelled in the social tenure relationship class (Figure 9).

The informal settlement spatial unit class depicted in figure 10 shows the property unit and the different classifications that exists. The spatial unit table describes the nature of the property and the land uses. The property is described as land only or land and buildings while single or multiple land uses are described. The primary and most dominant secondary land use are documented.

The informal settlement spatial unit class contains information about the land parcel, buildings, municipal services (table 3) available and risk vulnerabilities (table 4) that the dwellers are in potential danger of. The building unit sub-class describes the materials with which buildings are constructed and roofed with and the material for perimeter walls. Brick walled houses (figure 10) stand greater chance of remaining erect than metal sheets (figure 7) while a brick perimeter wall is a better barrier to heavy winds and runaway water that contribute to flooding.

Table 3. Services Class

Services		
	Attribute	**Options**
	Electricity	Yes
		No
	Water	Yes
		No
	Sewer	Yes
		No

Table 4. Disaster Risk Class

DisasterRisk		
	Attribute	**Options**
	Floods	High
		Medium
		Low
	hailStorms	High
		Medium
		Low
	Fire	High
		Medium
		Low
	strongWinds	High
		Medium
		Low
	epidemicVulnerability	High
		Medium
		Low

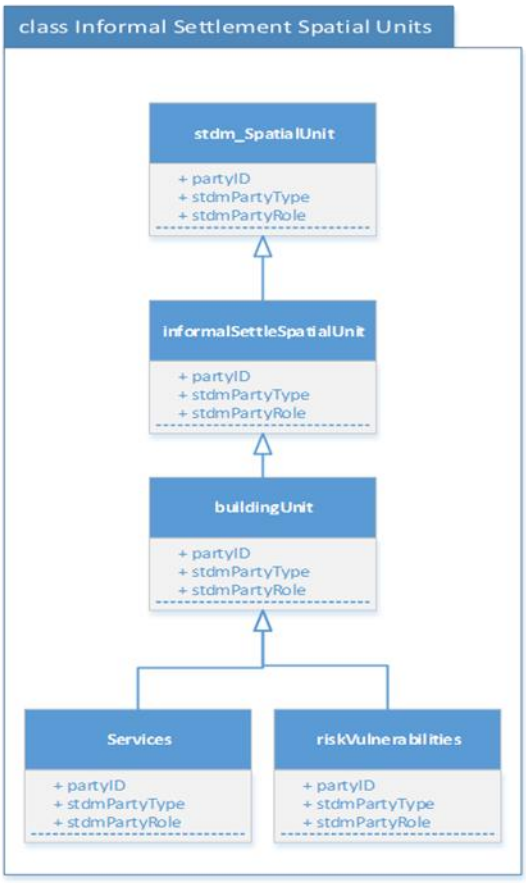
Source: Authors elaboration

In cases where there are fire outbreaks, when there are many buildings in a property the fire is likely to extend to neighboring properties as structures in neighboring properties will be in close proximity. The number of buildings correlates to the number of people and or families living on a particular property. The information collected from this table is usefully in making decisions of disaster vulnerability per property or per a group of properties.

The major risks identified from the social tenure modelling are floods, hailstorms, fire, strong winds and epidemics and are embedded in the informal settlement spatial unit class (see figure 10). These variables are measured on an ordinal scale with high, medium and low as possible values. From figure 3, the informal settlement is in the proximity of a dam which the public could use as a source of drinking water and attract various water borne diseases which are represented by the riskVulnerabilities sub-class in figure 10. Where there is no electricity it means firewood is a major source of energy which can result in fire outbreaks. Where electricity has been supplied, there may be

electrical fires due to overload of the network as a result of illegal connections to transformers. The services sub-class collects information on services provided my municipal authorities in the informal settlement which are largely electricity, water and sewer. When there is no water and sewer connections the risk of epidemics is high.

Figure 10: Informal Settlement Spatial Units Class – Modified from (Griffith-Charles 2011)



spatialUnit		
	Attribute	**Options**
	unitType	Land only
		Land and Buildings
	primaryUse	Residential
		Business
	secondaryUse	Business
		Residential
		Agriculture
		None

Houses or Structures in Gomorrah Informal Settlement [Photograph taken on 5 August 2019 at location (-25.702612, 28.126781)]

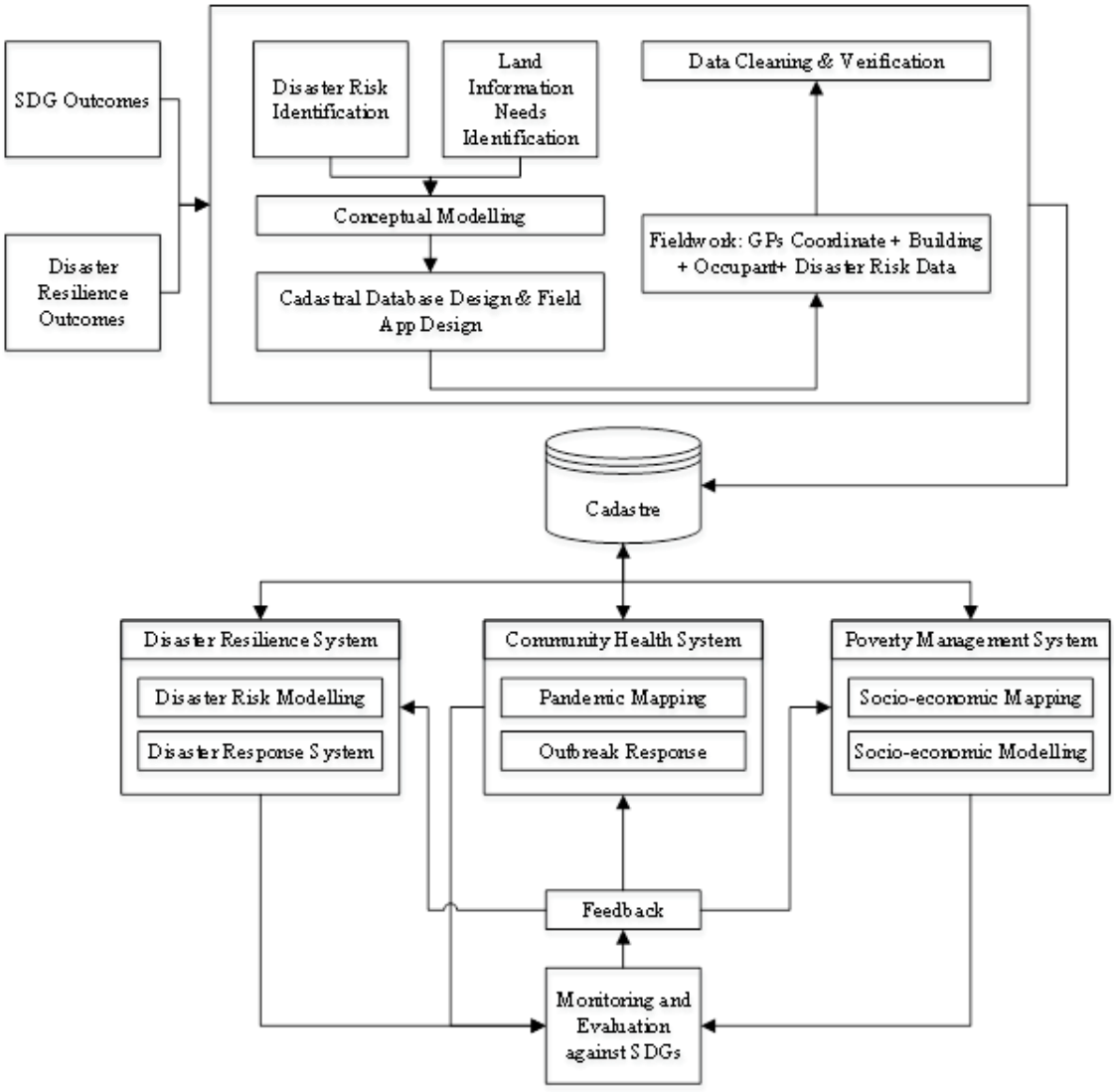
6. ACHIEVING THE SUSTAINABLE DEVELOPMENT GOALS

The cadastre can serve many purposes, one of which is to store and manage information about property boundaries, ownership, use and value. Above this basic information, the required outcomes from the sustainable development goals and disaster resilience needs of the informal settlement can also guide the secondary functions of the cadastre (see figure 11). From those outcomes, field parties can then identify the disaster and epidemic risks that the community is susceptible to and the required land information to improve disaster preparedness and management.

With this information, conceptual modelling using the social tenure domain model is then done to identify the different classes (figures 8, 9 and 10) and attributes for the cadastral database. After conceptual modelling, the cadastral database is designed together with a field mobile app for data collection. After collecting and verifying field data, the land information is transferred to a central storage with three main functions: Disaster Resilience, Community Health and Poverty Management.

The purpose of the disaster resilience system is to improve resilience through predicting, monitoring, managing and improving response to disasters. The community health system monitors epidemic outbreak and the development of eradication scenarios, their implementation and approaches to circumvent them. The poverty management system is for poverty mapping and targeting interventions that reduce poverty through economic empowerment programs, food packages and educational bursaries for learners.

Figure 11: Linkage between SDGs and Informal cadastre and Disaster Resilience



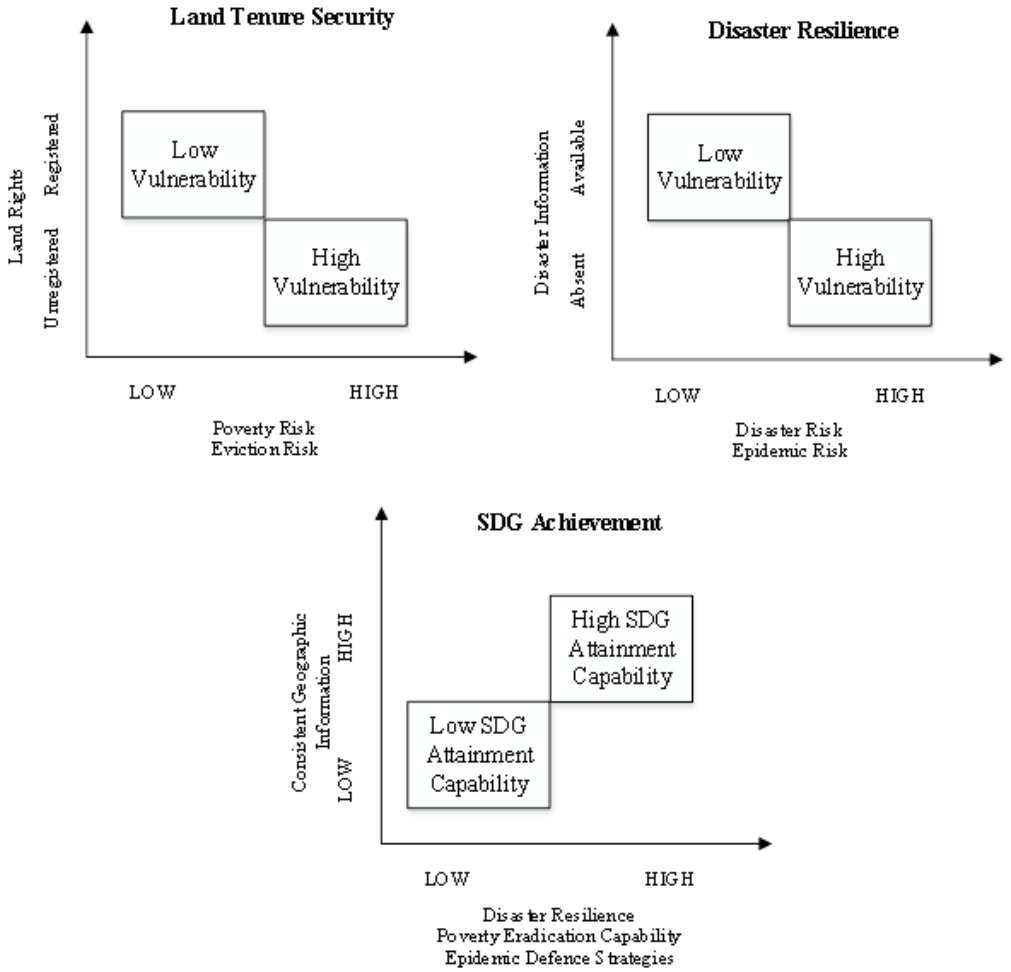
Source: Authors elaboration

The activities from these three systems are evaluated against the indicators set together with the outcomes required from the sustainable development goals and feedback provided for improvement. As this feedback cycle continues and improvement measures effected, the SDG outcomes will eventually be realized and community resilience enhanced.

7. ANALYSIS

Natural disasters such as floods have been increasing in intensity and frequency (Salami et al, 2017a; Rajabifard et al, 2018; Kurwakumire et al, 2019). Flood disasters thus claim the lives of millions worldwide. They also result in massive destruction of real property and other economic infrastructure (Salami et al, 2017b) such as roads, bridges and telecommunications networks. Informal settlements have higher exposure to floods because they often occur in restricted areas (Doberstein and Stager, 2013; Abunyewah, 2018) such as wetlands and alongside dams as they provide dwellers with a source of water. The natural disasters occur in the wake of poor disaster preparedness by communities in informal settlements (Abunyewah, 2018).

Figure 12: Risk Vulnerability Mapping



Source: Authors elaboration

It is impossible to reduce or prevent natural disasters in informal settlements, but the impact of such disasters can be reduced (Tas et al, 2013) such that communities are less vulnerable to risk. This is achieved through disaster risk planning and decision making which requires land information from cadastres (Unger et al, 2019). This greatly enhances the disaster resilience of the communities and the municipalities (Rajabifard et al, 2018; Kurwakumire et al, 2018). In figure 12, land tenure security and disaster resilience influence the achievement of the SDGs. The combination of low risk in poverty and eviction coupled with registered land rights translates to low vulnerability to risk by the community. Communities with available disaster information can lower disaster and

epidemic risks due to their ability to plan around risk mitigation strategies hence improving their community resilience. The use of spatial data for disaster resilience, designing poverty eradication capabilities and epidemic defense strategies enhances the achievement of the sustainable development goals.

The expansion of the model in figure 7 provides a more detailed view of the social tenure situation and how it can be mapped. The detailed models depicts the complex nature of land tenure systems and hence land administration systems. This view provides the different tenure arrangements (see figure 10) prevalent on the ground in informal settlements and the disaster vulnerabilities faced by inhabitants. It provides a basis to record adequate land information to support disaster planning and management.

While family land described in (Griffith-Charles, 2011) relates to customary tenure, it still lies on the informal rights sections of the continuum of rights models discussed in (Whittal, 2014) in a similar manner to informal settlement land rights. Family land is more formal and recognised by authorities unlike informal settlements. There are thus similarities in the manner in which land information can be recorded as demonstrated in figures 8 to 10. Both family land and informal settlements can use general rather than fixed boundaries extracted from satellite imagery as a low cost boundary determination approach as recommended in (Kurwakumire and Chaminama, 2012). Present day, it is easier to carry out a drone survey and use the imagery for boundary mapping for the spatial unit (Figure 10) and mapping of individual structures for the building unit. Of interest is the point parcel represented by the centroid coordinate as it provides a geographical address and is used for network analysis which is useful in emergencies when disasters strike.

8. CONCLUSIONS

The aim of this study was to design conceptual models for the development of an informal cadastre that documents land information in informal settlements. This procedure was broken down into boundary determination and mapping and UML modelling. Boundaries where extracted from google earth imagery using AutoCAD software and the cadastral layer with parcel numbering and centroid coordinates generated. The land tenure arrangements in informal settlements where successfully modelled using unified modelling language (UML) resulting in the Informal Settlement Spatial Unit, Informal Settlement Party and Social Tenure Relationship classes. Disaster risk information was integrated into the Informal Settlement Spatial Unit class as disasters occur or impact on the land object. Parties or people are affected by these disasters because they dwell on the spatial units. It is recommended to integrate the class diagrams provided in this study with municipal bylaws into a more comprehensive conceptual model. This conceptual model can then be operationalised through the development of a database that can be applied for recording land information and disaster risk planning in informal settlements. This study demonstrated that the social tenure domain model can be applied in modelling land rights in informal settlements based on a pro-poor land administration approach through inexpensive boundary survey mapping. Mapping informal tenure rights and disaster risk information is a starting point for building community resilience. With this information disaster management can be effectively executed thus minimising risk in communities. Minimising risks translate positively towards attainment of SDGs 1 and 3 as these are linked to land information availability and the level of resilience to disasters by these communities. Land information is key to the development of strategies supporting disaster resilience,

poverty eradication and improvement of community health systems. The cadastre provides consistent spatial data for targeting interventions towards achievement of the sustainable development goals.

REFERENCES

Abunyewah, M., T. Gajendran, and K. Maund K. (2018). Profiling Informal Settlements for Disaster Risks. *Procedia engineering*: 238-245.

Adger, W.N., T.P. Hughes, C. Folke, S.R. Carpenter, and J. Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science* 309 (5737): 1036-1039.

Augustinus, C. (2010). Social tenure domain model: what it can mean for the land industry and for the poor. *Proceedings of the International Federation of Surveyors Congress*. Sydney. April 11-16.

Bello, O.M., and T.A. Aina. (2014). Satellite remote sensing as a tool in disaster management and sustainable development: towards a synergistic approach. *Procedia-Social and Behavioral Sciences* 120: 365-373.

Craglia, M., and A. Johnston. (2004). Assessing the impacts of spatial data infrastructures: Methods and gaps. *7th AGILE Conference on Geographic Information Science*. Heraklion. Greece (Vol. 29).

David, A.M., S.P. Mercado, D. Becker, K. Edmundo, and F. Mugisha. (2007). The prevention and control of HIV/AIDS, TB and vector-borne diseases in informal settlements: challenges, opportunities and insights. *Journal of Urban Health* 84 (1): 65-74.

Deinlnger, K., and H. Binswanger. (1999). The evolution of the World Bank's land policy: principles, experience, and future challenges. *The World Bank Research Observer* 14 (2), 247-276.

Doberstein, B., and H. Stager. (2013). Towards guidelines for post- disaster vulnerability reduction in informal settlements. *Disasters*: 28-47.

Evangelidis, K., A. Agrianidis, K. Perakis, T. Papadopoulos., and K. Papatheodorou. (2018). Web-GIS Development of Geospatial Data Dissemination in EU Operational Programmes. *European Journal of Geography* 9(2): 21-36.

Ferreira, M., and M. Marujo-Ferreira. (2019). Using Geospatial Analysis Techniques for Evaluating the Association between Socio-Environmental factors and the Geographical Distribution of Leptospirosis in Sao Paulo, Brazil. *European Journal of Geography* 10(3): 137-153.

FIG. (1995). *FIG Statement on the Cadastre - FIG Publication No. 11*. International Federation of Surveyors.

Galiani, S., and E. Schargrodsky. (2010). Property rights for the poor: Effects of land titling. *Journal of Public Economics* 94 (9-10): 700-729.

González González, M. J. (2017). Planning, urban sprawl and spatial thinking. *European Journal of Geography* 8(1): 32-43.

Griffith-Charles, C. (2011). The application of the social tenure domain model (STDM) to family land in Trinidad and Tobago. *Land use policy* 28 (3): 514-522.

Hasan, A. (2006). Orangi Pilot Project: the expansion of work beyond Orangi and the mapping of informal settlements and infrastructure. *Environment and Urbanization* 18 (2): 451-480.

Henssen, J.L.G. (1995). Basic principles of the main cadastral systems in the world. *Proceedings of the one day seminar of FIG Commission 7 – Vision on Cadastre 2014*. Delft.

Hofmann, P., J. Strobl, T. Blaschke, and H. Kux. (2008). Detecting informal settlements from QuickBird data in Rio de Janeiro using an object based approach. *Object-based image analysis*: 531-553.

Hofmann, P., H. Taubenböck, and C. Werthmann. (2015). Monitoring and modelling of informal settlements-A review on recent developments and challenges. *2015 joint urban remote sensing event (JURSE)*: 1-4. IEEE.

Huchzermeyer, M. (2006). The new instrument for upgrading informal settlements in South Africa: contributions and constraints. *Informal settlements: A perpetual challenge*: 41-61.

Huchzermeyer, M., and A. Karam. (2006). *Informal Settlements: a perpetual challenge?*. Juta and Company Ltd.

Hurskainen, P., and P. Pellikka. (2004). Change detection of informal settlements using multi-temporal aerial photographs–the case of Voi, SE-Kenya. *Proceedings of the 5th African Association of Remote Sensing of the Environment conference*. Nairobi.

Jahantab, Z., A.A. Ale-Sheik, A.D. Boloorani, and H. Teimouri. (2017). Spatial-Temporal modelling of land-vegetation degradation, using weighted overlay index model. A case study on Nineveh Province, Iraq. *European Journal of Geography* 8(4): 118-141.

Kurwakumire, E., and N. Chaminama. (2012). An Analysis of Data Handling Techniques in Zimbabwe. *FIG Working Week 2012 - Knowing to manage the territory, protect the environment, evaluate the cultural heritage*. Rome. Italy.

Kurwakumire, E. (2013). Towards the design of a pro-poor land adjudication procedure for communal land. *SASGI Proceedings*. Kempton Park. South Africa.

Kurwakumire, E., T.P. Mapurisa, and S. Kuzhazha. (2018). Resilience Thinking in Support of Sustainable Smart Cities. *Casle Conference*. Lusaka. Zambia.

Kurwakumire, E., P. Muchechetere, S. Kuzhazha, and G.B. Ikokou. (2019). Geographic Information and Geo-visualization in support of Disaster Resilience. *International Cartographic Conference*. Tokyo. Japan. DOI: 10.5194/ica-proc-2-68-2019.

Lemmen, C., C. Augustinus, P. van Oosterom, and P. van der Molen. (2007). The social tenure domain model: design of a first draft model. *Proceedings of the FIG Working week 2007*.

Lemmen, C., J.A. Zevenbergen, M. Lengoiboni, K. Deininger, and T. Burns. (2009). First experiences with High Resolution Imagery Based Adjudication Approach for Social Tenure Domain Model in Ethiopia. *World Bank and FIG*.

Lemmen, C. (2010). *The Social Tenure Domain Model: A Pro-Poor Land Tool*. International Federation of Surveyors. Copenhagen. ISBN 978-87-90907-83-9.

Lemmen, C., P. van Oosterom and R. Bennett. (2015). The land administration domain model. *Land use policy* 49: 535-545.

Lengoiboni, M., C. Richter, and J. Zevenbergen J. (2019). Cross-cutting challenges to innovation in land tenure documentation. *Land use policy* 85: 21-32.

McCallin, B., I. Scherer I, and J. Duyne. (2015). *Urban informal settlers displaced by disasters: challenges to housing responses*. IDMC and NRC.

McFarlane, C. (2008). Sanitation in Mumbai's informal settlements: State,'slum', and infrastructure. *Environment and planning A* 40 (1): 88-107.

Mendola, M., and F. Simtowe. (2015). The welfare impact of land redistribution: Evidence from a quasi-experimental initiative in Malawi. *World Development* 72: 53-69.

Morales, J., C. Lemmen, R. de By, M. Molendijk, E. Oosterbroek, and A.E. Ortiz Davila. (2019). On the design of a modern and generic approach to land registration: The Colombia Experience. *8th International FIG workshop on the Land Administration Domain Model*. 1-3 October. Kuala Lumpur. Malaysia.

Mutisya, E., and M. Yarime. (2011). Understanding the grassroots dynamics of slums in Nairobi: the dilemma of Kibera informal settlements. *Int Trans J Eng Manag Appl Sci Technol*: 197-213.

Napier M., and R. Margot. (2002). Managing environmental and disaster risks affecting informal settlements: lessons in innovative practice from South African local authorities. *Proceedings of the international conference and meeting of CIB Task Group*. Surabaya.

Nedkov, S., M. Zhiyanski, B. Borisova, M. Nikolova, S. Bratanova, L. Semerdzhieva, I. Ihtimanski, P. Nikolov, and Z. Aidarova. (2018). A geospatial approach to mapping and assessment of urban ecosystem services in Bulgaria. *European Journal of Geography* 9(4): 34-50.

Ngqakamba, S. (2019). 80 shacks catch fire in Alexandria, 88-kilovolt overhead line falls on top of structures. News24. 5 March. https://www.news24.com/SouthAfrica/News/ems-on-the-scene-after-20-shacks-catch-fire-in-alexandra-20190305 (Accessed 2020-03-03).

Nyussupova, G., A. Kalimurzina, and R. Kelinbayeva. (2017). Social and geographical research in the Republic of Kazakhstan with the use of GIS technologies. *European Journal of Geography* 8(3): 109-125.

Onyekachi, A. F. (2014). Prospects and challenges of informal settlements and urban upgrading in Abuja. *International Journal of Innovation and Scientific Research* 11 (2): 420-426.

Otero, J.A, and M.L. Torres. (2017). Spatial data infrastructures and geography learning. *European Journal of Geography* 3(8): 19-29.

Passalent, L., E. Borsy, M.D. Landry, and C. Cott. (2013). Geographic information systems (GIS): an emerging method to assess demand and provision for rehabilitation services. *Disability and rehabilitation* 35 (20): 1740-1749.

Rai, P.K., and C. Singh. (2016). GIS in electrical asset mapping: The case of Bhadohi, India. *European Journal of Geography* 7(4): 19-33.

Rajabifard, A., K.E. Potts, M. Torhonen, A.F. Barra, and I. Justiniano I. (2018). Improving Resilience and Resilience Impact of National Land and Geospatial System. *Proceedings of the World Bank Conference on Land and Poverty*. Washington DC.

RSA. (1996). *Constitution of the Republic of South Africa*. 8 May 1996. Amended 11 October 1996.

Safarabadi, A., S. Moayedfar, and H. Varesi. (2015). Urban sustainable development with emphasis on the empowerment of informal settlements in urban areas: the case of Yazd, Iran. *European Journal of Geography* 6(1): 83-97.

Salami, R.O., J.K. von Meding, and H. Giggins. (2017a). Urban settlements' vulnerability to flood risks in African cities: A conceptual framework. *Jàmbá: Journal of Disaster Risk Studies*: 1-9.

Salami, R.O., J.K. von Meding, and H. Giggins. (2017b). Vulnerability of human settlements to flood risk in the core area of Ibadan metropolis, Nigeria. *Jàmbá: Journal of Disaster Risk Studies*: 1-14.

Sawada, Y., and Y. Takasaki. (2017). Natural disaster, poverty, and development: An introduction. *World Development* 94: 2-15.

Scott, G., and A. Rajabifard. (2017). Sustainable development and geospatial information: a strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-spatial information science* 20 (2): 59-76.

Shatkin, G. (2004). Planning to forget: Informal settlements as' forgotten places' in globalising Metro Manila. *Urban studies* 41(12): 2469-2484.

Singh, K. (2019). Durban floods damage estimated at over R650m. News24. 26 April. https://www.news24.com/SouthAfrica/News/durban-floods-damage-estimated-at-over-r650m-20190426 (Accessed 2020-03-03).

Somdyala, K. (2019). About 700 homes affected by Cape Town rains, flooding – City. News24. 6 June. https://www.news24.com/SouthAfrica/News/about-700-homes-affected-by-cape-town-rains-flooding-city-20190606 (Accessed 2020-03-03).

Sylia, O., D. Antonio, and J. Gitau. (2018). Low-cost Land Information System for Sustainable Urban Development: Case Examples in Kenya and Zambia. *Proceedings of the World Bank Conference on Land and Poverty*. Washington DC.

Taing, L., S. Pan, J. Hilligan, A. Spiegel, and N.P. Armitage. (2013). Challenges facing sanitation-provision partnerships for informal settlements: a South African case study. *Journal of Water, Sanitation and Hygiene for Development* 3 (2): 230-239.

Tamilenthi, S., and R. Baskaran. (2013). Urban Change Detection Based On Remote Sensing and GIS Study of Salem Revenue Division, Salem District, Tamil Nadu, India. *European Association of Geographers* 4(3): 50-59.

Tas, M., N. Tas, S. Durak, and G. Atanur, G. (2013). Flood disaster vulnerability in informal settlements in Bursa, Turkey. *Environment and Urbanization*: 443-463.

Teoman, D.C. (2018). The impact of the refugee crisis on urban development: The case of Vienna. *European Journal of Geography* 9(2): 149-163.

Tjia, D., and S. Coetzee. (2013). Application of the Land Administration Domain Model to the City of Johannesburg Land Information System. *South African Journal of Geomatics*: 260-278.

Unger, E.M., J. Zevenbergen, R. Bennett R, and C. Lemmen. (2019). Application of LADM for disaster prone areas and communities. *Land use policy*: 118-126.

Un-Habitat. (2011). *Affordable land and housing in Asia*. Volume 2. ISBN Number: 978-92-1-132369-6.

Un-Habitat. (2018). *Securing land rights for all*. Global land Tool Network. Nairobi. ISBN:978-92-1-131961-3.

van der Molen, P. (2005). Unconventional Approaches To Land Administration: A first attempt for an international research agenda. *Proceedings of the ITC Lustrum Conference on Spatial Information for Civil Society*. Enschede.

van Oosterom, P., C. Lemmen, T. Ingvarsson, P. van der Molen, H. Ploeger, W. Quak, J. Stoter, and J. Zevenbergen. (2006). The core cadastral domain model. *Computers, Environment and Urban Systems*: 627-660.

Vishwakarma, C.A., S. Thakur, P.K. Rai, M.S. Kamal, and S. Mukherjee. (2016). Changing land trajectories: a case study from India using a remote sensing-based approach. *Eur J Geogr* 7(2): 61-71.

Wadduwage, S., and A.C. Millington (2019). The implications of urbanization on peri-urban land-use change: A literature review. *European Journal of Geography* 4: 21-40.

Whittal, J. (2014). A new conceptual model for the continuum of land rights. *South African journal of geomatics*: 13-32.