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Application of LADM for disaster prone areas and communities

Eva-Maria Unger[a,*], Jaap Zevenbergen[a], Rohan Bennett[b], Christiaan Lemmen[a]

[a] University Twente, Faculty of Geo-Informaiton Science and Earth Observation, Department of Urban and Regional Planning and Geo-Information Management, Enschede, The Netherlands

[b] Swinburne University of Technology, Department of Business Technology and Entrepreneurship, Melbourne, Australia

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ABSTRACT

Disaster prevention, response and recovery require information about land tenure. Though, in many high-risk contexts, such records are non-existent or not up to date. As a result, vulnerable groups are often passed over by the government during risk management activities. At present there exists no dedicated tool for supporting land tenure recordation of all people-to-land relationships for the purposes of disaster risk management. More specifically, the required supportive data models and standards that could enable integration of concepts from the respective domains of land administration and disaster risk management are also lacking. Standardized data models could support software and service designs. This paper introduces a model linking the domains of land administration and disaster risk management – with the goal of supporting resilience against natural disasters and providing an approach for collecting data once, and using it multiple times. A design approach was used to develop the model – with adaption of the international Land Administration Domain Model (LADM) standard acting as a basis. Key features of the model include the support of interoperability through standardisation, the inclusion of all people-to-land relationships including those specific to disaster contexts, and the potential of the model to contribute to each of the disaster phases. The model is suggested to be highly applicable in natural disaster contexts where no land tenure information exists or the national mapping authority already uses a land administration system compatible with LADM. Overall, the model is considered as a step toward an implementable strategy for applying responsible land administration in the context of disaster risk management.

1. Introduction

Responsible land administration[1] and disaster risk management both focus on empowering vulnerable groups to become resilient communities. When land administration is implemented responsibly, it underpins good land governance and ultimately supports sustainable land administration by providing strategies and tools to document all people-to-land relationships (Zevenbergen et al., 2015). Disaster risk management and especially community based disaster risk management (CBDR) aim to evaluate and manage natural disaster risks at the local level – and highlights the role of communities when it comes to disaster risk reduction (Asian Disaster Preparedness Center, 2016).

Contemporary research suggests a relationship between different levels of land tenure security and the negative consequences experienced by groups of people in the context of natural disasters (Mitchell et al., 2017; Unger et al., 2017; UN-Habitat, 2010; Rajabifard et al., 2018). The impact is argued as most severe at the community and household levels, and can be witnessed, for example, through loss of income, loss of shelter and minimal measures for disaster preparedness and mitigation. Moreover, these impacts are greater if land tenure is not secured and if the people-to-land relationships are neither known nor documented (Mitchell, 2011).

On a global level, significant effort remains focused on securing land and property rights for all, seeking to accelerate the proportion of recognized and recorded people-to-land relationships. The 2030 Agenda for Sustainable Development with its defined Sustainable Development Goals (SDGs), together with the Sendai Framework for Disaster Risk Reduction, stimulate innovative and transformative approaches to secure land and property rights for all (UN, 2015). The Sendai Framework (UN, 2015) specifically calls for investments in research and the development of a methodology and models for disaster risk assessment. In (Rajabifard et al., 2018) a World Bank and FAO funded research project is exploring ways to improve resilience and resilience impact of national land and geospatial information systems.

At a more theoretical level, (Unger et al., 2017) argues that a relationship between the two disciplines can be understood conceptually

* Corresponding author at: University of Twente, Faculty ITC, PO Box 217, 7500 AE Enschede, The Netherlands.
E-mail address: unger_eva@outlook.com (E.-M. Unger).

[1] In this paper, the term 'responsible land administration' is used to refer to the definition in (Zevenbergen et al., 2015) addressing all people to land relationships.

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via three driving forces - people, land, and disaster - and three disaster risk drivers - exposure, vulnerability and hazard. Combined, these elements provide an entry point for developing integrated land administration and DRM activities that adequately prepare, prevent, mitigate and respond to natural disasters. Further the need for data modelling is driven by the fact that well-designed and documented conceptual and logical models support and allow stakeholders to identify areas for improvements. Consequently the demand for a shared ontology, which allows all stakeholders to act globally, increases with any software development requiring alignment and standardisation to achieve data compatibility and interoperability (West and Fowler, 1999). Within the land administration domain a globally agreed ISO standard exists, the Land Administration Domain Model (LADM) (ISO et al., 2012). Within disaster risk management many frameworks already exist that are used to develop practical approaches in DRM. However, none of these models deal directly with the overlap between land and disaster related data.

Potentially complicating the landscape of data management domain relating to land and disasters, in recent years a new wave of data modeling and data provision techniques emerged. Developments such as predictive modeling, algorithm intelligence, self-describing data formats, design adaptive databases (Barry and Roux, 2012) are likely to impact on future data modelling efforts in the land and disaster domains. Although, as yet most initiatives remain only experimental or at the demonstrator level (Bennett et al., 2018). Moreover, standardized models such as the LADM (ISO et al., 2012) can continue to decrease the complexities of achieving efficient data interoperability and storage.

Synthesizing the above-mentioned issues, demand for a data model linking the land and disaster related data appears high. Accordingly, the aim of this research is not to develop yet another data model, but build on what is already developed so that standardisation efforts are further met and used conditionally. It is suggested by the authors that this integrated LA-DRM[2] model should be capable of capturing the people-to-land relationships in supporting disaster risk management objectives. The model has to encompass attributes describing the nature and scale of vulnerability, exposure and hazard – in order to be used for disaster risk management as well as deliver land tenure security for all. It needs to enable involved stakeholders to communicate over disciplines and institutions. The model further needs to be flexible in order to include bottom up and top down land data governance approaches, in regards to data acquisition, provision and sharing of data (at municipality, regional, national but also global level).

Therefore, in this paper an experimental LA-DRM model that seeks to support land tenure security issues in disaster prone areas is presented in terms of design and applicability. First, the motivation and background of the intended model are provided. Justification and an outline of the selected methodology used to develop the model are presented. Subsequently, the section 'Starting Points' examines and compares existing models from each domain, available for adaptation. This leads to a description of the outcomes of the data modelling, including a representation of required classes and attributes. The potential application of the model in different contexts and phases of disaster risk management is then explored. Finally, the limitations of the LA-DRM model are drawn, preceding the conclusion and encapsulation of future research opportunities.

2. Methodology

In order to develop an experimental LA-DRM model, a methodology called 'design approach', as shown in Fig. 2 Design Approach, was followed. Justification of the approach is found in similar research related to tenure security (Lemmen, 2012) (Hay, 2014), and (Lemmen et al., 2015) and related to disaster risk management (Li et al., 2007; UNISDR, 2015). Throughout this design approach Unified Modeling Language (UML) diagrams, along with textual and graphical descriptions, were used for the representation of all activities, processes, classes, attributes and associations. Especially with regards to the research area of disaster risk management a flexible approach has to be considered: reality is dynamic and with that all the data representing the reality is under constant change, which brings limitations to modelling the real world. The key to address this complexity as well as a constant change in data is to work with standards and conceptual models. The conceptual model as defined in (Unger et al., 2017) identified already the associations between different classes at the highest, most abstract level (Fig. 1). The conceptual model, developed through knowledge acquisition, determination of objectives and definition of requirements, and conceptual modelling techniques, was used as the base for the LA-DRM model.

Following on, the design approach was applied (Fig. 2). The first step of the design approach was a review (1) of existing standards, models and tools used in both disciplines. Theses findings lead to the draft model abstraction (2), followed by an initial definition (3) of classes, attributes and associations. These outputs were used to develop questionnaires and methods to identify tenure security issues in a post disaster context. A preliminary version of the model was then piloted in Nepal within a project, named 'Support for Land Reform in Nepal and Land Tenure Initiative' (SILTIP) in Dolakha. Dolakha is one of the most affected districts from the earthquakes, which hit Nepal in 2015. Therefore Kadaster[3], UN-Habitat Global Land Tool Network (GLTN), UN-Habitat Nepal and Human Rights Awareness and Development Centre (HURADEC) implemented a project in 3 sites of Bhimeswor Municipality, and one in Bigu rural Municipality in 2017, to address land tenure issues in the post-disaster context. The model's ability to support the process was tested, and data gaps revealed, which were previously not identified, but were seen to be required for an adequate representation of reality. Thereafter, various experts from UN-Habitat, GLTN, University Twente Faculty ITC and Kadaster discussed the developed questionnaires and the underlying data model. The outputs from the resulting Expert Group Discussion were seen as the first validation of the first draft model (4). Findings of the discussion proceeded in a re-definition (5) of classes, attributes and associations. The integrated model was then implemented through the Social Tenure Domain Model (STDM) tool, a plugin for QGIS (an open source geographic information system), which is based on the LADM (GLTN, 2014). At the data level, a separate data validation was conducted by the enumerators and communities who and where the model was implemented. The final validation was conducted through the analysis of the generated data using queries (6). Through the analysis, the potential and limitations of such an integrated model were assessed. Combined, the findings from the questionnaire development, the expert group discussion and the physical implementation, using GIS software, as well as the validation at data level are considered the fundamental validation and foundations for the design and development of the final draft of the integrated model, as presented in this work.

3. Starting points

When a structured approach to data modelling is accepted, then standards are needed for such an integrative and interdisciplinary approach. Both domains, land administration and disaster risk management work with various data and process models, implemented within Geographic Information System (GIS) tools, to generate land or disaster related data. But as far as the authors are aware this research is the first attempt to combine the concept of land administration, specifically

[2] LA-DRM Land Administration – Disaster Risk Management

[3] Cadastre, Land Registry and Mapping Agency of the Netherlands – with its International Branch Kadaster International

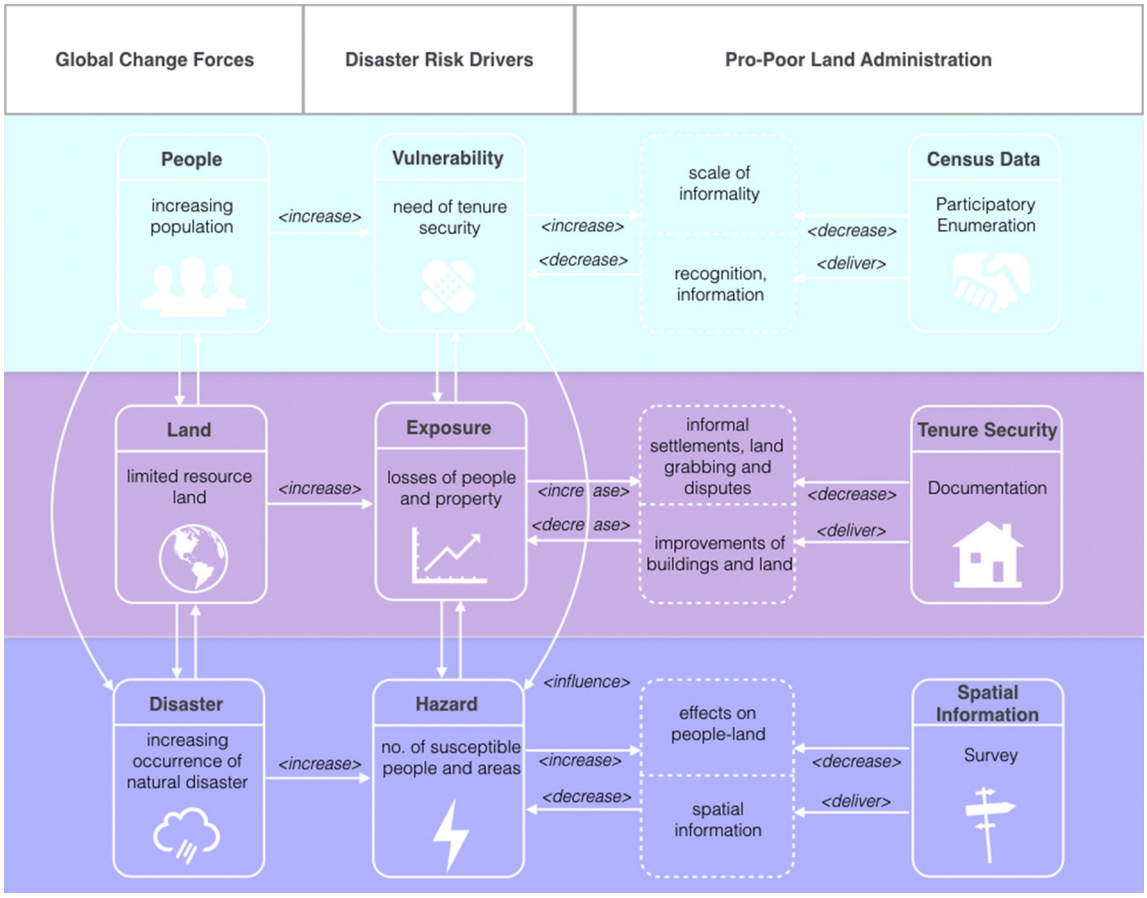

Fig. 1. Conceptual Model (Unger et al., 2017).

responsible land administration, with research on disaster risk management, in order to develop a model using a globally agreed ISO standard.

An audit of existing models and tools, currently utilized within both disciplines, was undertaken and the outputs summarised in Fig. 3.

Within disaster risk management there is currently no international agreed domain standard. But the global community agreed on the Sendai Framework (UN, 2015), which calls for resources in research and the development of a methodology and models for disaster risk assessment. Further, this framework calls for action regarding inadequate land management and calls for inclusion of informal and non-permanent housing in risk assessments. The tools developed in the disaster risk management domain tend to focus on a specific application or areas (Li et al., 2007) or a specific kind of disaster (UNISDR, 2015), which is justified through the variety of disasters and its different impacts. At the global level, models such as the Earthquake Risk Model (EQRM) or the Florida Public Hurricane Model, are used to model disasters and to quantify their duration, magnitude, calculate probabilities and so on (UNISDR, 2015). Furthermore, various databases and GIS systems such as Disaster Inventory System (DesInventar), The International Disaster Database (EM-DAT), and Global Disaster Identifier Number (GLIDE), are used to deliver indications about the costs and impact of disasters (UNISDR, 2018). Further investigation of various disaster risk management tools and applications concluded that most address land issues such as tenure security or resettlement only at the parcel level, or not at all. Inspiration for a way forward can be found in the W3C (W3C, 2009), an international community, where member organisations, staff and the public work together to develop Web Standards. Within the community, two emerging Information Systems were reviewed, one developed by Sahana Foundation and the other by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA). Based on that review a model was built by the W3C, providing a harmonized view of both. The model uses three core classes 'who' (organisations or people) does 'what' (activity) 'where' (location information).

Within land administration various national models and tools for the integration and distribution of land administration data are implemented. In Switzerland, for example, INTERLIS a Swiss standard was developed (Bundesamt für Landestopografie swisstopo, 2018). On the other hand the Land Administration Domain Model (LADM) is intended to be a universal knowledge model for land administration, which stimulates the development of software applications and accelerates the implementation of land administration systems (Lemmen et al., 2015). Within literature there are arguments that LADM is already a basic standard when focusing on the mandatory attributes (Lemmen et al., 2015). The implementation of this international ISO Standard on land administration can be seen as a milestone, which supports the development and implementation of the global agenda on land tenure. A specialisation of LADM that presents a generic and inclusive approach for responsible land administration was developed by UN-Habitat GLTN, the Social Tenure Domain Model (STDM) (GLTN, 2018). In parallel, FAO, likewise influenced through the development of LADM, developed SOLA an open source tool with the aim to provide land administration alternatives for land agencies (SOLA, 2016).

The review (Fig. 3) showed that the model built by W3C fits well with the basic structure of the ISO standard LADM and STDM (Fig. 4), and as such LADM/STDM could be considered as a base for the LA-DRM model. Further the iterative process of defining a standard as the base of the LA-DRM model was supported by experiences learned in the field in Nepal. LADM and STDM provide an inclusive approach to tenure security and also address the 'who', 'what' and 'where' - and are flexible in accommodating various additional attributes and code tables.

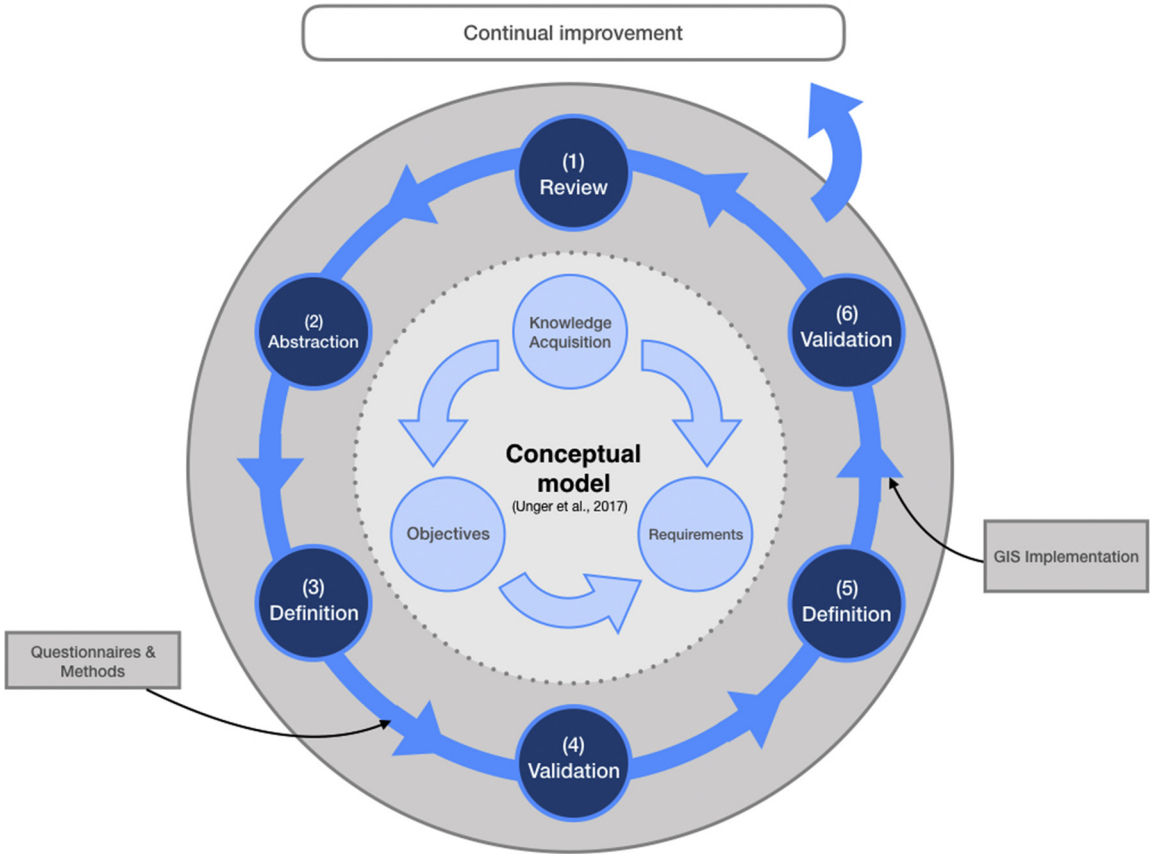

Fig. 2. Design Approach.

Furthermore, LADM as well as its specialisation, STDM, can be summarised or abstracted to a simplified object-subject relation which, depending on the application and institution can be used for all processes in the real world. In addition, through the very basic and simplified modelling, minimal changes are necessary and also the amount of attributes can be minimized, which is essential in such dynamic and agile domains. Finally, the researchers want to highlight that the spatial representation in LADM is seen as sufficient to be used for the LA-DRM model. Following, it was concluded that the base design of the LA-DRM model could be based on the LADM/STDM concept. The already

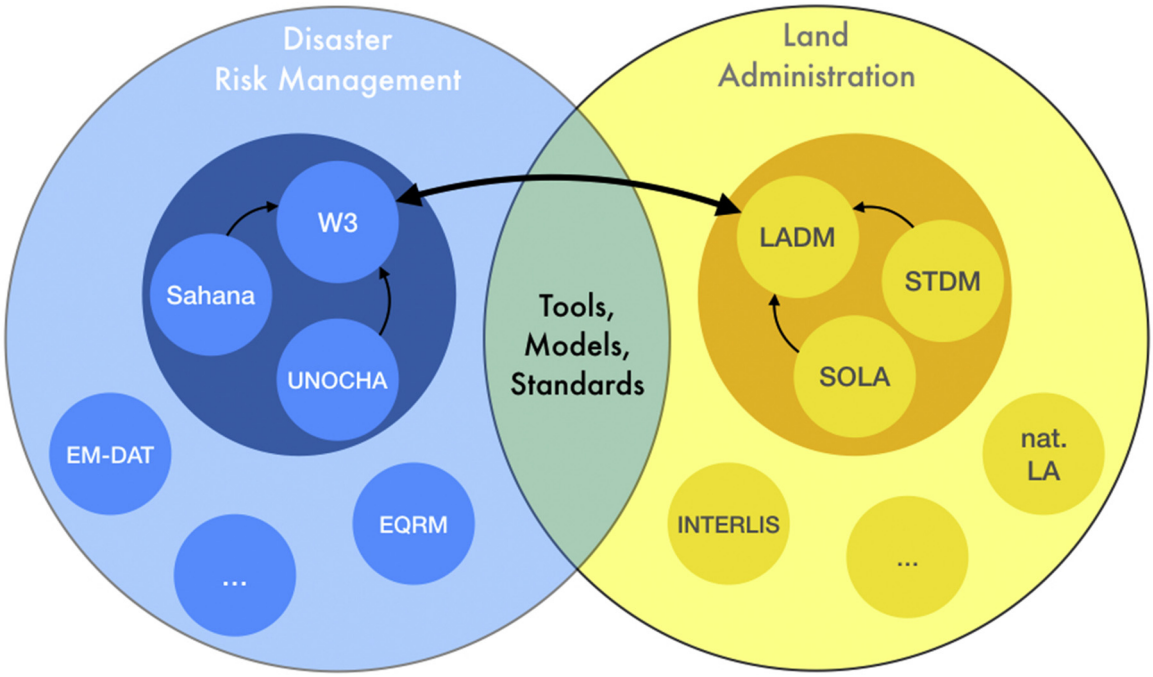

Fig. 3. Review of Tools, Models and Standards.

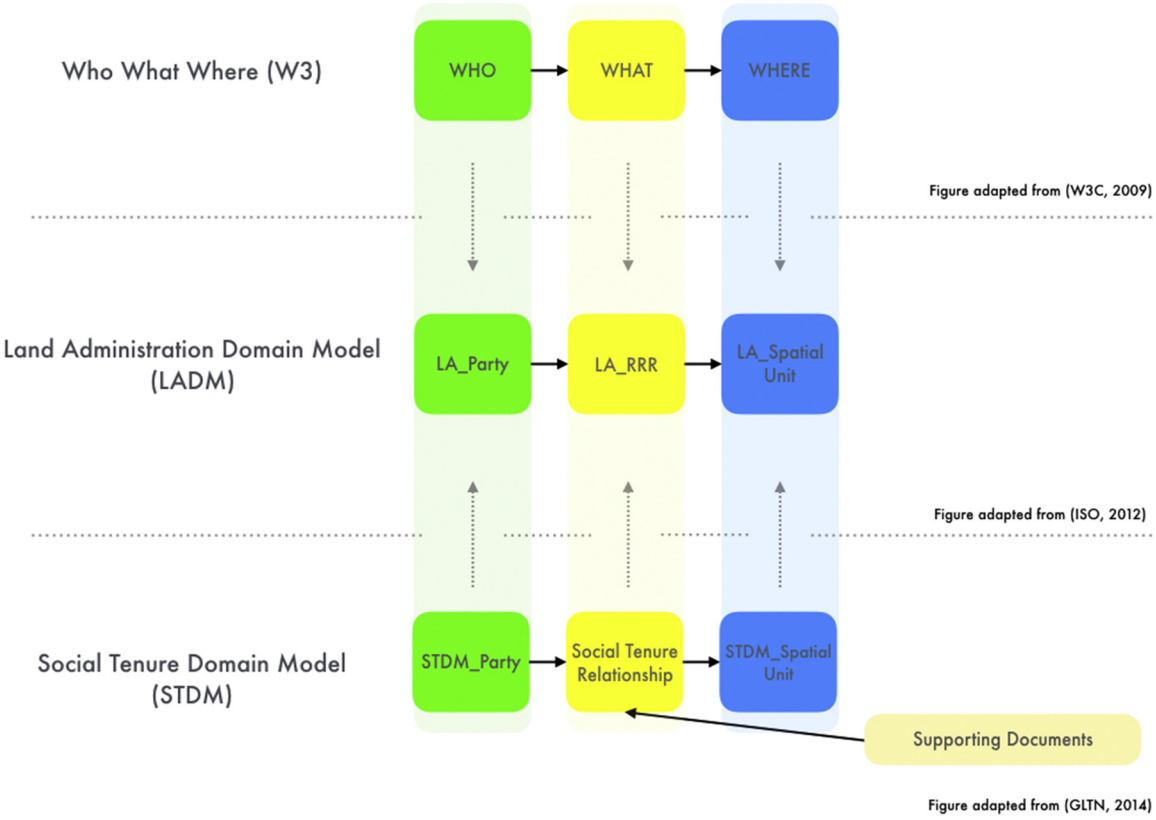

Fig. 4. LADM/STDM as a base for the LA-DRM model.

existing W3C and LADM links, coupled with the focus on a participatory and inclusive development approach, and together with the premise to use already existing standards, tools and knowledge, lead to this decision.

4. Elements of an integrated LA-DRM model

The introduced LA-DRM model is based on the LADM/STDM concept, using the same classes but with additional attributes describing the scale of vulnerability, hazard and exposure. LADM and STDM provide a standard set of terminology, classes and associations. Nevertheless, both models are flexible and can accommodate other attributes and associations, and are extensible to allow inclusion of other situations and disciplines. The core classes of LADM are the spatial unit (LA_SpatialUnit, this can be a parcel), the party (LA_Party, this can be a natural or non-natural person) and the rights, responsibilities and restrictions (LA_RRR), which links the two other classes (ISO et al., 2012). Those core classes of the LADM can also be found in the STDM, but are named differently as they focus on a different context, SpatialUnit, Party and SocialTenureRelationship (GLTN, 2014). The difference in terminology is based on the fact that the attributes in STDM describe legitimate rights instead of the statutory rights as in LADM (Zevenbergen et al., 2013). The SocialTenureRelationship is described through the continuum of land rights, as defined by (GLTN, 2014), to describe all people-to-land relationships. It can also be used to describe secondary use rights, overlapping rights or where people perceive their rights contradictory.

The development of the LA-DRM is based on literature review, expert group discussions and field experiences from Nepal. Since the LA-DRM is based on the LADM/STDM all the requirements as defined in (Lemmen et al., 2015) are considered to be valid. Various requirements (Table 1) were adapted and some additional ones were added.

In response to the above requirements, various attributes need to be added and changes made to LADM/STDM in order that the LA-DRM model is able to deliver on those identified needs in (Unger et al., 2017) and (Lemmen et al., 2015). Those changes and additional attributes are further explained below.

4.1. Individual and community defined vulnerabilities pre- and post disaster

The integrated model enables a 'party' to be for example a household, or family – so that also the children are recorded. The scale of vulnerability regarding the 'party' though can then be described and identified at individual but also at household, family, organisation or business level. These vulnerabilities can be identified and can be represented in a code list or as a Boolean value. Vulnerabilities could be, for example, lack of sanitation, educational possibilities/institutions, or lack of electricity, to name a few. Furthermore, at individual 'party' level, information about the level of literacy or education could be recorded, which further indicates the scale of vulnerability. Those identified vulnerabilities enable different stakeholders such as governmental representatives, NGOs or CSOs, to purposefully address them.

4.2. Status info

The scale of vulnerability in a post disaster context can be described through an attribute 'StatusInfo' in all core classes. For the 'SpatialUnit', the current or previous structure/building can indicate a different status and therefore should be described with a separate attribute under SpatialUnit. This may need a distinction between the parcel and the building/construction. The information shall give an indication whether the rebuilding process at the SpatialUnit has already started, if the construction is under the threat of collapsing, or if measures have been taken for mitigation and prevention, and so on.

For the 'Party', the 'StatusInfo' could give an indication whether or not the 'party' already applied for reconstruction grants. This could be realised through a Boolean value giving an indication whether the party applied or not. Another 'StatusInfo' regarding the 'Party' which can be

Table 1
LA-DRM requirements.

Requirements based on (Lemmen et al., 2015)		
No.	Requirement	Impact
1	A continuum of land use right claimants (subjects or parties)	The requirement No. 2 as defined in (Lemmen et al., 2015) is extended with the following: The LA-DRM model enables a 'party' to be, for example, a household, family, or group of families (e.g. 4 families live in 1 building) with each person to be recorded. Especially in regards to DRM, the inclusion of children in any system is essential and needs to be recorded. Further gender information is currently not explicitly covered by LADM. In any case women, have to be represented by the LA-DRM model, and therefore recordation of men and women is necessary.
2	A continuum of spatial units (objects)	The requirement No. 3 as defined in (Lemmen et al., 2015) is extended with the following: DRM requires the building or any construction to be recorded and changed / updated over time.
3	A range of data acquisition methods	The requirement No. 5 as defined in (Lemmen et al., 2015) is extended with the following: Data acquisition methods especially in regards to DRM should support and include community acquired data. Further collaboration and data sharing with different domains should be facilitated and encouraged e.g. weather radar stations, ministries of forest and agriculture, geological and geophysical institutions etc.
4	A range of authentic source documents	The requirement No. 6 as defined in (Lemmen et al., 2015) is extended with the following: In case of a natural disaster all kind of documents can be destroyed and may not be able to be retrieved from any system. Further witnessing through neighbours may not be applicable in case they are deceased; therefore any kind of source document at different stages should be supported.
5	History	The requirement No. 8 as defined in (Lemmen et al., 2015) is extended with the following: disaster risk management is describing an agile and fast environment whereas land administration is defined through long-term processes and defined rules and regulations with fewer changes over time. A disaster is in great numbers influencing the life cycle of the core classes immediately. Normally change in either 'party', 'social tenure relationship' or 'spatial unit' are long on-going processes but in case of a natural disaster, this life cycle can be seriously disrupted, ad hoc, or changed into a non-existing stage. Further historical data give information on the pre-and post disaster status.
Additional Requirements		
No.	Requirement	Impact
16	Vulnerabilities	Vulnerabilities at individual, household, family, organisation or business level shall be described. Those vulnerabilities should also deliver information such as the level of literacy, education or poverty.
17	Status Info	Each core class should be supported by a 'Status Info' attribute, as for example each party/individual can have a different status as e.g. a party can be deceased, can be handicapped etc., which all influence the social tenure relationship. Also, the spatial unit itself can have different statuses in the phases of a natural disaster. Therefore, interoperability and data exchange with other domains will be supportive in data maintenance and complete coverage based on the principle" collect once and use multiple times".
18	Source Document	Based on the extended requirement No. 4 this requirement now describes that various timestamps for the source documents are needed and should be supported by the system. Those dates could be, for example, the date of acceptance, or recordation, or reconstruction. This is especially relevant when the issuance of land documents should be enabled in the aftermath of the disaster.
19	Model Boundaries	LADM is organised into several packages, which already cover the needed packages for the LA-DRM. Nevertheless this requirement shall describe and emphasise the importance of linking such a model to other registers such as the population register, taxation, addresses, land use and land cover and valuation systems.

relevant is,f or example, if the party is deceased, is handicapped and so on, all influencing the social tenure relationships and indicating the scale of vulnerability and exposure.

Furthermore, the attribute 'StatusInfo' at 'SocialTenureRelationship' level can describe the level of recognition, whether the 'SocialTenureRelationship' is recognised by the legal framework or socially recognised. Therefore a code table with various STR_Types could be introduced. Finally, the 'SocialTenureRelationship' can change in case of relocation or resettlement, both measures of disaster risk management.

4.3. Inclusiveness

Further, the LA-DRM model needs to be able to accommodate households at 'party' level with a various amount of spatial units and subsequently varying 'STR'. This is relevant in case of collecting, for example, agricultural information at household level. This can describe the scale of exposure when it comes to livelihood. In previous versions of the STDM model only one people-to-land relationship could be established (GLTN, 2018). After field-testing STDM in a disaster risk context in Nepal this seemed to be inefficient and not representative for example for the landlord-tenant relationship. This is further relevant when it comes to disaster risk management, which involves for example, modelling resettlement processes as mitigation and prevention measures, where n-numbers of spatial units can be involved.

4.4. Additional considerations

Further, in the case of a natural disaster procedures, which can take quite some time in a conventional system, may need to be shortened. This means rules and business logic, if incorporated in the model, need to be adjusted and need to be supported by the legal and institutional framework. Additionally, in the model, it needs to be possible to go back in the lifetime of processing a land right. This can be the case, for example, immediately in the response phase when a title or any kind of document is needed to apply for reconstruction grants. Later on, these documents should be made eligible and then included in the national administration system.

Tenure information regarding the structure itself, but, also the tenure information of the land the structure is built on, and other land information, for example, agricultural use related to the party, can be gathered and would give additional indication of the level of vulnerability and exposure.

It is important that the integrated model is covers all people, for example, from a settlement, community or the area of interest. Also the people-to-land relationship needs to describe the children being related to the spatial unit. Population growth, migration, urbanization and economic development are all processes increasing the scale of exposure (UNISDR, 2015). All those dynamics need to be linked to the people so that in case of a disaster, nobody and no relevant information is left behind. Therefore, it is important to facilitate a link of the class 'party' to the population and business register.

Furthermore, in a post disaster context, resettlement measures such as previous and current locations, as well as different tenure types for

each location need to be enabled. All classes in LADM, except 'source' are a subclass of the so-called class 'VersionedObject'. This superclass enables land administration systems to maintain and manage the history of land administration objects. Therefore it is, in a refined manner, also used in the integrated model to accommodate the agile and fast changing characteristics of natural disasters, but, this model includes also the 'source' as a subclass. Therefore, every class inherits from the class VersionedObject. In this way, each class can cover the Tmin and Tmax attributes in the core classes, Party, SocialTenureRelationship and SpatialUnit. The VersionedObject can further manage information of the pre- and post- disaster status regarding the core classes and is indented to provide information when it comes to disaster responses such as, migration or resettlement.

4.5. Integrated LA-DRM model

All these changes are important to be accommodated by the integrated model. Nevertheless, those changes only reveal a small part of what is possible with such an integrated model and can be needed in disaster prone areas. But also some of those requirements and attributes may also be points of attention and useful for an updated version of the LADM/STDM. The researchers want to emphasise that the main aim of this integrated data model is to establish the link between disaster risk management and land administration, and to show that by enabling communities through responsible land administration, resilience against natural disasters is also enabled. The aim of the proposed LA-DRM model is not to cover the whole range of disaster risk management and land administration activities, but to be a model that can be used to give an overview and provide the information needed to enhance the resilience of communities.

These additional attributes and requirements lead to the following extension of the LADM UML model (Fig. 5):

The attributes represented in Fig. 5 LA-DRM Model are examples of measures which can be collected when recording the people-to-land relationship in a disaster-prone area, and which can be used to describe the scale of vulnerability, exposure and hazard. This model can be extended and adapted to local situations and is considered able to represent most people-to-land relationships and land issues in regards to disaster risk management.

5. Potential and limitations of the LA-DRM model

The integrated model enables stakeholders to identify the most vulnerable groups pre- and post- disaster to adequately prepare, respond and mitigate. Analysis in Nepal showed that vulnerable or at-risk groups are: children, women, elderly, persons with disabilities, the poor and marginalized groups, and especially people affected by tenure insecurity. They differ in their resilience to recover from a disaster. Mapping these vulnerable groups based on their needs, priorities and marginalization can be done during the different stages of disaster risk management.

The researchers have further analysed the potential of the LA-DRM model based on the disaster cycle and its phases as shown in (van Westen, 2009). Nevertheless it needs to be emphasised that there are different definitions of the disaster risk management phases and stages depending on the institution, organisation and purpose of intervention. In (Mitchell, 2011), for example, a paradigm shift to conceptualize DRM as continuum describes the transition from pre- during and post disaster situation as fluid, in particular for countries, which are regularly exposed to hazards. The analysis (Fig. 6) was done using a phased model framework, as used in (W3C, 2009). This presents a structured approach where the disaster phases as separated but related activities are used to show how the integrated model with its classes (Party, Social Tenure Relationship and Spatial Unit) evolve and contribute over time. The phases, the researchers are working with, are Mitigation and Prevention, Preparedness, Prediction and Warning, Response, Recovery, and Risk Assessment – based on the definitions in (UNISDR, 2017) and (van Westen, 2009). Fig. 6 Disaster Risk Management Phases and Potential of the LA-DRM Model may not cover all potentials and activities, but aims to provide a general overview. The identified potential further allows preparing for the changing demands and needs in the different phases. To highlight the relation to the base model, the LADM, the same colour code for the core classes was used.

As shown in Fig. 6, Disaster Risk Management Phases and Potential

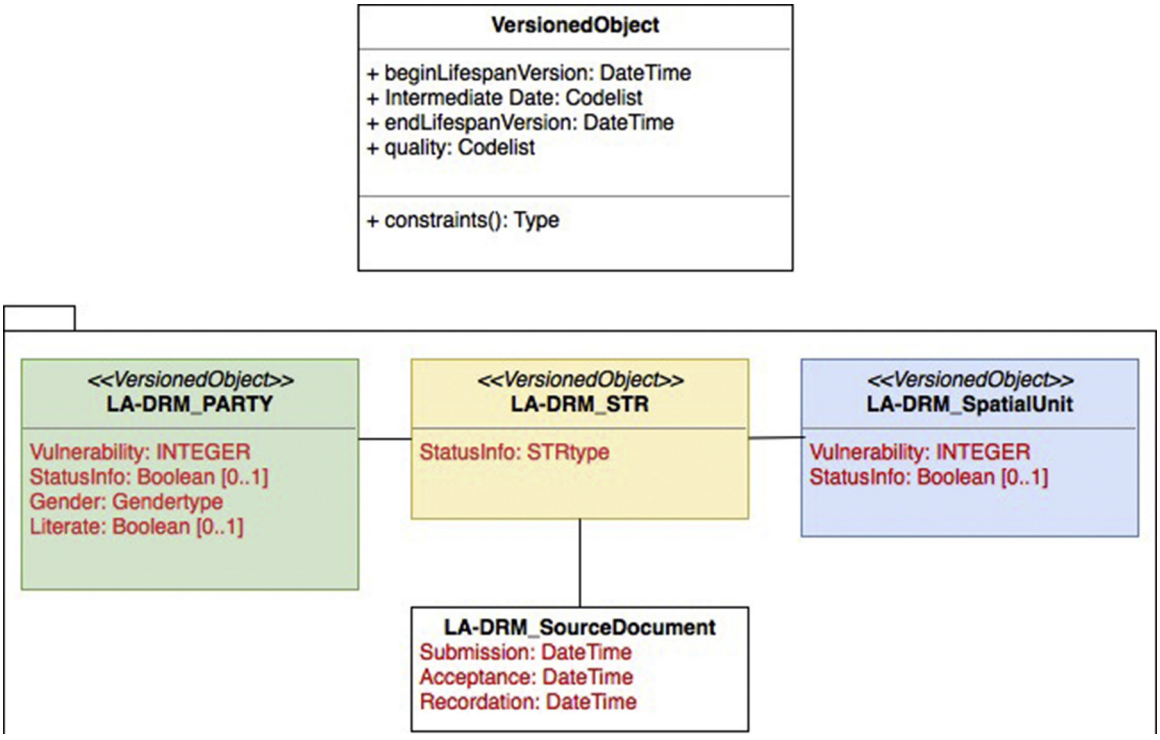

Fig. 5. LA-DRM Model.

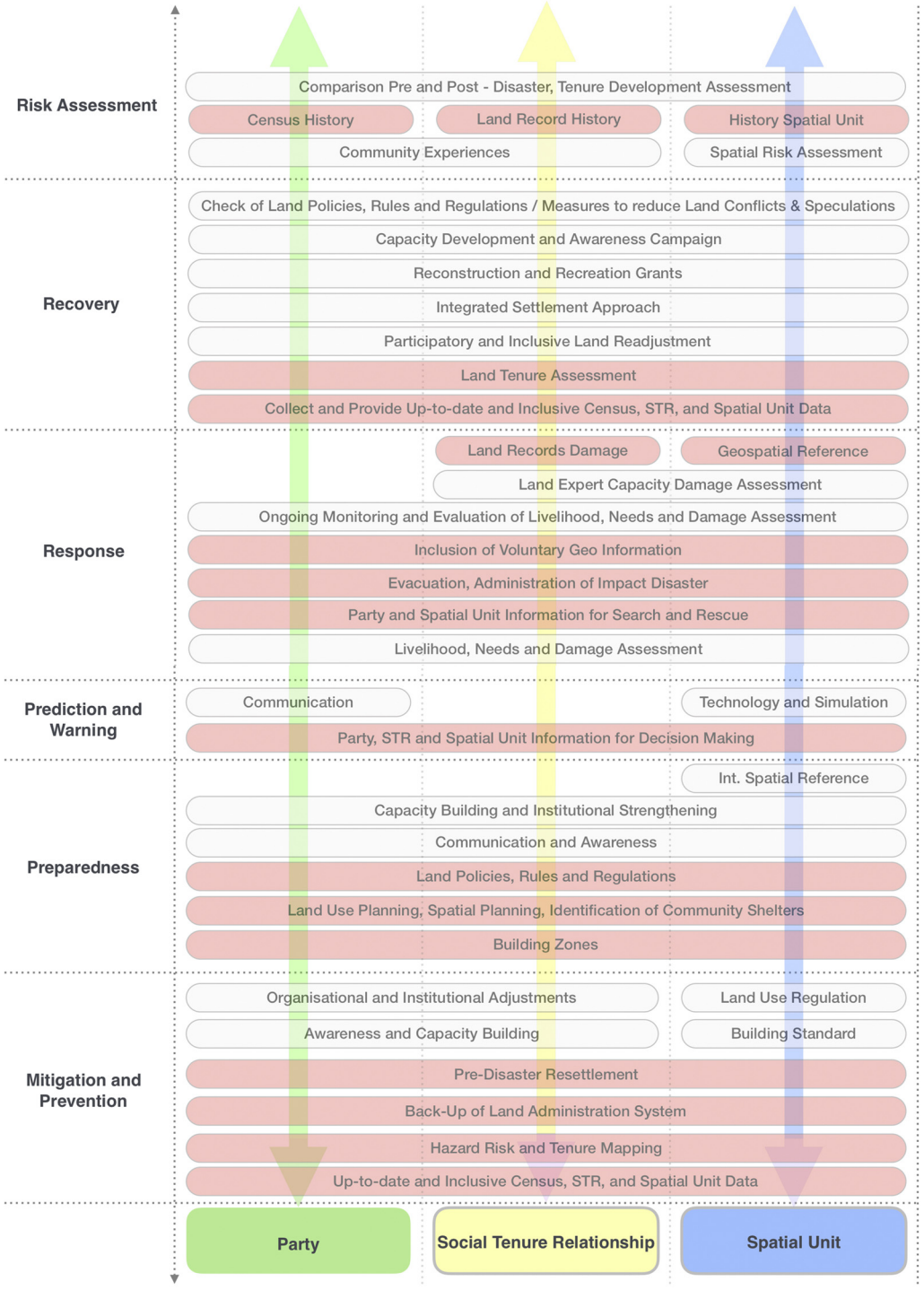

Fig. 6. Disaster Risk Management Phases and Potential of the LA-DRM Model.

of the LA-DRM Model, the light highlighted activities can make direct use of the integrated model and the data generated, whereas the LA-DRM model could assist with, for example, generated data or findings to the not highlighted activities. As shown in the figure, tenure security and therefore the LA-DRM model play an eminent role in each of the disaster phases and stages. Further, the integrated model could be used when organising and deploying response and recovery strategies, answering the underlying questions 'who', 'what' and 'where'.

The development of the LA-DRM model outlined that focusing on disaster management policies with a long-term perspective may have to be directed towards tenure security, poverty and vulnerability reduction. Disaster management should integrate structural with non-structural measures such as increasing tenure security, as a first act towards resilient communities. Especially disaster prone communities should be engaged in the process of land administration and disaster related decision making in order to increase the resilience of these communities.

Having demonstrated the development and potential of the LA-DRM model, which captures both the people-to-land relationship, as well as the link to disaster risk management, from the conceptual perspective, it is also necessary to articulate the limitations.

One of the most prominent limitations was already mentioned in

(Unger et al., 2017), which is the visualisation. Any kind of visualisation can lead to misinterpretation and misunderstandings. Furthermore, it needs to be kept in mind that land administration, as well as disaster risk management, are domains, which are dealing with constantly changing data. STDM uses a less specific model to address this dynamism in reality, as represented in the data. Nevertheless, it needs to be taken into account that according to (Hay, 2016), queries therefore become less reliable (or more complex) because there is less certainty regarding the data stored in the system. Further land administration systems are country specific systems. Through using standards, this limitation in regards interoperability and cross boundary data exchange, is partly already addressed, but cannot be fully solved. Therefore, introducing such a model at the physical level does mean that there may be adjustments needed in order to use the model in another case or region.

Traditional concerns regarding big data and therefore limitations linked with storage and processing capacity can be addressed by virtualisation and parallel computing, which is a type of computation where processes are carried out simultaneously.

Yet, the introduced LA-DRM model is considered accurate and complete at the present moment with the focus applied, tools, methods and literature used.

6. Conclusions and key lessons

The introduced LA-DRM model may, in its implementation, improve the management of land information when it comes to natural disaster contexts. Land issues arising during a disaster may not be sustainably addressed if the current approach of ad-hoc legislative design and separation of disciplines and systems continues. The research shows that it is possible to link land administration and disaster risk management, at the data capture level, and that the occurrence of disasters is the most evident reason to include all people-to-land relationships in any land administration system. People and or communities who are not recorded or registered are falling through the safety net of any disaster risk measures.

Moreover, there is no need to develop and entirely new model to service the data management gap, instead using what is already available is more efficient and also means standardisation efforts are enhanced, rather than being compromised.

When it comes to disaster risk management, the disasters and all its impact needs to be mapped, which may be done through cooperation and by information sharing across domains. To administer natural disasters and govern the impact of any disaster, basic questions regarding, What? Where? and How? need to be answered. Therefore, the need to access and share various information, which is facilitated by interoperability and standardisation measures, needs further facilitation.

In summary, this research has shown the development, potential, and also limitations of the required LA-DRM model. The research also highlighted that participation is crucial in enabling the poor to minimize vulnerabilities and disaster risks through an inclusive land tenure security approach to prevent, mitigate, prepare and respond to natural disasters.

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