Land Systems, Natural Hazards, and Risks. How a Unique Geospatial Model Integrates Multi-natural Hazard Risks into the Land Administration System

Rodolfo Salazar[1,2](✉), Dennis Ushiña[3], and Yomaira Quinga[4]

[1] Universidad de las Fuerzas Armadas ESPE, Av. Gral. Rumiñahui s/n, P.O. BOX 171-5-231B, Sangolquí, Ecuador
rjsalazar@espe.edu.ec

[2] Departamento de Desarrollo Regional e Integración Económica, Universidad de Santiago de Compostela, Campus Santiago, Santiago de Compostela, Spain

[3] Faculty ITC, University of Twente, Hengelosestraat 99, 7514 AE Enschede, The Netherlands

[4] Departamento de Geografía y Ordenación del Territorio, Universidad de Zaragoza, Pedro Cerbuna 12, 50.009 Zaragoza, Spain

Abstract. The frequency and magnitude of natural disasters, increased by anthropic factors such as the intensification of agricultural activities, population growth, pressure on natural resources, and climate change, cause economic losses and negatively impacts the economy, health and security. One of the most effective solutions to deal with the risks associated with these events is prevention through proper land use planning, in which land administration systems provide land-related data for better decision-making, policy frameworks, and information infrastructures. The Land Administration Domain Model (LADM), ISO 19152:2012, allows each plot's rights, restrictions, and responsibilities, among others, to be considered at the municipal level, in accordance with adequate risk management. In this work, 1) the LADM, 2) the AS/NZS ISO 31000:2009 risk management system developed for New Zealand, and 3) the criteria used in Ecuador for the spatial planning of municipalities are combined in a single process. Next, applying the business management model to define the stakeholders and the main integrated processes in a single system was considered. Finally, the conceptual model for using land administration tools in managing natural hazards is presented, relating in a single system, the cadaster, tenure, value, planning, and use of the land.

Keywords: Natural hazard · Risk · Land administration system

1 Introduction

Vulnerable communities fail to create a complete land use planning (LUP) process to prevent or avoid natural multi-hazard losses increased by the characteristics and location

T. Guarda et al. (Eds.): ARTIIS 2022, CCIS 1676, pp. 112–124, 2022.
https://doi.org/10.1007/978-3-031-20316-9_9

of the communities and the lack of mitigation subjects in their local plans and development ordinances [1]. The significance of spatial planning for disaster prevention and mitigation is a better approach than the emphasis given to the preparedness and response processes usually resulting in more severe disasters [2]. Many case studies show that poorly planned land development, as well as urbanization and chaotic population growth on impermeable soil, increase the risk of disaster, and human and physical high damage.

"Natural disaster management has more to do with people than with land" [3] is a true statement related to poor land administration in less developed countries, where local governments have little incentive to develop strong hazard mitigation planning programs on their own [1].

Planning organizations are spread, resistant to change, not critical of their limitations, and usually have inadequate human, technical, and economic resources, reducing the research capacity to create scenarios for their local problems; therefore, collaborative synergies between planning institutions and research organizations can be a first positive step. At the national level, universities and research institutions can identify impacts and risks, and scientists can help in understanding the results of those models, encouraging the discussion to reduce their uncertainty [4], to finding the needs for new local specific research.

The LUP paradox is established when local governments fail to adopt mitigation practices even though disaster losses are primarily local because of the lack of mitigation measures that are not always visible in the short term of elected authorities. Local land use planners think that hazard mitigation planning is not under their profile but is under the control of emergency planners nationally that opposite have limited experience in LUP. On the other hand, local administrators believe that the government will meet their needs to minimize risk and recover from disaster and have less incentive to spend limited resources on mitigation [1]. Therefore, an integration process to develop risk disaster information in a unique distributed system is needed.

1.1 Overview of Concepts

In this part of the paper, among others, the United Nations International Strategy for Disaster Risk Reduction, UNISDR (2009) main concepts regarding to land governance (LG) and risk governance (RG) are considered, analyzed, and adapted within the land administration (LA) domain.

Land Use Planning (LUP). LUP is a public state responsibility process proposed to predict future land developments and to transform them into programs, plans, and activities including the practice of zoning for the best location of areas for different residential, commercial, industrial, and recreational uses, as well as to identify risky zones, using a multi-hazard risks reduction approach. It is a practical community empowered based process to provide people awareness of natural disasters, improve emergency plans for evacuation, relocation, and resettlement, and share information to reduce natural hazards´ losses making communities be resilient [1].

Land Governance (LG). LG is a political process considered the basis for human development and the creation of a sustainable living environment [5]. Related to natural disaster management, it is concerned to predict, prevent, and mitigate potential risks by integrating LUP processes with developing master and local plans, legal zoning, regulated standards, participative land policies, and the legal rights, restrictions, and responsibilities of all land uses [6]. It can be applied when urban communities have skilled planning offices to build consensus among stakeholders, integrating complementary planning within the social, economic, cultural, and biophysical dimensions to create multidimensional perspectives. Together with national and state institutions, as well as private experiences, local governments can develop LG instruments to increase financial and technical resources to support the study, design, and implementation of actions to reduce their vulnerability and enhance their adaptation [4] to the risk of disasters.

Land Administration (LA). Efforts to reducing poverty and social inequity can contribute to reduce social vulnerability by providing opportunities for sustainable development in rural and urban areas. One of these efforts is the use of LA to secure land tenure (LT) and reduce the vulnerability of people to natural disasters through improving the capacity on decision making to developing land policies using, among others: 1) the lessons learned from previous disasters, 2) real land valuation, and 3) the integration of risky areas and resettlement options in LUP in consultation with the community [7].

Poor people frequently have informal tenure, and usually are the most vulnerable to natural disasters when their houses are in risky and unplanned areas. LT including ownership and residential rights is usually considered within the traditional cadastre while restrictions and responsibilities may be additionally considered according to the new concepts of the Land Administration Domain Model (LADM) [8]. The LADM describes each parcel (object) with its proper characteristics like area, boundaries, and type of rights (rights, restrictions, and responsibilities) associated and identified by the name, legal title, address of the owner/holder (subject), as well as the knowledge about the land physical features like topography, soil, natural resources, infrastructures and networks, natural hazards, and roads.

Integrating the whole land information (LI) provided by a multi-purpose cadastre, it becomes easy to identify every parcel affected by multi-hazards and its landowner. If comprehensive LT and land valuation (LV) processes are additionally included, the local authority may have enough information to implement the legal issues related to land use (LU) rights, restrictions, and responsibilities in potential disaster areas, describing how resources and benefits need to be allocated into the management of land [9]. LA is the support of sustainable development that include institutional arrangements, legal frameworks, processes, standards, land information management and dissemination systems, spatial data infrastructures (SDI), and technologies required to support allocation, land markets, valuation, control of use, and development of interests in land (Bennet et al., 2013).

Risk. Risk has different meanings, and the most common concept refers to the probability of some potentially damaging event or a combination of likelihood and consequence. The well-known definition is Risk = Vulnerability x Hazard [2], or as stated by van Westen & Damen (2013), Risk = Hazard x Vulnerability x Quantity (of elements exposed). Risk results from the combination of hazards, conditions of vulnerability and insufficient capacity of measures to reduce the potential negative consequences. The risk of disaster is usually considered as the combination of the exposure to a hazard, the conditions of vulnerability and the lack of capacity to cope with the potential negative consequences, sometimes considered as the social or economic value of losses [10]. When the hazard becomes a reality, it is a disaster, whose impacts may include loss of life, injury, disease, and other negative effects on human and social well-being, damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.

Risk Management (RM). "Risk management is a formal planning process used to identify risk, estimate its potential impact, develop strategies to manage it, and monitor it over time.", and "mitigation is part of a larger risk management process and specifically refers to a-priori structural and non-structural actions or measures taken to reduce the potential impact of disasters."; the concept of prevention is related to the actions taken to avoid totally the damage from hazards [2].

Risk Governance (RG). "Risk governance applies the principles of good governance to the identification, assessment, management and communication of risks" [11].

2 Methodology

2.1 Processes and Interactions Among LUP and LA

LUP is a political process to legalize what is administrative and reasonably suitable for a space of land and, among others, what is restricted or under responsibility in a vulnerable area. It synchronizes different land uses (LU) according to national, regional, and local land policies, considering all tenure rights, providing regulations, and creating standards [1] to regulate the intensity of uses by formulating legal and administrative instruments to support the process. LUP tools, including zoning (ZO), subdivision regulations, building codes, and public financing of capital improvements to limit the level of exposure to hazards before an event occurs, should be applied by practicing mediation, negotiation, facilitation, and policy dialogue with all stakeholders involved [1].

The complexity of LUP increases due to continuously changing conditions such as the relation of land components and uses (residential, forest, water, agricultural soil, natural hazards), and the national, regional, local, or specific jurisdictions shared by multiple authorities that can promote different patterns of LU according to changing circumstances [12]. These ZO and land allocation processes divide a delimited territory into zones specifying permitted or prohibited uses and construction regulations to reduce potential conflicts between different land uses and disaster risk areas. Zoning maps, policies, regulations, and standards are created to enforce legal restrictions and responsibilities in sensible locations.

Improving LT in LUP processes also provides security to protect access to land, reducing the risk of future disasters to those holders of rights including owners, renters, as well as squatters considered the most vulnerable groups [13]. Creating restrictions and responsibilities in conjunction with recording all existing land rights, may contribute to each phase of disaster risk reduction (DRR): preparedness, recovery, risk identification and assessment, and prevention and mitigation; these also allow standards to be developed for areas vulnerable to natural disasters. In Fig. 1, letters A, B, C, D, E, F, G, and H describe the interactions between processes and represent the information provided and received from each other, which are specified later in Fig. 2.

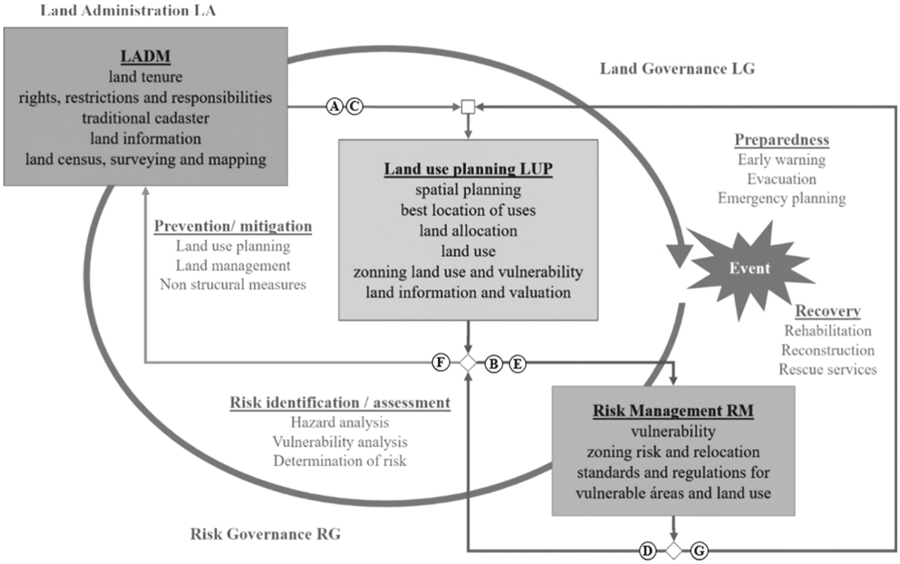


Fig. 1. RG, LG and LA within the DRR phases.

Before an event occurs, decisions and actions must have been planned in order to lead the recovery phase, considering: the affected population by displacement, relocation or resettlement, the demolition and reconstruction of damaged immoveable, the sites for disposal of waste and potentially recycling of these materials, the energy, the water and service lines for supply and transportation, and the farmland. Poor coordination between authorities could increase the magnitude and severity of natural disaster emergencies. In this context, one of the LUP's most essential tasks is coordinating the institutions and actors of RM representing specific interests. In most emerging countries, the LUP department and those responsible for RM operate in separate organizations; this brings little coordination among them due to specific mandates, orientations, and budgets. There is a mutual competition or ignorance with regarding land allocations such as transportation, environment, agriculture, residential, commercial, military, and parks, and little agreement on land and infrastructures development priorities [6].

In a good RG, the preparedness must have institutional, legal, and financial support to develop knowledge and capacities at all social and governmental levels. Given the bases to create well-organized response and recovery organizations that encourage resilient communities and individuals to anticipate, respond, and recover from the impacts of predicted multiple hazards. The prevention process deals with avoiding adverse impacts of natural hazards through actions taken in advance like the construction of dams or embankments to eliminate flood risks, the creation of land use regulations to restrict settlements in high-risk zones, and the improvement of seismic engineering standards for building in any predicted scale of earthquake. When the anticipation of losses is not entirely possible, prevention shifts into a mitigation process considered a sequence of structural and non-structural processes to reduce future damages, minimizing the impacts of natural hazards and disasters. It is divided into four categories: public information (hazard, exposition, mapping, and education), structural property protection (building and infrastructure strengthening, standards for construction), natural resource protection (preservation of ecosystems like dunes wetlands, and forests) and hazard avoidance (limited development, and relocation) [1].

3 Results and Discussion

Laws and ordinances regulate the development by dividing the community into zones and setting development criteria for each zone. ZO can keep inappropriate development out of areas located in hazardous zones and can improve LUP by placing certain areas for conservation, public use, or agriculture. A comprehensive LUP provides a mechanism to prevent development in hazardous areas and allows some developments in a manner that minimizes damage from hazards.

The levels of LUP depend on national, regional, and local public institutions and including RM in the planning process defines the ZO, nature and level of risks. Conformity among national, regional, and local planning is compulsory. First, by clarifying the national LUP at the regional level by locating and delimiting a risky zone more precisely and, secondly, by creating local legal standards to ensure control on LUP (providing restrictions and responsibilities), LT (providing formal property or possession rights) and LV (providing parcel value used primarily for taxation and conveyance). ZO can be used for DRR by prohibiting certain uses and constructions within risky flooding, landslides, erosion, volcanic or tsunami zones, and is a way to translate the concept of vulnerability in terms of restrictions and responsibilities to the spatial location of vulnerability and hazards.

Incorporating legal considerations, the ZO should enforce restrictions and responsibilities to land and property proper use. It does not mean that a state takes into custody a private land or property that must remain in the hands of the legal owner, who is obliged to respect the restrictions and responsibilities related to LU. It might be a prohibition to do something (restriction), like construct a residence in a flooding zone, or an obligation to act in a certain way (responsibility) like relocation after a certain period of time [14]. Therefore, within LA, risk assessment process, ZO may represent the spatial extension of risky zones associated with a set of regulations and standards concerning land use, land sub-division, and building.

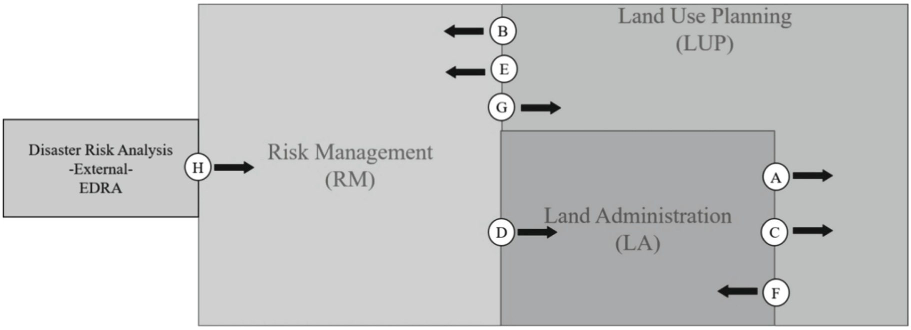
Non-agriculture and risky land usually do not have formal LT, have limited infrastructure with poor LG support, and the parties occupying these areas have settled there because they do not have other means of access to land. These landholders need to find ways to live with the threat of the disaster, respond when the disaster occurs, and to rebuild their homes and livelihoods after the event [7]. This is the case of annual flooding in lowlands of the river basins in Ecuador. Therefore, security of tenure is an essential factor in the reconstruction and restitution after a natural disaster and should be considered as an element of the vulnerability of communities to natural disasters in a good LG approach.

Using property data overlapped with multi hazard data is crucial to identify vulnerable structures and assess vulnerability and loss estimation. A good RG process reinforces the creation of websites to access and download hazard information. It should encourage the development of a community-based risk spatial data infrastructures (SDI) to continue promoting comprehensive and cost-effective analyses to be used in local land use plans and ordinances that reduce losses due to natural hazards. An example of the importance of creating SDI that includes not only land data, but also environmental and natural hazards information is the case of Portoviejo, Ecuador. The city was most affected by the 2016 earthquake; after the casualties and losses caused by natural phenomena, the municipality has implemented an SDI containing all municipal spatial data. It has emphasized planning and natural hazard information; nevertheless, the information is not yet adequately linked to parcels in the form of restrictions and responsibilities.

3.1 A Conceptual Business Process Approach to Integrate Multi Hazard Risk Analysis in RG, LUP and LA

LA process needs to consider standards such as ISO 19152 LADM [8], to continuously improve the requirements related to a variety of spatial registers of land like topography or buildings, and administrative information like names of persons, companies and their addresses [9]. It is important to define the contents of these data to avoid overlaps and to allow the re-use of information. However, there must be a constant updating of these independent/related registers to maintain consistency within and among databases. Spatial data support decision-making, spatial planning, and land and risk governance processes when integrated into an SDI to provide easy access and databases distribution.

Integrated inter-organizational business process management reduces administrative efforts based on good cooperation; solving territorial problems require information from many stakeholders with the complexity that it is stored at different locations and in specific data models [8]. The business process provides a clear methodology to visualize and organize the main processes and data produced by RM, LUP, and LA, where the ISO 19152 LADM can be the standard to shift into a parcel-based analysis. The first level of interactions is presented in Fig. 2, where the Disaster Risk Analysis is considered an external process (EDRA), provided by institutional processes outside the local (municipal) RM, which is the case in Ecuador. Each process at the same time is composed of sub-processes interacting through receiving, processing, providing, and sharing information. They are represented in the second level of processes and interactions.



A. Cadastral Information (Traditional multi-purpose)
B. Land Use Planning Information
C. Land Administration Information in LADM
D. Risk Information
E. Land Use Information
F. Parcel Based Land Use Information
G. Vulnerability and Exposure Information
H. Disaster Risk Analysis Information

Fig. 2. Main interactions among LUP, RM and LA

The RM uses disaster risk analysis information provided by external organizations and transforms it into vulnerability, exposure and risk information by combining it with land use planning and land use information, which is produced using cadastral and land information.

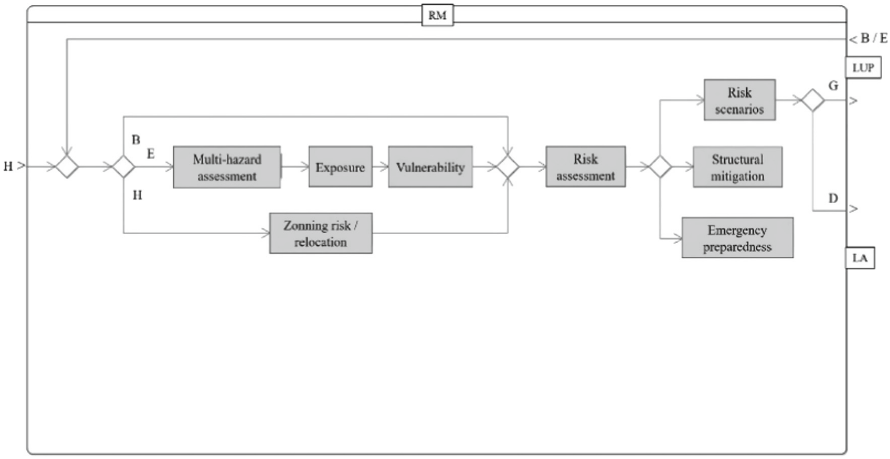


Fig. 3. Second level processes of RM related to LUP (B/E, G), LA (D) and EDRA (H).

The sub-processes considered in RM, at the second level, Fig. 3, are multi-hazard risk analysis, exposure and vulnerability definition, zoning risk and relocation, risk assessment, the definition of risk scenarios, preparation of issues for structural mitigation and emergency preparedness. The inputs for this process are the disaster risk analysis

(H), the land use (E) and the land use planning (B) information; the outputs are the vulnerability and exposure (G) and the risk information (D).

The sub-processes inside the LUP process are the definition of land uses, preparation of spatial planning, zoning and land use planning, Fig. 4, where the inputs are cadastral information (A), land administration (C), vulnerability and exposure (G) information; and the outputs are land use (E), land use planning (B) and land use parcel-based information (F).

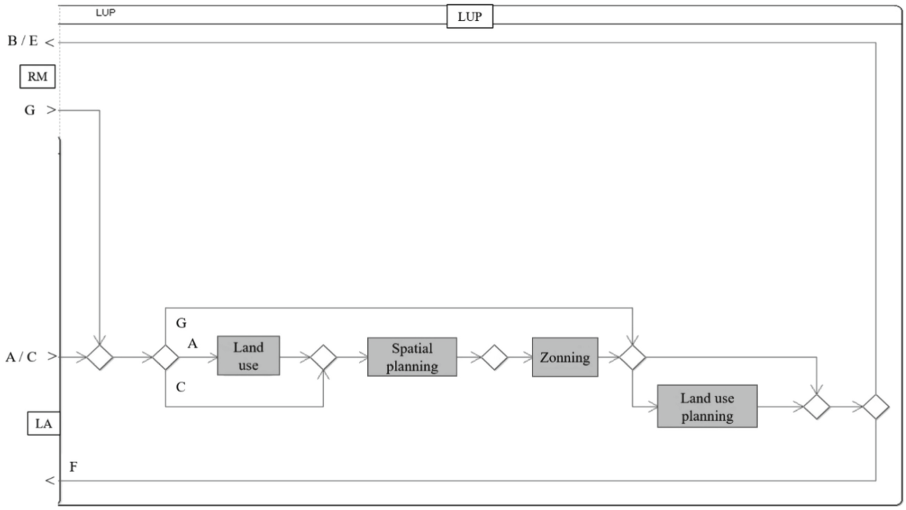


Fig. 4. Sub processes of LUP in second level and relations to LA (A/C, F) and RM (B/E, G).

Finally, in Fig. 5, the integrating process LA comprises the ongoing sub-processes of the land census, traditional cadastre, land information and valuation. These sub-processes produce land allocation, the definition of standards and land tenure policies, and the restructuration of cadastral information in terms of LADM ISO 19152, incorporating the tenure rights, risk restrictions and responsibilities which will be used in a parcel-based LUP process. The inputs are risk information (D) and parcel-based land use information (F); the outputs are cadastral (A) and land administration (C) information.

The restrictions and responsibilities are introduced (c) in Fig. 5, not just considering parcel and rights information from the traditional cadastre but complemented with the restrictions and responsibilities defined by the LUP process and risk analysis. At this point, the LA, the RM, and LUP processes are integrated into a unique parcel (Object/Spatial Unit) based information process. The parcel-based information process provides the rights, restrictions, and responsibilities (Rights/RRR) acquired from the risk and land use analysis, together with the parties involved (Subjects/Parties). This schema fits the new cadastre conceptual framework of Cadastre 2014, Objects - Rights - Subjects [15].

To provide a first approach to the classes used in the new integrated LADM model, the restrictions and responsibilities established in an external Basic Administrative Unit, such in this case as the river basin, are incorporated, Fig. 6.

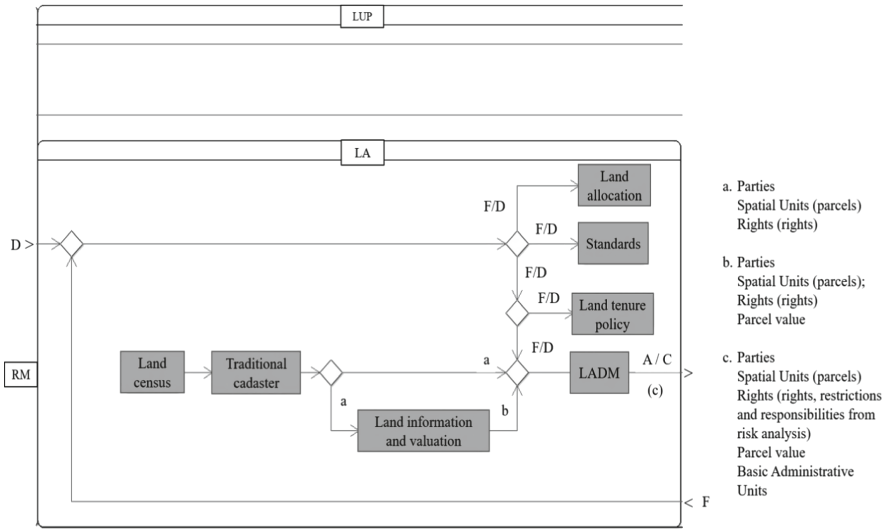


Fig. 5. Integrating LA using LADM as the link between RG (D) and LUP (A/C)

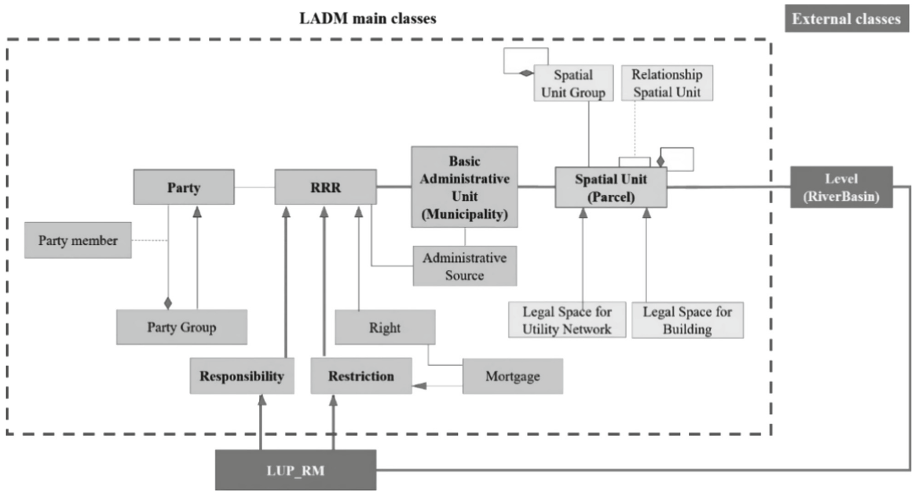


Fig. 6. Linking RM (restrictions and responsibilities) in LA using the LADM 19152 concept

The process of managing this risk results are LUP and RM which interactions correspond to the outputs B (Land Use Planning Information), E (Land Use Information), G (Vulnerability and Exposure Information), and D (Risk Information) as it is presented in Fig. 3 and Fig. 4.

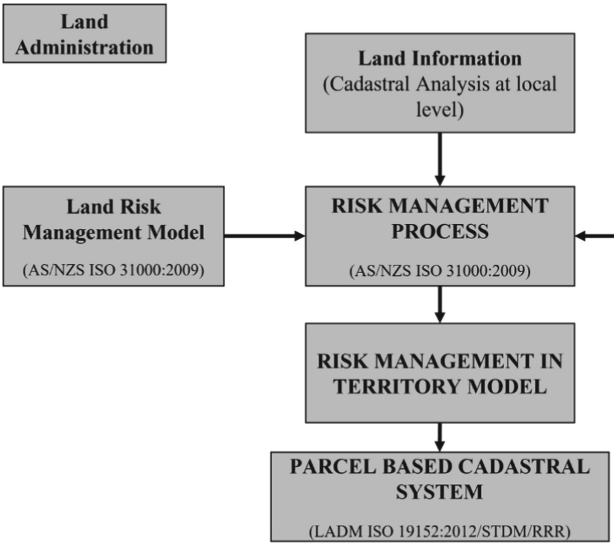


Fig. 7. Integrating AS/NZS ISO 31000:2009 in LADM 19152, adapted from [16]

This external-based approach named Level (River Basin) to manage the risk comes from using the conceptual model “Risk Management in Territory Model” to identify the vulnerability in terms of restrictions and responsibilities as can be seen in Fig. 7 [16]. The conceptual model in the figure relates two methodologies that link land data and land planning with disaster risk management. The first is the “Land Risk Management Model”, which proposes an improved and effective management of risks affecting stakeholders and treating land and property; the second is the “Risk-Based Planning Approach”, created to include the assessment of the risk of natural hazards in the land planning. Developed in Australia and New Zealand correspondingly, these methodologies not just highlight the stretch relation between LA and disaster risk management but the importance of using standards such as AS/NZS ISO 31000:2009 (for vulnerability assessment), and LADM ISO 19152:2012 (restrictions and responsibilities).

4 Conclusions

Innovation within the use of the LADM may benefit jurisdictions without sufficient standardization and integration for RG, LG, and LA processes. This issue mainly affects countries with no tradition in including risk analysis in planning processes, no proper registration of tenure rights in the cadastre, and where different organizations are in charge of executing these processes at different levels of government decision-making.

The main idea is to use LADM in LA to link RM and LUP in a parcel-based model to provide information on the vulnerable parcels considering restrictions and responsibilities in an LUP process including RM. Working in terms of processes allows managing the isolated input/output information in a single system, although they are executed by different organizations and in different places; that is one of the goals of SDIs.

As it was considered, in Ecuador, the DRA is an external process executed by state organizations together with universities and research institutions. However, LA is a typical municipal process developed mainly for taxation; meanwhile, land tenure rights are under the property registry autonomous process. Land administration has the concept of territorial order and is considered a product following the LUP. Another critical issue is that there is no standard or model for the core cadastre system at the time of this research, driving the municipalities to have different cadastral systems and regulations. Therefore, the main idea is to standardize a group of municipalities in a unique methodology, process, and information management for DRR, including LUP, RM, and LA, using the LADM ISO 19152 standard to integrate them.

In the same way, it is important to consider the vulnerabilities, hazards and risks within the proposed model for the planning of new areas to be urbanized, leaving aside the traditional cadastre that consists of determining the relationship of geometric, economic, and legal data of the parcels with their owners, as in the case study developed in the municipalities of Aloag, Aloasí and Machachi, where a support tool is incorporated to design a land administration model with biophysical, socio-environmental, and risk criteria in areas of urban expansion.

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