

# A research agenda on geoinformation sciences towards responsible land administration in Colombia

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## SUMMARY

After *Peace Agreement 2016*, new challenges in Land Administration and Land Tenure take relevance in Colombia. This document presents new perspectives on the challenges around land tenure in Colombia. We did three activities a SWOT analysis, a workshop on the research subject, and a literature review about the topics studied by the researchers. As a result, we found the internal and external relationships between Universidad Distrital, different actors, and trends in geoinformation science and land administration. For an efficient and reliable Land Administration System in the mid-term, Colombia needs articulation among different entities responsible for the different parts of the process. In that way, it is necessary to have an infrastructure for implementing multipurpose cadastre, tertiary roads, irrigation, electricity and connectivity, and areas of interest for conservation, which in Colombia are fundamental elements of the peace agreement for the comprehensive rural reform. This way, it is necessary to provide the country with knowledge and information that integrates technical concepts, geospatial technologies, and data sources.

## 1. Introduction

The contemporary discussion on land tenure has two concepts about land administration and territory. When discussing land and territory, there often needs to be more understanding of associating them with the same concept. Therefore, it is necessary to clarify these concepts' differences from a general point of view. On the other hand, "Territory" refers to a broader and less limited space: the totality of the habitat of regions that are occupied or otherwise used; that is, the land, but also the natural resources used by the human population and the environment (Snoeck et al., 2014). Land tenure security (*LTS*) corresponds to the perception of landowners that their rights will be defended by society (Sjaastad and Bromley, 2000).

However, the measurement of that perception needed to be sufficiently documented over the years, and conventional approaches seem to fail for the most vulnerable (Zevenbergen et al. 2013, Zevenbergen et al. 2015, Abdillah 2022). It is possible to mention four factors guide the variability and complexity of land access pressures over time: a) the pressure exerted by the most powerful (vertical power); b) that exerted by peers or people of the same social status (horizontal power); c), technological dynamism that allows the expansion of limits towards land use for obtaining more resources and, d) catastrophes induced by natural or anthropic events

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(Sunderlin and Holland 2022). In addition, tenure security varies due to gender, ethnicity, and social class. Therefore, an in-depth analysis of LTS requires careful studies of the contexts and history of the populations of interest (Sunderlin and Holland, 2022). In this sense, the study of land tenure has to do with the geographic component and the economic, legal, and coexistence implications. However, in countries like Colombia, such analysis has traditionally focused on the geographic part with fiscal intentions.

Geographic information activities in Colombia have been the Instituto Geográfico Agustín Codazzi (IGAC) responsibility for more than 80 years (Gonzalez 1977). The Institute has been responsible for producing the Colombian official map and basic cartography, as well as the National Cadastre, the inventory of soils, and conducting geographic research throughout the process, i.e., studying the geodetic, topographic, cartographic, photogrammetric, and information systems components, and also coordinates the spatial data infrastructure (Duarte 2001). The IGAC supports the system that guarantees land tenure in the country and provides the parcels' geographic information, and the Registry office is responsible for granting land titles. This system has its advantages and disadvantages. In the first place, the cartographic updating processes are complex due to the scarcity of resources and the high technical specifications required. Secondly, the registry information is usually found with higher levels of updating, but they are obtained from various sources that generate uncertainty about their validity. Finally, the cadastre-registry system is mainly oriented towards the ownership of private parcels. There is a neglect of institutional parcels and public use properties such as roads and national lands such as river and coastal strips and environmental conservation areas or areas of national interest, among others (Duarte 2001).

## **2. Research priorities in geoinformation science in Colombia**

In Colombia, in the last five years, a series of events have taken place that has become challenges for the country's development. On the one hand, the Peace Agreement signed with the FARC guerrilla in 2016 established a path towards comprehensive rural development. That includes a comprehensive agrarian reform in which, among others, the creation of a land fund, an issue of 7 million hectares of land titles, development of quality rural cadaster, and an offer of complementary programs including road infrastructure, communications, irrigation, and land improvement, as well as education and health programs (Melo et al. 2016). The comprehensive rural reform then focuses on access to and formalization of land and, through Law 902 of 2017, defines the recipients, creates the Land Fund and its forms of access, the formalization of private property and its legal security, and the procedure for the implementation of the social ordering of rural property (Camargo 2018, Bedoya et al, 2020). Indeed, comprehensive rural reform involves aspects of rural development, agricultural growth, and the consideration of the territory as a planning unit for the implementation of strategies that allow the economic and social growth of communities (Machado 2009).

For its part, the CONPES policy 3958 issued in 2019 establishes the strategy for the implementation of the Multipurpose Public Cadastre Policy in such a way that there is a complete, updated, and reliable cadastre with a multipurpose approach that is consistent with the registry of property ownership, digital and interoperable with other information systems by

2025. The first is that the cadastre historically worked as a fiscal tool for obtaining resources. The second is that the information is disseminated in different entities, which is acceptable but could be better. However, sometimes the same information is obtained separately, so its consistency could be improved.

In addition, Colombia has also signed international agreements to meet the Sustainable Development Goals (SDGs), which encourage nations to establish sustainability as a fundamental axis of their public policies in their development models. Goals such as the reduction of greenhouse gas emissions, carbon capture, protection and conservation of forests and watersheds, food security, providing safe and affordable housing and transportation, resilient and smart cities, adaptation to climate change, and conservation of coasts and seas require measurements and monitoring as an observatory for compliance with the goals proposed by the SDG (Pardo and Cotte 2021).

Even though Colombia has a land administration system, there are different challenges from all the national and global agreements. Hence, all these programs require a robust geographic infrastructure that includes reference frameworks, spatial data infrastructure, interoperability of geographic information, geographic databases, and techniques for capturing geographic information from different sources, among the most important. Therefore, the development of applied research constitutes a platform to obtain the missing information and support urban and rural communities in the management of geo-information for decision-making and support in the construction of infrastructure under the challenges posed by public policies and the peace agreement (Perea 2019).

The objective is to present new perspectives on the challenges around land tenure in Colombia. This document consists in providing researchers and other stakeholders with new perspectives on the challenges around land tenure and geoinformation under the analysis of aspects from direct and indirect methods for data acquisition, data science applied in geospatial technologies, and the treatment of tenure in unconventional parcels such as natural parks, roads, and river corridors.

### **3. Methods**

To formulate a research agenda, the group ran discussions to identify key issues, challenges, and research opportunities. The first step was a SWOT analysis of Universidad Distrital research on Land Administration, and Geoinformation presented in Table 1. The group was integrated by faculty members of the Universidad Distrital and the University of Twente, with different approaches to LA Cadastral and Geodetics, Data Science and Civil Engineers, Economist and Mathematicians were there. Also, they did doctorate programs related to Land Administration, Geosciences, Geodata Sciences, Geoinformation Systems, Environmental Valuation, Social Sciences, and Sustainable Infrastructure. Other participants from Colombian institutions like the National Planning Office, The National Department of Statistics, and The National Registry provides the issues they face nowadays.

*Table 1. Swot Analysis Land Administration Research at UD.*

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<b>Strengths</b>	<b>Opportunities</b>
There are consolidated research groups classified in the Science and Technology Ministry.	In the coming years, the National Government will develop policies related to LA, where research groups can actively participate.
The Universidad Distrital's policy supports research projects proposed by professors and students.	There is an important need for LA professionals in different fields, including research.
The Universidad Distrital has a high-performance computing center that supports research projects.	The development of geo-technologies allows direct applications for Technologists and Engineers of the Universidad Distrital in the implementation in LA.
The curriculums of the Cadastral and Geodesy engineering and Land Survey Technology academic programs have been updated to include LA topics.	New technological advances in geographic information sciences and earth sciences as support for decision-making at all levels (national, local, and regional).
Universidad Distrital leads the training of LA professionals in Colombia	In recent years, the country generated a wide range of national regulations in the area of land administration.
There is an important group of alumni working in different dimensions of LA.	Because LA is a multidisciplinary field, other professionals are leading their topics in cadastral engineering and surveying technology.
	The University has agreements with different national and local institutions related to LA.
	The Universidad Distrital can become the leading educational institution in Land Administration and Geotechnologies, achieving participation in rural and urban development policy-making.

<b>Weaknesses</b>	<b>Threats</b>
The low number of interdisciplinary and multidisciplinary research projects in the Faculties of Engineering and Environment and Natural Resources	National academic programs in Technology and Engineering have been strengthened in Land Administration and Geotechnologies faster than the Universidad Distrital.
The few research projects related to Land Administration and Geotechnologies focused on vulnerable communities and society in the territories of Colombia.	The Universidad Distrital has been outside of the LA public policy.
There needs to be a communication strategy to promote and disseminate research work and completed projects to the academic community of the Universidad Distrital.	There is no national research agenda for Responsible Land Administration in Colombia
Low interaction with the international scientific community for academic cooperation.	No community or academic networks in LA related to land management
Students need more incentives for research activities to be able to participate in research projects.	LA policy needs a long-term strategy, generating uncertainty for the country.
Research projects generate marginal impacts on the curriculum and the academic community of the University.	Lack of research funding
Lacking LA dimensions in the undergraduate curriculum and research limits theoretical, conceptual, and methodological developments.	
Need for long-term research agenda with the stakeholders of the national LA system.	

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Neither the Universidad Distrital nor its academic programs impact the country's public policy.

With SWOT analysis was possible to conclude three important results. First, despite the weaknesses recognized, UD has a relevant group of researchers in Land Administration and geoinformation sciences to conduct a new research agenda. Second, Due to the Colombian Peace Agreement and new national policies, UD has a wide spectrum of opportunities to contribute to the decision-making in Land Administration and Geoinformation. Thirdly, it is necessary to increase the visibility of research activities and projects made by UD to recognize Colombian society. Finally, despite the scarcity of research funding, it is an opportunity to look for international support and participate in cooperation projects with international partners.

As a second step, a workshop about the research subject was established. In the brainstorming, we defined the target of four key elements to develop the research agenda in the mid-term period. Figure 1 presents the relationships between those four main topics, the internal and the external ones. The former is related to the politics of the Colombian Peace Agreement (2016) and the geographical framework of Universidad Distrital. Colombia's peace agreement includes Land Tenure Security, Mobility, and Food Security, and the faculty members planned to work in Bogotá Region.

The latter is the international topics in geoinformation sciences related to theoretical concepts, Data Sourcing, and Technology. Furthermore, the topics where the researchers have any expertise to develop in land tenure and responsible land administration related to Socio-Political dimensions, Environmental Valuation, Data acquisition, Fit for Purpose LA, Geo Data Science, and Public Areas.

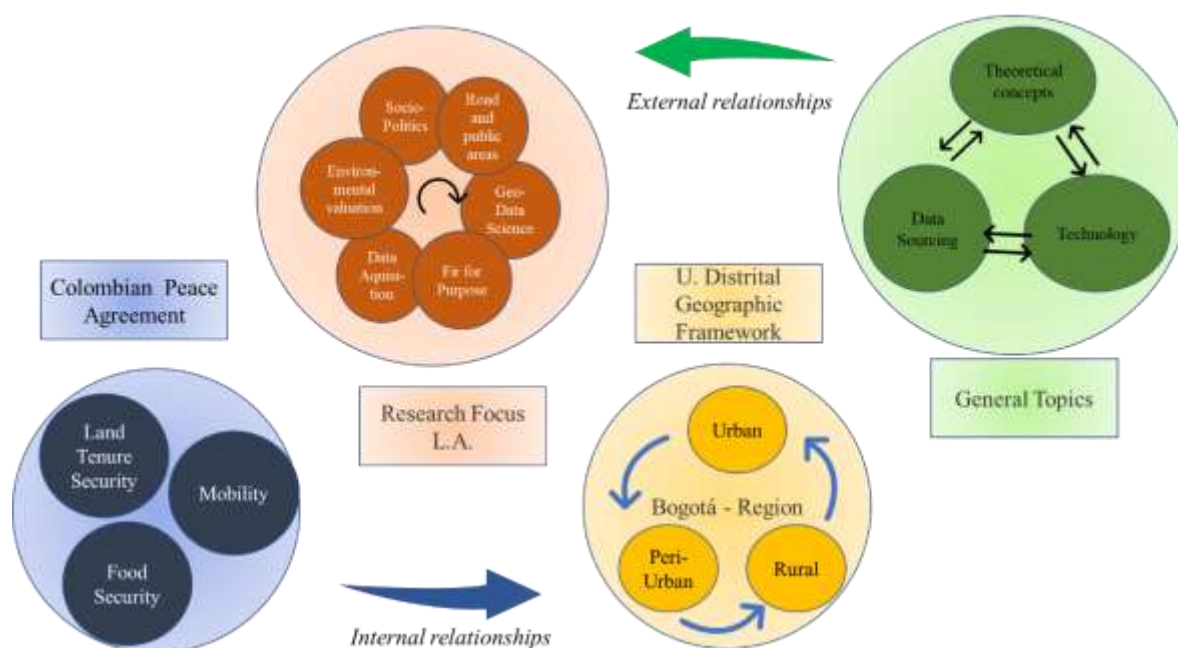


Figure 1. Key elements of the Research Agenda

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The third step consisted of a review of those topics that emerged in step two. The themes in figure 1, named Research focus LA, regarding General Topics and the Colombian Peace Agreement, especially in Land Tenure security. At this step, we had to inputs the Peace Agreement and the geographic framework, viz: Bogotá region. After that, we related the last two elements with the external relationships shown in figure 1. The General Topic refers to the three main research topics related to geoinformation sciences, and the Research Focus is related to the strengths of the formulation group of this agenda. After several discussions, the group defined the themes established in figure 1 as the Research focus. With these themes, every integrant develops a document with a literature review and the challenges Colombia needs to address to reach a good Lan Administration. A summary of these documents is presented in section 4.

The review was oriented by the following guiding questions: (1) How is the subject matter conceptualized within the literature; (2) What methods have been used to reach the results; (3) What results have been reported; and (4) What are the important areas for future research? The review explored different academic and scientific databases such as Google Scholar, Scopus, Web Of Science, and Science Direct with the keywords land tenure, public land tenure, land tenure for conservation, land formalization, rural land, property, rural poverty, and land administration system combined with socio-politics, road and public areas, environmental valuation. Data acquisition, fit for purpose, and geo data science.

## **4. Research agenda**

### **4.1 Socio/political dimensions of land administration in the context of tenure regulation.**

Together with the implementation of a new multipurpose cadaster model, the need to think not only of the census exercise -cadastral- but also of a broader perspective that articulates the whole set of units, entities, jurisdictions, and dimensions of land tenure relations: *Land Administration System (LAS)*, as it is internationally referenced. In Colombia, a tacit land administration system has always been implemented according to the ups and downs of historical, socio-political, and institutional needs (Tello 2020). The difference between the current context and before in the country is that we want to formalize LA under an institutional concept with normative and regulatory institutional frameworks (Botero et al., 2020). From this perspective and based on the hypothesis that the pre-existing forms of land administration in Colombia coexist with the recent incursion of a multilateral approach to *LAS*, it is necessary to characterize in this research agenda what these perspectives imply, their dimensions, their characteristics, their approaches, their challenges, their dynamics, their tensions, lessons learned and perspectives.

From an institutional perspective, a *LAS* is a mechanism to support the management of the land property of a country or a political-administrative jurisdiction. Land administration processes include regulating land development and ownership, using and conserving land, capturing land revenues through sales, leasing, and taxation, and resolving conflicts regarding land ownership and use (Williamson et al., 2010). In the case of Colombia, the law establishes the commitment to regulate the implementation of a National Land Management System, which would be based

on information from the multipurpose cadastre, the public land registry, and land use planning. According to Páez (2018), who emphasizes the post-conflict situation and the challenges that legislation must have to promote policies based on equity and operability, today, it is possible to say that the development of a modern registration system and cadastre of property in Colombia has failed. To address this issue is necessary to articulate Land Administration, Autonomy, Automation, and public-private partnerships (Paez 2018).

Land administration is an umbrella that provides the conceptual framework to ensure land use, land value, land development, and land tenure security (Kalogianni E. 2020). Autonomy refers to the fact that territorial entities must be autonomous and develop their administration processes and territory recognition. With automation, the idea is to convert complex processes into small ones for linking technologies to reduce time and costs (Enermark 2021). Finally, public-private partnerships, because the IGAC does not have the operational capacity to solve all the country's territorial problems, other actors must be involved to solve the problem, in this case, private enterprise (Paez 2010). The challenge consists of articulating these four concepts with real practice in Colombia.

#### **4.2 Land tenure and inclusion of environmental valuation**

The study of environmental elements and the relationship of land tenure security presents important challenges in the evaluation, uses of information, evaluation methods, and evaluated variables, among others, aspects necessary to guarantee a LAS that generates policy inputs to advance in the implementation of sustainable development objectives and biodiversity conservation strategies and ecosystem services (Enemark et al., 2005; Long et al., 2018). Therefore, the analysis of environmental attributes complements the assessment of land tenure security and the implementation of LAS with conservation and protection objectives for areas of environmental interest (Bose, 2017; Novikova et al., 2018).

In Colombia, the land tenure problem has been addressed mainly in regulatory, social, and economic issues (Albertus et al., 2013). Tenure security and its relationship with environmental aspects have yet to be included in the diagnoses of municipalities in rural and urban areas, with little development of their cadastral information (Armenteras et al., 2011). Information gaps persist in the country that limits research in areas of environmental interest due to land use conflicts (Etter et al., 2006; Sanchez-Cuervo et al., 2013). Likewise, there is a lack of recognition of the importance of conservation areas in the country that does not have a property reality of key areas for biodiversity conservation (Bautista-Cespedes et al., 2021; Etter et al., 2000; Suarez et al., 2018). Indeed, environment and land tenure are relevant topics in the research of the country's LAS that explains the forms of occupation of areas of interest for conservation or the provision of ecosystem services.

#### **4.3 Land tenure on roads and public areas**

Lands of public character include parks, monuments, protected areas, refuges, national parks, reserves, marine sanctuaries, riverbeds, forests, jungles, and roads, which are considered assets of the nation and provide natural resources and services to the inhabitants of their surroundings (Black B, 2014). Different researchers have addressed the tenure of public lands, especially for conservation purposes and the management of natural resources (Katusiime, J., & Schütt, B.

2020, Robinson, B. E, 2018). For their part, roads have been the territory's transformers. They are an important factor in land tenure, given that they allow access to places and enter public services such as electrification, television, communications, and drinking water.

In contrast, negative effects such as forest loss are associated with the penetration of roads and other infrastructure (Aguilar et al., 2022). Although access to territories by roads is synonymous with occupation, most of the time, and plots along roads may have greater tenure security, evidence on the legal security of tenure of territories along roads and even more so of the roads themselves is scarce (Hausner et al., 2015). On the other hand, other areas of a public character, such as rivers, streams, and ravines that include their banks, are territories that still need more clarity on tenure. Even when they are considered public use and conservation areas, the limits assigned to them correspond to fixed distances from an axis that is not always proportional to the flows and backwater areas that are variable due to the dynamics of their behavior. Although there are guidelines on the public use strips that are part of the roads and riverbanks or coastal areas, the legal treatment, registration, and tenure of these areas is still uncertain, which constitutes a challenge for the research to clarify the situation and how to incorporate them into the LAS effectively.

#### **4.4 Direct data acquisition methods**

The land administration system's acquisition of geographic data on plots and parcels is a sensitive element. The quality of the spatial data's geodetic information (latitude, longitude, and height) ensures an adequate cartographic representation (Dermanis, A., and Rummel, R 2000, Devillers, R., and Jeansoulin, R. 2006). So, the *geometric* information of the land is transformed and must be adjusted in a *cartographic reference system*. The titling processes were initiated to improve tenure security and facilitate access to land for cash crops in Ghana, Africa, for which an implementation of modern database systems and high-precision GNSS was carried out to meet the requirements of the Land Commission (Asiama et al., 2017).

In Colombia, there is a wide range of regulations on land administration related to GNSS, and there are political guidelines for implementing the public policy on Multipurpose Cadastre. The IGAC is responsible as cadastral manager for the cadastral's physical and legal components, necessary for the social organization of property or those associated with the development of strategic projects of the national order prioritized by the Ministry of Agriculture and Rural Development. Based on the above, the guidelines and procedures for correcting or clarifying, updating, rectifying boundaries and areas, physical modification, and including real estate areas have been regulated. In addition, the technical specifications of the planimetric survey are adopted for massive property survey activities, and the technical specifications of the topographic and planimetric survey are for specific cases. In addition, the technical specifications of the country's official basic cartography are formulated, with scope in orthoimages, digital terrain models, and the cartographic database. The technical specifications for the information products generated by the cadastral formation and updating processes with a multipurpose approach are established. The Extended Cadaster Registration model of the LADM\_COL model is adopted in the approved version as a standard for the interoperability of the multipurpose cadastral information.



The challenges of implementing multipurpose cadaster must include the standards and regulations for acquiring massive geodetic data that comply with national regulations for planimetric and altimetric surveys. In this case, Geodesy, as the science in charge of the quality infrastructure of the systems and reference frameworks in the implementation of multipurpose cadaster, is a science that plays a determining role in the quality of spatial data, for the fulfillment of the precision in the acquisition of mass data of cadastral properties, not only in the control of geodetic networks but also in the control of the quality of the data acquired with other massive techniques such as indirect ones.

#### **4.5 Geospatial data science**

*LAS* requires a solid conceptual basis and an appropriate technological platform to fulfill their objective of securing land tenure (Ting and Williamson 1998, Fourie, C. 2002, Williamson, I., Grant, D., and Rajabifard, A. 2005, Williamson I. et al., 2010). The approach that can be offered from geospatial data science is to work on an agile and economical hardware and software architecture in the process of capturing, consolidating, presenting, and managing the information involved in land tenure, using international standards and references adapted to the Colombian reality.

Evidence in geospatial data science has been applied in different fields, showing innovative ideas that can be adapted to improve some of the processes of land administration (Milindi D. et al., 2022, Williamson I. et al., 2010). The new policies framed in the land administration in Colombia implemented since 2019, specifically in the multipurpose cadastre, are defined in a standard model based on LADM (Lemmen et al., 2015). However, its adaptation to the reality of Colombia implies developments for its effective implementation. Therefore, spatial data science plays a preponderant role in the different necessary applications that respond to the needs required in its construction.

Thus, to address the land tenure problem, there is currently a *LAS* that has difficulties but can be improved. Therefore it is necessary to obtain access to decision-making to integrate research and administrative capacities since it is not easy to move from theory to practice, so the academy can play a decisive role in achieving the goal. The Universidad Distrital can become a conceptual, application, and dissemination reference in implementing methodologies for land administration and multipurpose cadastre through the practical development of projects that show the effectiveness and viability of its developments adjusted to the practice of the state agencies responsible for land administration.

#### **4.6 Fit For Purpose Land Administration - FFPLA**

Geospatial Technologies are indispensable tools for geographic information management. Using these technologies in managing spatial information from different sources is a challenge, specifically applying indirect methods such as the *Fit for Purpose* Land Administration (FFPLA) methodology. FFPLA is a concept focused on the construction of sustainable land administration systems adjusted to the conditions of developing countries. This proposal arises from the cooperation between the World Bank and the International Federation of Geometers

(FIG) in response to the SDGs the United Nations Development Programme (UNDP) put forward in 2016. The FFPLA methodology is currently in an implementation and evaluation stage to assess its effectiveness and to verify the benefits for which it was conceived (Lemmen 2015).

In the FFPLA, *LAS* should be designed to meet the security of tenure for all in a short time and low cost, adapting, to that end, the relevant legal, spatial, and institutional frameworks. The first objective is to achieve broad coverage and a comprehensive overview and then gradually improve over time, through improved accuracy, legal requirements, and institutional processes, in supporting the achievement of the SDGs (Molendijk et al., 2018). In this methodology, technology for geospatial applications is an important tool for its implementation. In Colombia, FFPLA initiatives have been conducted at the level of pilot projects and involve a limited number of stakeholders, finances, and strict timelines. Even if these pilot projects were successful, scaling up these initiatives to a regional or national level is a major challenge, given the complexity of national government institutions. While the necessary technical and administrative tools have been developed to improve territory management and formalized records, the challenge is to involve new technological tools for these innovative proposals (Rocha et al., 2019).

In the framework of the pilot projects, the data capture method used in Colombia for FFPLA is the field survey with portable GPS, and the extraction of boundaries from radar images has been explored in a very preliminary way. The results achieved in implementing FFPLA in Colombia have focused on data capture and public inspection, both in post-conflict municipalities and with indigenous communities (Molendijk et al. 2018). The generation of geographic information for Colombian municipalities could be faster and more efficient, given the low budgets of municipal governments. Likewise, the existing information needs to be updated, which is why the proposed FFPLA methodology is an alternative that allows obtaining cadastral data in an agile way from different sources to streamline processes. Thus, alternative methods can be explored and validated in the FFPLA methodology.

## **5. Discussion and conclusions**

This manuscript aims to present new perspectives on the challenges around responsible land tenure in Colombia. Under the analysis of the socio-political dimensions of land administration and including aspects of direct and indirect methods for data acquisition, data science applied in geospatial technologies and the treatment of tenure in unconventional parcels such as natural parks, roads, and river corridors. The big challenge is analyzing external and internal components to reach Land tenure security. In Colombia, we faced the Peace Agreement, and the UD has a territory influence as called here as internal elements. Hence, the global trends in geoinformation (external elements) would be addressed to link technology and data based on theory to accomplish the country's needs.

In practice, what could be called the Administration System of the Colombian territory certainly already exists and has been constituted according to the ups and downs of historical, socio-political, and institutional needs. However, this fact has generated that the inter-institutional

processes have a weak and unsatisfactory interrelation in understanding the certainty of tenure, value, land use, and its social, economic, cultural, and environmental relations. As aforementioned, political and institutional priorities have weighed more on this pre-existence than the clear pretension to solve the socially problematic situation. Land Administration without people's engagement is a major constraint to the achievement of land tenure regulation.

Efficient and reliable LAS requires an infrastructure that allows articulation between responsible entities on the different parts of the process. For the implementation of multipurpose cadaster, tertiary roads, irrigation, electricity, and connectivity, areas of interest for conservation, among others, which in Colombia are fundamental elements of the peace agreement for comprehensive rural reform. This way, it is necessary to provide the country with knowledge and information that integrates technical concepts, geospatial technologies, and data sources. In the case of technical concepts, progress must be made in areas such as the geoidal model, geoidal undulation models for cities with flat topography, local topographic plans, atmospheric correction studies for GPS in the equatorial zone, and adjustments to reference systems. On the other hand, the geospatial technologies topics are intended to continue with the broad discussion on GNSS Services and the Internet of things with geographic applications. Geovisualization, Augmented Reality and Virtual Reality, Building / Infrastructure Information Modeling, Digital Twins, Geographic Big data and cloud computing, Machine learning, advanced geospatial applications for smart cities and regions, location-based services, data fusion, disruptive technologies, and precision agriculture. Thirdly, regarding data sources, topics such as Mobile Mapping Systems, UAS-oriented sensors, Point cloud processing, Remote sensing data fusion, Information extraction from LIDAR, Hyperspectral image processing, and Collaborative, crowdsourced cloud mapping, among others, should be addressed.

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