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Application of Participatory Methods to Explore Changes in Land Use of a Tropical Dry Forest Basin

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Abstract

Tropical hydrographic basins have undergone significant land use change processes in recent decades and correspond to areas of high population growth and development of economic activities. This article explores the causes of land use change in a tropical dry forest watershed, taking the Canalete river basin as a case study. For this purpose, stakeholder analysis techniques and participatory methods were applied. The results showed that the main causes of land use change in pastures were associated with biophysical factors, while forests-shrubs and crops were associated with direct and subyacents socioeconomics factors respectively. The participatory mapping allowed obtaining a desired land use scenario for the year 2030, observing a decrease of more than 16.2 ha of pasture, compensated by an increase of almost 2.4 thousand ha of crops and 13.8 thousand ha of forests and shrubs. Similarly, the hydrological impact of changes in land use was observed, especially in terms of flooding.

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1. Introduction

Tropical regions experience natural changes in land cover due to varied factors such as growth of forest stands and climatic processes. Nonetheless, anthropogenic disturbances, such as deforestation, are the major alteration factors (Smithsonian Tropical Research Institute, 2015). The favorable climate conditions in these regions have encouraged rapid expansion of human settlements and establishment of economic activities that modify plant cover and land use. Therefore, efforts should be increased towards understanding of drivers of change and processes in tropical ecosystems (Kalácska *et al.*, 2005).

According to FAO (FAO (Food and Agriculture Organization), 2016), in the tropical countries there was a net loss of forests of 7 million ha/year from 2000-2010. Underlying factors affecting forest conversion include population growth and changes in food consumption habits. The expansion and intensification of agricultural production is the immediate cause of 80% of deforestation worldwide (Kissinger *et al.*, 2012).

Globalization and increased incomes have created growing demands for products, which, with land availability in the tropics, have boosted cultivation and grazing in rural and forest lands (Lambin & Meyfroidt, 2011). Commercial agriculture, including crops and pastures is the most crucial factor in deforestation of tropical and subtropical countries causing 40% of deforestation, subsistence agriculture, 33%; and the rest is distributed among urban expansion, infrastructure and mining (Hosonuma *et al.*, 2012). Overall, cattle farming is the major driver of biodiversity loss (Marques *et al.*, 2019).

On the other hand, river basins constitute an area where natural environment and socioeconomic systems interrelate (Garcia, 1998), reason why it becomes a unit of analysis conducive to the identification and analysis of changes in land use. Also considering that basin management is deemed as an integrated system within which multiple decisions are made regarding land and water use (Smithsonian Tropical Research Institute, 2015).

Nevertheless, the Inter-American Development Bank (Banco Interamericano de Desarrollo, 2012) has defined as good practices for basin management: knowledge of conditions and behavior of natural and socioeconomic resources, active participation of relevant stakeholders and the long-term vision. Participation in basin management is an essential element because social stakeholders are determinants in land uses (Reed, 2008), which becomes even more relevant in tropical basin due to economic development and population growth processes involved, and for the needs of populations (Coxhead & Shively, 2005). For instance, Colombian government authorities have a watershed planning instrument, called POMCA by its acronym in Spanish (Plan de Ordenamiento y Manejo de Cuencas hidrográficas) (Bolaños-Valencia *et al.*, 2019), which includes a participation strategy in its different stages (Aranda Echavarría & Vidal González, 2020).

This article explores change causes in land use in a tropical dry forest basin, taking as a case study the Canalete river basin. Stakeholders' analysis techniques and participation methods were applied to identify the change causes in land use, to build a desired scenario by 2030 and research on the perception of the relationship between hydrology and land uses. The aims of this research are: 1. Identify the set of dominant drivers of land use change processes, 2. Recognize the needs and interests of key stakeholders in a future scenario, 3. Investigate the key stakeholders understanding of a socio-hydrological system.

In the context of a tropical dry forest basin, an ecosystem with strong seasonality and recognized as one of the most threatened by changes in land use, the research questions are: Are the causes of change in land use biophysical or socioeconomic (direct and underlying)? Is it possible for the key actors to jointly express a future scenario and their interests? Do the key stakeholders recognize the relationship between land use and hydrology? We applied participatory methods that represent a novel and applicable research approach to explain complex processes, where there is no universal link between causes and effects.

After this introduction, the second section of this paper presents a Literature review and theoretical framework for causes of land use changes. Section 3 describes the study area and methodology proposed for explore changes in land use of a tropical dry forest basin. Section 4 contains the application to the case study and results and Section 5 concludes.

2. Literature review and theoretical framework

Causes of land use changes can be classified as direct and indirect. According to Lambin *et al.* (Lambin *et al.*, 2003) direct causes are human activities (e.g., commercial reforestation) and indirect or underlying causes that constitute conditions in the human-environment relationship (e.g., population density).

Direct causes generally operate at local level (individual farms, families or communities), in contrast to underlying causes that originate at regional or global levels, with complex interactions at organizational levels. Regarding tropical deforestation, empirical evidence suggests that there is no universal link between causes and effects. Decline in tropical forests is determined by combinations of direct and indirect causes that vary according to geographical and historical context (Geist & Lambin, 2002).

In parallel, Mitsuda & Ito (Mitsuda & Ito, 2011), classify factors affecting land use in: socioeconomic and environmental. Environmental factors are related to topography and land productivity, while socioeconomic factors can be classified in accessibility, local community development, spatial configuration and political restrictions. They explain that accessibility, represented in the construction and improvement of roads, is a critical factor in the deforestation of tropical natural areas.

Hettig, Lay, & Sipangule (Hettig *et al.*, 2016) conducted a systematic review of studies related to causes of land use change in tropical regions, given the complexity of change processes. They suggest classifying these causes into: property rights and institutions, accessibility to markets and infrastructure, domestic characteristics, income and wealth, entry and exit of markets, adoption of agricultural technology, population and migration, and key policies.

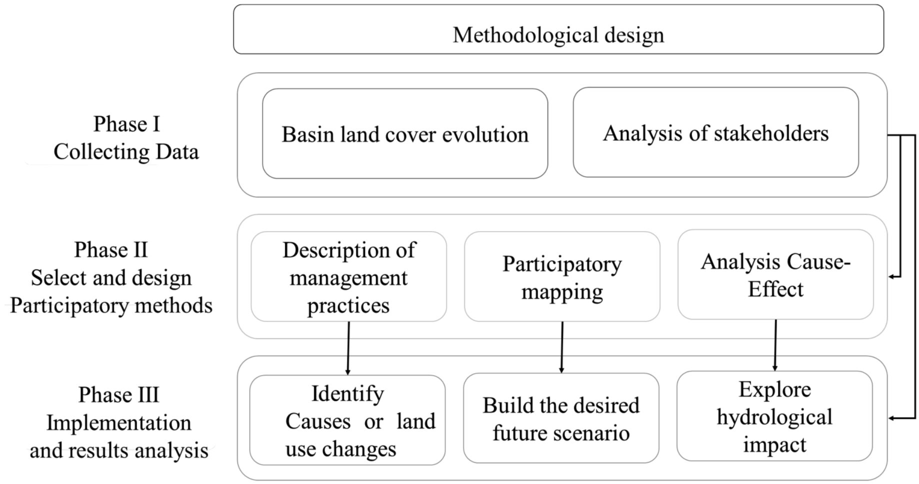
In the other hand, Lovett & Shutidamrong (Lovett & Shutidamrong, 2008) have studied land use and its management in a tropical basin and points out that land use planning requires innovations in analytical techniques in integrating methods of various disciplines. Their research focuses on identifying, applying and evaluating methodologies to facilitate participation of stakeholders in management decisions, and reduce conflicts over land use. Decision-making on basins is most effective when water managers, officials, community members, researchers, professionals and consultants, are included. Their participation allows to understand the underlying problems in the basins, including causes and viable solutions (Robles-Morua *et al.*, 2014).

Recent scientific approaches such as socio-hydrology suggest the joint studly of water and human systems, also recommending public participation (Geilfus, 2008). Some works have explored integrating knowledge and perceptions in a framework of cause-effect links, e.g. in groundwater systems (Guldan *et al.*, 2013), in decision-making in resource water conservation policies (Sanderson *et al.*, 2017), in the identification of socio-environmental effects of land acquisition (Johansson & Isgren, 2017), in the causes of increased cultivated land, settlements and consequences in the water and soil degradation (Wubie *et al.*, 2016).

3. Materials and methods

The methodology has three phases as shown in Figure 1. Phase's I objectives are (i) to build land cover of basin for different periods, (ii) to identify and analyze the stakeholders. The results of first phases are the data to the next phase. Phase II focuses on the selection and design of participatory methods. Finally, phase III focuses on implementing the participatory methods and analyses of results.

Figure 1 - Methodological design



Source: Authors.

3.1. *Study area*

The Canalete river basin, in the northwestern area of the Colombian Caribbean coast, is in an agricultural region and is geographically located in the Cordoba department which includes the territory of the municipalities of Canalete, Puerto Escondido, Los Córdobas and Montería. The basin corresponds to an ecosystem of Tropical Dry Forest and at the beginning of the 20th century most of the coverage was forested (CVS & Universidad Pontifica Bolivariana, 2008).

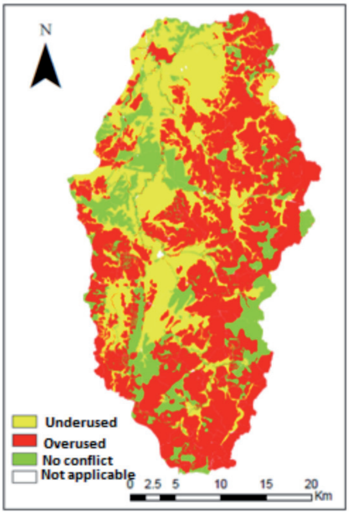
In the environmental diagnosis of the basin, developed by the environmental authority in 2005, it is highlighted that the economy of the Canalete river basin is based mainly on livestock production, including, breeding, fattening, milk production and commercialization of cattle, which is done extensively, and requires large areas planted with pastures.

Agriculture is also a relevant sector, with transient, semi-permanent and permanent crops. Transient crops are represented by corn, rice, cassava, yam and watermelon. Their short cycle makes economic activities dynamic. Semi-permanent crops are mainly bananas, being a product with demand in internal and external markets. Finally, permanent crops are represented by fruit trees such as coconut and cocoa (CVS & FONADE, 2005).

In recent years, forestry has become an important activity in the basin. The most sown forest species is teak (tectona grandis), an exotic species adapted to the region conditions. Other native species planted are oak, mahogany and cedar, all in demand in national markets (Corporación Autónoma de los Valles del Sinú y San Jorge - CVS, 2020; CVS & Universidad Pontifica Bolivariana, 2008).

On the other hand, conflicts over land use in the Canalete river basin include overutilization and underutilization, Figure 2 prepared by the environmental authority, called CVS by its acronym in Spanish (Corporación Autónoma Regional de los Valles del Sinú y del San Jorge), show the conflict map confronting units of vocation for use and current use (CVS *et al.*, 2017). 50% of the area of the Canalete river basin, approximately 46 thousand hectares are overused. Overutilization conflicts are related to uses exceeding soil capacity, corresponding especially to agricultural activities on slopes greater than 25%. Underutilized area in the basin reaches 30%, with land used below its capacity for agricultural or forestry production. The areas without conflict correspond to 18%, the remaining 2% includes urban areas and bodies of water, referred to as "not applicable".

Figure 2 - Map of land use conflict



Source: Authors.

3.2. *Data*

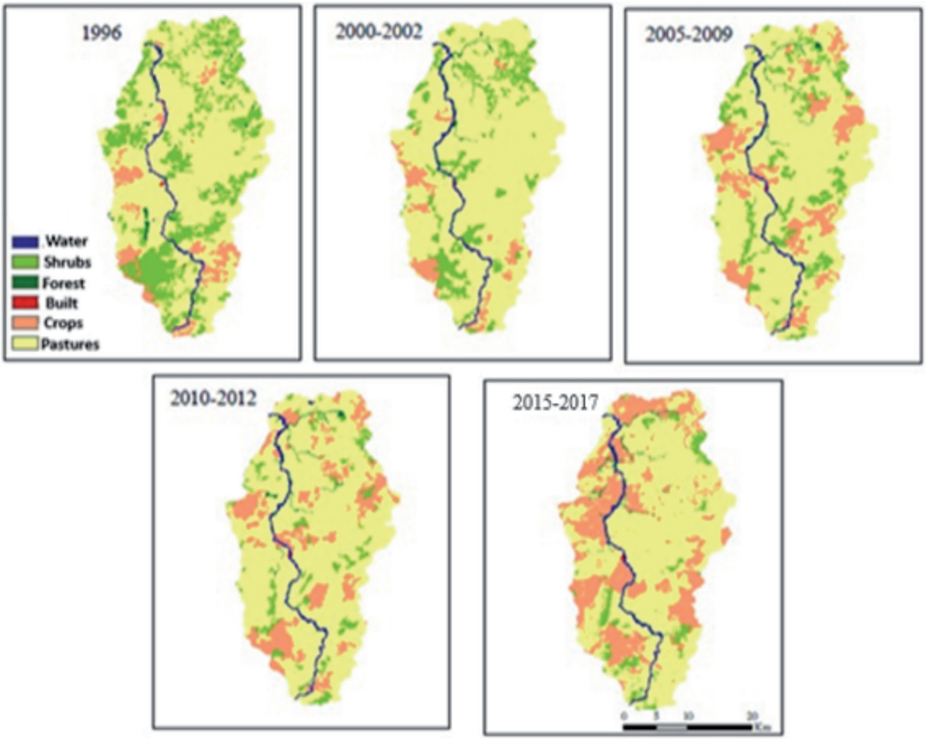
3.2.1. Basin Land cover for different periods

Coverages for different periods of the Canalete river basin are prepared using the Corine (Coordination of Information on the Environment) Land Cover methodology adapted for Colombia. The purpose of this methodology is to make a homogeneous inventory of the biophysical cover (coverage) of the earth's surface based on visual interpretation of computer-assisted satellite images and generation of a geographical database. The national land cover legend for this methodology, at a scale of 1: 100000, is structured in a hierarchical manner, at levels 1 to 6 in the distinct types of coverage (IDEAM, 2010).

The coverage configuration for year 1996 was developed from LANDSAT satellite image (U.S. Geological Survey, 2017) at a 1:100000 scale. Land cover for three periods 2000-2002, 2005-2009, 2010-2012 were constructed from configurations nationwide, developed from Landsat 1:100000 images and 30-meter resolution. Finally, the 2015-2017 configuration was facilitated by the region's environmental authority and developed from RapidEye satellite images at a scale of 1:25000 and a 5-meter resolution (CVS *et al.*, 2017).

For the coverage of the Canalete river basin, levels 3 and subsequent of the Corine Land Cover methodology adapted for Colombia were used. With this classification, six categories were defined representing the basin coverage.

Figure 3 - Land cover for the Canalete river basin



Source: Authors.

These categories were called: built, pastures, crops, shrubs, water, and forests (the latter includes forest plantations).

Coverages of the Canalete river basin prepared five or different periods: 1996, 2000-2002, 2005-2009, 2010-2012 and 2015, Figure 3 shows how pastures are the predominant coverage in the basin. It is also noted that the areas of forests and shrubs have gradually decreased in the basin, while the cultivation areas have been increasing, especially in recent years.

3.2.2. Identification and analysis of stakeholders

To apply the participatory methods, a stakeholder analysis was previously carried out. The analysis of stakeholders was approached based on the identification of 32 actors described in the current Management Plan of the basin (Corporación Autónoma de los Valles del Sinú y San Jorge - CVS, 2020; CVS & Universidad Pontifica Bolivariana, 2008), including legal or institutional, technical and social stakeholders.

Analysis of stakeholders includes identifying stakeholders and adapting the classification categories for the research purpose (Chevalier & Buckles, 2008). Then, stakeholders were differentiated according to their relationship with the research phenomenon, the change in land use in the Canalete river basin, as follows: i) primary stakeholders: directly related to land use; ii) secondary stakeholders: with participation or influence in the regulation of land use; iii) tertiary stakeholders: with little influence on land use. The result of this initial classification allowed to identify 17 actors between primary and secondary, then these actors were categorized analytically.

Analytical categorizations are a set of methods in which stakeholders are classified based on levels of attributes such as: interest, influence, cooperation, competition, conflict, legitimacy, among others; such methods usually make use of matrices (Reed *et al*., 2009). In this research, three levels (low, high, and medium) were used for two attributes: influence on land use and conflict with other actors over land use. With this classification it was possible to identify key stakeholders, those that have great interest and influence in land use.

Table 1 shows the classification matrix by attributes of stakeholders. Participatory methods were applied by summoning the key stakeholders, in this case, those found in the quadrants: high-high, high-medium, medium-high, and medium-medium.

The analysis of key stakeholders allowed to identify the key stakeholders in the basin, in relation to land uses. These stakeholders were summoned to

Table 1 - Matrix of Classification of Stakeholders

Influence in land use		Low	Medium	High
	High	Livestock Federation	Agricultural Institute Reforesters	Land Authorities Regional Environmental Authority Cattlemen and Agriculturalists
	Medium	Environment Ministry Highways Institute	Public and Private Universities Agricultural Research Corporation Learning National Service	Non-Govermental Organizations Geographic Institute Institute of Hydrology and Meteorology
	Low	Fishers	Territorial Development Financial Trade Federation	

Source: Authors.

the a workshop in December 2017 and with them the participatory methods were developed, in which there were a total of 20 people. Table 2 lists the key stakeholders involved and their action level.

Stakeholder analysis has become increasingly popular among natural resource management policy makers (Reed *et al*., 2009). Stakeholder analysis is also used to understand the wide range of interests (Friedman & Miles, 2006) and to assess viability of future options (Brugha, 2000). In this research, stakeholder analysis was used both to recognize the causes of changes in land use, its hydrological effects and to build a potential future scenario.

Table 2 - Key Stakeholders List

Key Stakeholder	**Action Level**
Land Authority: Mayor's Office of Montería	Local
Land Authority: Mayor's Office of Canalete	Local
Land Authority: Mayor's Office of Puerto Escondido	Local
Land Authority: Mayor's Office of Los Córdobas	Local
Cattlemen and agriculturalists	Local
Regional Land Authority: Government of Cordoba	Regional
Environmental Authority: Corporación Autónoma CVS	Regional
Corporación de Investigación Agropecuaria [Agricultural Research Corporation] - Corpoica	Regional
Instituto Geográfico Agustín Codazzi [Geographic Institute] – IGAC	Local/Regional
Instituto Colombiano Agropecuario [Colombian Agricultural Institute] – ICA	Local/Regional
Private University: Universidad Pontificia Bolivariana	Local/Regional
Public University: Universidad de Córdoba	Local/Regional
Servicio Nacional de Aprendizaje [National Learning Service] – SENA	Local/Regional
Non-Governmental Organization: GIZ	Local/Regional

Source: Authors.

3.3. *Participatory methods*

Approaches to stakeholder participation are tools or methods facilitate collective knowledge, action and solution, also, allow to recognize and transform the existing environment. The methods are chosen based on the type of participation required and on problems people face and how they will be addressed. Stakeholder participation can enhance the quality of environmental decisions by considering more comprehensive information inputs and exploring complex processes (Bolaños-Valencia *et al.*, 2019). This research applies participatory methods because land use change involves different institutions and economic sectors, also involve multiple and interconnected causes and effects.

With the key stakeholders, a participatory workshop was held in December 2017, at the facilities of Universidad Pontificia Bolivariana Seccional Montería supported by the Environmental Engineering Program. The participation workshop was carried out emphasized the need to selecting the relevant tools but adjust to the research purpose and the need to a skilled facilitation. The participatory methods selected, adjusted, and applied were:

1. Description of management practices (Geilfus, 2008) to identify Land use change causes.
2. Participatory mapping (Reilly *et al.*, 2017) to build the desired future scenario.
3. Analysis Cause-Effect (Johansson & Isgren, 2017) to know the perception about the hydrological impact of land use changes.

The workshop was developed in one day and in three stages: First, a general context of the study area and the research objectives were presented to the key stakeholders. Also, the key stakeholders and facilitators introduced themselves. Second, the participatory method number one was explained in detail, which consisted of a format that contained the list of the causes of land use change identified in the literature review, participants filled out the format individually with the support of facilitators if required. The first two stages were done in the morning hours.

Third, in the afternoon after a break, participatory methods number two and three were developed. For method number two, the participants were divided into 3 groups and each group drew the desired scenario on a sketch map. The facilitators provided coverages map as a guide and handed out colored pencils. Then the three maps of the desired land use scenario to 2030 were consolidated, the participants also declared the reasons of their work. Finally, participatory method number three was developed using a survey in which the key stakeholders individually, wrote down their perception of the hydrological impact of land use in an agreement scale.

All this thanks to facilitators who supported the workshop, they were ten people, including undergraduate students, graduate students, professors, and researchers. Facilitation allows expression of diverse ways of thinking and respect for opinions. Thus, in the workshop, stakeholders were able to express ideas in an atmosphere of trust.

3.3.1. Description of management practices to identify Land use change causes

In the carried-out workshop, each actor was presented a tend graph with evolution of land cover, also provided with a list of 45 causes, variables or change drivers in land use, shown in Table 3 and discriminated in: Biophysical Causes and Socioeconomic Causes, the latter were classified as: demographic, life quality, economic, institutional, infrastructure and security. These causes were selected from review of literature in tropical contexts

(Hettig *et al.*, 2016); (Eric F. Lambin *et al.*, 2003); Mitsuda & Ito, (Mitsuda & Ito, 2011); (Newman *et al.*, 2014) and of the explanatory variables used in the geographical modeling of land use.

Table 3 - List of Change Causes in Land Use

	Biophysical	
Hight Slope Proximity to the river Proximity to the coast	Proximity to a village Proximity to a hamlet Proximity to the forest Proximity to marshes and wetlands	Soil erosion Soil Productivity Weather Conditions Natural Threats
	Socio-economics	
Demographics	**Life Quality**	**Economics**
Number of children Number of Adults Number of Elders Number of Foreigners Population Density and Distribution	Life Conditions Employment Conditions Educational Coverage Illnesses in people Debt	Trade and earned Price Trade and Harvest Price Sale Price of Harvests Commercial Reforestation Illigal Logging of Natural Forest
Institutional	**Infrastucture**	**Safety**
Public Resources Subsidies Taxes Intitutional Presence Land Ownership Govermental Programs	Aqueduct System Sewerage Aqueduct Technology Proximity to Roads Road Infrastucture Extension	Presence of Armed Groups Kiddnapings Displaced people Theft or Robbery

Source: Author.

Afterwards, stakeholders were requested to register in a survey type instrument, those causes they consider have influenced the evolution of each coverage (pastures, crops and forests-shrubs.

3.3.2. Participatory mapping to build the desired future scenario

In recent years, more attention has been paid to the value of incorporating participatory methods in scenario analysis (Patel *et al.*, 2007). Local stakeholders can develop land use scenarios that consider the environmental and economic impacts of their economic activities (Chantre *et al.*, 2016), the above allows developing a scenario as a planning tool.

The desired scenario was constructed through participatory mapping, a technique used to understand future perceptions from the stakeholders. Participatory mapping has been defined as the creation of maps by communities, organizations, governments, universities, and other actors involved in land planning development (Brown & Kyttä, 2018).

In this case, participatory mapping has been used for the communication of preferences on future land use. Year 2030 was selected as the time horizon of the desired scenario, considering that the basin environmental planning in Colombia is carried out at 12 years (Ministerio de Medio Ambiente y Desarrollo, 2014). Figure 4 shows stakeholders building the desired scenario.

Figure 4 - Construction of Desired Scenario

Source: Authors.

In the workshop, actors were divided into three groups, each group was given a map with the sketch of the basin at 1:80,000 scale and a base map corresponding to land uses (pastures, crops, forests and shrubs) for 2015-2017 that included the current of the Canalete River and human settlements.

The objective of this exercise is to produce a map that represents the desirable changes in land use (Geilfus, 2008). The stakeholders expressed on the map the desired land uses for 2030. They were also asked to indicate the reasons for wishing that scenario, to better understand the results. The maps of the three groups were consolidated in a single desired scenario in 1x1 km grids.

3.3.3. Analysis Cause-Effect to know the perception about the hydrological impact of land use changes

The hydrological impact of changes in land use was captured through a participatory analysis Cause-Effect (Johansson & Isgren, 2017) to know the perception about the hydrological impact of land use changes.

A survey was applied to the stakeholders in the workshop about their perception of the impact of changes in land use on the frequency and intensity of floods and droughts. The actors were asked to indicate their agreement, neutrality or disagreement with four questions: Do changes in land use impact the frequency of floods? Do changes in land use impact the intensity of floods? Do changes in land use impact the frequency of droughts? And do changes in land use impact the intensity of droughts?

The actors involved in the participatory workshop replied individually in written form, for each question they chose between five options 1: Strongly disagree; 2: Disagree; 3: Neutral; 4: Agree; 5: Strongly agree. Then the results were consolidated, as explained below.

4. Results and discussion

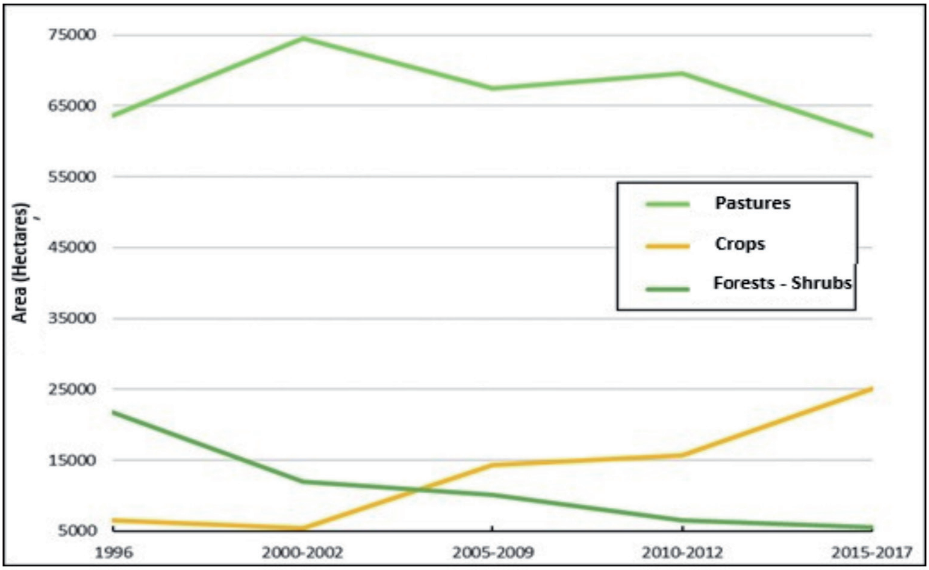
4.1. *Causes of Change in Land Use*

During the workshop, each actor was presented with the evolution of the land covers associated with the land use with the greatest area in the basin: pastures, crops and forests-shrubs. Figure 5 shows evolution of land uses in the basin.

It should be noted that forest and shrub cover were considered as one, given that they are natural or semi-natural cover and that plants in the tropical dry forest ecosystem, present in the basin, are characterized by growth habits of tree and shrub type (IAvH Instituo de Investigaciones de Recursos Biológicos Alexander von Humboldt, 2014). Thus, the characteristic vegetation of the dry forest present in the basin is presented jointly, which also facilitates the identification of change causes in land use by the actors.

Key stakeholders understood the evolution of land cover associated with land use and were able to recognize associated variables. They identified 17 causes of change in land use. These socioeconomic causes were classified as direct and underlying. Direct causes are human activities that operate at a local level and the underlying causes operate at a regional or national level, such as population dynamics and agricultural policies (Geist & Lambin, 2002). In this way it is highlighted that changes in land cover and land use are complex because they are driven by combinations of synergistic factors leading to increased pressure on environmental goods and services (Brugha, 2000).

Figure 5 - Evolution of Land Uses in the Canalete River Basin



Source: Authors.

Identification of change causes by key stakeholders of the Canalete river basin allowed to recognize a set of dominant drivers and a better understanding of crop expansion, deforestation and slight decrease of grasslands in the Canalete river basin. Table 4 shows the number of times each cause was selected, according to land use. It is noted that the biophysical causes were more frequently selected in the pastures. The direct causes were specially selected in the forest-shrubs and finally the underlying causes appear more frequently in the crops. The above shows us the cause types guiding the changes.

On the other hand, causes identified for each land use allow an understanding of factors that interact in this tropical context and how they influence decision making. Thus, the change for pastures originates in part due to natural conditions of the Canalete river basin. The strong seasonality of the rains, characteristic of the tropical dry forest (Dirzo et al., 2011) (Siyum, 2020) and the soil vocation, mainly agricultural, limit the livestock activity associated with pastures. The decrease of pastures is besides fueled by the effect of climatic variability and degradation processes affecting soils and pastures (Barragan, 2013; Garcia *et al.*, 2019).

Livestock is comprised by extensive systems, which in tropical contexts are characterized by low efficiency in soil use and by environmental damage

Table 4 - Identified Change Causes in Land Use

Land Use	**Pasture**	**Crops**	**Forests-Shrubs**
Biophysical Causes			
Soil Productivity	6	1	1
Weather Conditions	8	4	5
Proximity to the River	3	4	–
Soil Erosion	3	–	6
Direct Causes			
Road Infrastructure Expansion	2	-	1
Commercial Reforestation	-	-	2
Illigal logging of Natural Forest	-	-	8
Presence of Armed Groups	5	2	1
Underlying Causes			
Population Density and Distribution	3	6	4
Quality Conditions	2	4	1
Governmental Programs	2	9	3
Institutional Presence	1	4	5
Land Ownership	5	1	–
Land Size and Value	6	–	4
Trade and Price of Harvests	–	12	5
Trade and Price of Livestock	7	–	9
Livestock and Agricultural Techniques	2	1	–

Source: Author.

related to deforestation, burning, erosion, diversity loss, and soil compaction (Mahecha, 2003). Economic causes have also originated a slight decrease in pastures. Distribution inequality of land ownership that for the municipalities of the basin reaches a high Gini index higher than 0.7 (UPRA – Unidad de Planificación Rural Agropecuaria, 2017) and the seasonality, cycles and volatility of land prices cattle (Castillo, 2007), are economic factors that have operated at time scales and that result in individual and social responses to livestock activity and the pasture area.

Crop areas, associated with agricultural activity, have been increasing in the basin, especially due to combination of underlying drivers of change in the use of demographic, institutional and economic land. Rural population in the municipalities of Canalete, Puerto Escondido and Los Córdobas that are part of the basin is over 80% (DANE – Departamento Administrativo Nacional de Estadística, 2018), making subsistence agriculture relevant, that causes 33% of deforestation in the tropics (FAO – Food and Agriculture Organization, 2016).

To explain changes in land use, it is also important to understand institutions and their interaction with decision (Brugha, 2000). In Colombia, financing the rural sector has shown a favourable evolution in recent years, reflected in indicators of access and deepening; being key products for the dynamism of the agricultural sector: bananas, rice and corn, precisely present in the basin. Other agricultural policy mechanisms in the country have also favoured growth of crop areas in the basin, such as coverage of prices especially important for corn, the exchange hedging program for export products such as bananas and the Incentive of Rural Capitalization – ICR for purchase of machinery in special conditions for the rice sector (Finagro, 2014).

Finally, forest-shrub cover responds to a combination of biophysical and socioeconomic causes. Biophysical drivers can be as important as socio-economic ones in land use. Erosion is a limitation for establishment of commercial forest plantations (CONIF *et al*., 1998) and in the Canalete river basin, 66.29% of the landscape corresponds to erosional structural hills (IGAC, 2009). On the other hand, among the socioeconomic causes prevailing in forest-shrub cover, there is illegal logging of the natural forest, as a direct cause, also identified as one of the main causes of deforestation in tropical dry forest (Addo-Fordjour & Ankomah, 2017). The commercialization and price of livestock is an underlying cause of the shrinking forest-shrubs indicating that in addition to the use of subsistence forest, livestock drives deforestation to access grazing areas.

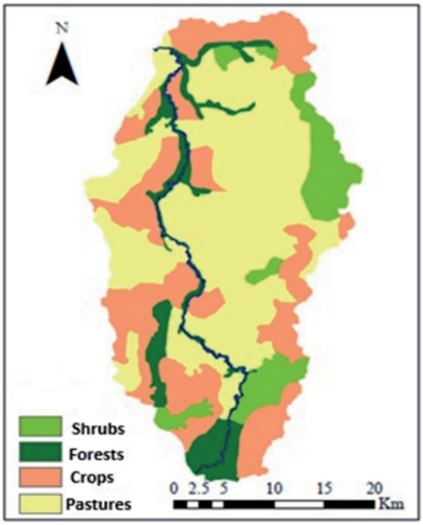
These results become a contribution that helps decision makers to identify land use policies, which can be command and control interventions affecting direct causes and other public interventions against underlying causes such as macroeconomic, market policies, subsidies, or taxes (Lambin *et al*., 2014). Particularly relevant in tropical contexts where agricultural expansion leads the change in land use and is generally favoured by government policies, coupled with market forces, poverty, and inadequate tenure of the land that drive the agricultural expansion process (Wassenaar *et al*., 2007).

4.2. *Desired Future Scenario*

The participatory mapping allowed to obtain a desired land use scenario by 2030, shown in Figure 6. With respect to the land use configuration 2015-

2017, a decrease of more than 16200 ha of pastures is observed, offset by an approximate increase of 2400 ha of crops and 13800 ha of forests and shrubs. In this participatory exercise, the stakeholders expressed their needs and interests to desire the scenario proposed for the year 2030, presented for each land use in Table 5.

Figure 6 - Scenario for year 2030 built with key actors



Source: Author.

Decrease of pastures in the future scenario, compared to the land cover 2015-2017 is explained by the actors with needs and interests that refer to the improvement of livestock production (such as with silvopastoral systems) and the improvement of social conditions in terms of equality. On the other hand, increase in crops is also related to the improvement of social conditions (income, food, and life quality) and to the use of the land vocation, among other aspects. Finally, stakeholders expressed interest in the increase of forests and shrubs for the recovery of strategic areas and decrease of erosion and floods.

Table 5 - Needs and Interests for the Desired year 2030

Pastures	**Crops**	**Forests and Shrubs**
Technified and sustainable livestock	Improve life quality and income of the inhabitants	Water round recovery
Implement silvopastoral systems	Take advantage of the soil agricultural vocation	Recovery of forested areas at the source of the river
Promote land equality	Ensure food security	Maintain wooded areas
Support owners of small farms	Allow crop irrigation	Reduce erosion and floods
Diversify productive activities	Implement agroforestry systems	Connectivity of natural areas with the coastal zone

Source: Author.

Despite the diversity of stakeholders and roles, it was possible to consolidate a single scenario map by 2030 and match areas for different uses, given different interests and needs. Additionally, some actors expressed other interests regarding contextual and cyclical conditions, such as support for ecotourism, articulation with post-conflict conditions in the country and with territorial planning tools of the basin municipalities. The pattern of underlying dimensions and territorial dynamics indicates that important challenges exist for the post-conflict period in Colombia. Relevant political implications for the Canalete river basin include environmental governance, preservation of protected areas, and sustainable agricultural and livestock practices (Garcia *et al.*, 2019). The challenge for the agricultural sector is to develop sustainable production strategies that improve the profitability of production (Julio *et al.*, 2022).

The desired scenario and land use change causes recognize that changes in land use are the result of a complex interaction between socioeconomic and environmental factors (Demissie *et al.*, 2017; Hewitt *et al.*, 2014). Stakeholder participation ensures that the analysis and findings of geographic modelling exercises provide correct answers and practical results (Garcia, 2018; Kalra *et al., 2015*).

4.3. *Hydrological Impact of Land Use Changes*

This paper presents an alternative for the study of these water and human systems, using participation tools of key stakeholders, the effects on hydrology of changes in land use in the Canalete river basin. Although, most outstanding feature of the tropical dry forest is the marked seasonality of rainfall (Dirzo *et al.*, 2011), research published in hydrology is rare (Farrick, 2014).

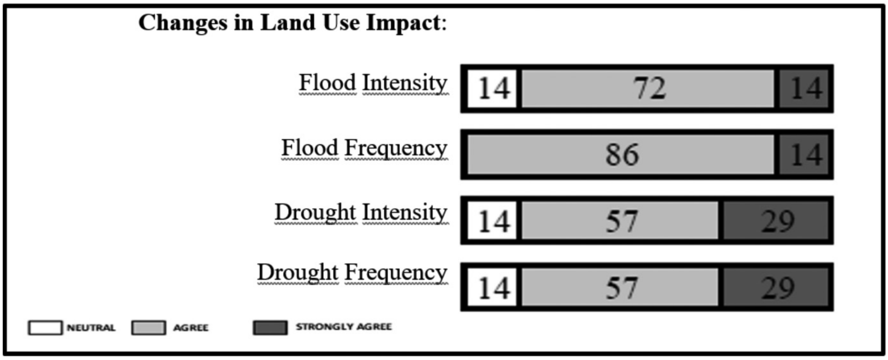
This proposed approach facilitates understanding of socio-hydrological systems and represents an opportunity to identify new data sources, to develop models that include important variables in basin modelling, even in cases where there are data limitations (Mostert, 2018), such as in tropical basins. Some authors indicate limitations in tropical basins due to the available information for example Hydro-meteorological, discharge, infiltration and calibration data (Beskow, 2009; Cornelissen *et al.*, 2013; Sierra *et al.*, 2017; Viola *et al.*, 2014).

The stakeholders revealed their perception of the hydrological impact of changes in land use in the Canalete river basin. Most of the stakeholders reported agreeing that changes in land use modify the intensity of floods, only 14% indicated neutrality in their response. One hundred percent of the stakeholders agreed that changes in land use modify the frequency of flooding.

Regarding drought processes, 57% and 29% of the stakeholders agreed and strongly agreed, respectively, that changes in land use impact the frequency and intensity of events. Only 14% expressed neutrality in their responses.

Results are presented in Figure 7, such as percentage of stakeholders, it is observed that they generally agree on changes in land use impacting basin hydrology, especially in terms of flooding. Hydrological impacts of the different land use changes related above reiterate the importance of including socioeconomic variables within the hydrological analysis of basins. Identifying the causes of land use changes requires an understanding of how people make decisions and how a range of factors, like hydroclimatics, interact in a specific context.

Figure 7 - Percentage of stakeholders



Source: Authors.

Changes in soil characteristics often affect the mechanism of runoff generation (Rodriguez *et al*., 2010), especially in relation to floods and droughts (Gumindoga *et al*., 2014). The research of human activities that have a significant impact on hydrology and the factors that can explain these activities, helps a better understanding of how society interacts with the hydrology of a basin (DeFries & Eshleman, 2004).

5. Conclusions

In this article, participatory methods were applied as an alternative to allow exploring changes in land use in the tropical basin of the Canalete River. In this exercise it was possible to reduce from 45 to 17 incident variables in the change in land use, become a contribution that helps decision makers to identify land use policies. These causes of change in land use included processes related to pastures and crops, in addition to deforestation processes most studied, relevant in tropical contexts where agricultural expansion impacts the environment. Identification of causes of change in land use and construction of a desired scenario, provide important qualitative information, very useful in the parameterization of geographical models of change in land use, which becomes an approach integrating analytical and discursive domains.

It is recognized that changes in land use in tropical basins have had effects on hydrological processes. In this paper, an alternative is presented for the study of these socio-hydrological systems, using participation tools, finding agreement between the stakeholders against the impact of changes in land use on hydrology.

However, this work has some limitations: the coverages for different periods of the Canalete river basin were prepared from different scales and the participatory methods are replicable but adapting to the context and convening capacity of the key actors. Finally, it is important to highlight that the basin is in a tropical dry forest, recognized as one of the most threatened ecosystems hence, participatory methods applied represent a novel and applicable research approach where complex processes are presented and there is no universal link between causes and effects.

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References

Addo-Fordjour, P., & Ankomah, F. (2017). Patterns and drivers of forest land cover changes in tropical semi-deciduous forests in Ghana. *Journal of Land Use Science*, *12*(1), 71-86. doi: 10.1080/1747423X.2016.1241313.

Aranda Echavarría, D., & Vidal González, D. (2020). *La participación ciudadana en la formulación del Plan de Ordenamiento y Manejo de Cuencas Hidrográficas – POMCA –: La Experiencia del POMCA de los ríos Lili-Meléndez- Cañaveralejo*. Universidad del Valle.

Banco Interamericano de Desarrollo (2012). *Evaluación Sectorial y Temática El reto del Manejo Integrado de cuencas hidrográficas.*

Barragan, W. (2013). *Sistemas silvopastoriles para mejorar la producción de leche y disminuir el estrés calórico en la región Caribe Colombiana*. Universidad de Antioquia.

Beskow, S. (2009). *Lash Model: A hidrological simulation tool in GIS framework*. Universidade Federal de Lavras.

Bolaños-Valencia, I., Villegas-Palacio, C., López-Gómez, C.P., Berrouet, L., & Ruiz, A. (2019). Social perception of risk in socio-ecological systems. A qualitative and quantitative analysis. *Ecosystem Services*, *38*(65), 100942. doi: 10.1016/j.ecoser.2019.100942.

Brown, G., & Kyttä, M. (2018). Key issues and priorities in participatory mapping: Toward integration or increased specialization?. *Applied Geography*, *95*(December 2017), 1-8. doi: 10.1016/j.apgeog.2018.04.002.

Brugha, R. (2000). Stakeholder analysis: a review. *Health Policy and Planning*, *15*(3), 239-246. doi: 10.1093/heapol/15.3.239.

Castillo, O. (2007). Estacionalidad, ciclos y volatilidad en los precios del ganado macho de levante en Montería, Colombia. *REvista MCZ Córdoba*, *12*(1), 897-911.

Chantre, E., Guichard, L., Ballot, R., Jacquet, F., Jeuffroy, M.-H., Prigent, C., & Barzman, M. (2016). Co-click'eau, a participatory method for land-use scenarios in water catchments. *Land Use Policy*, *59*, 260-271. doi: 10.1016/j.landusepol.2016.09.001.

Chevalier, J.M., & Buckles, D.J. (2008). SAS2: A Guide to Collaborative Inquiry and Social Engagement. In *Sage Publications*. doi: 10.1080/09614520903220891.

CONIF, OIMT, & Ministerio del Medio Ambiente (1998). *Guía para plantaciones forestales comerciales.* Córdoba.

Cornelissen, T., Diekkrüger, B., & Giertz, S. (2013). A comparison of hydrological models for assessing the impact of land use and climate change on discharge in a tropical catchment. *Journal of Hydrology*, *498*, 221-236. doi: 10.1016/j.jhydrol.2013.06.016.

Corporación Autónoma de los Valles del Sinú y San Jorge – CVS (2020). *Actualización del Plan de Ordenación y Manejo de la Cuenca Hidrográfica del río Canalete, Los Córdobas y otros arroyos localizada en los departamentos de Antioquia y Córdoba*.

Coxhead, I., & Shively, G. (2005). *Land Use Change in Tropical Watershed: evidencie, causes and remedies*. CAB International.

CVS, Consorcio Ambiental, & Fondo de Adaptación (2017). *Mapa de cobertura Metodología Corine Land Cover. Rio Canalete, río Los Córdobas u otros arroyos.*

CVS, & FONADE (2005). *Diagnóstico Ambiental de la Cuenca Hidrográfica del Río Canalete.*

CVS, & Universidad Pontifica Bolivariana (2008). *Plan de ordenamiento y manejo integral de la cuenca hidrográfica del río Canalete.*

DANE (Departamento Administrativo Nacional de Estadística) (2018). *Boletín técnico: Mercado laboral por departamentos 2017.* DANE. -- Online at: www.dane.gov.co/files/investigaciones/boletines/ech/ml_depto/Boletin_dep_17.pdf (accessed July 2018). -- www.dane.gov.co/files/investigaciones/boletines/ech/ml_depto/Boletin_dep_17.pdf.

DeFries, R., & Eshleman, K.N. (2004). Land-use change and hydrologic processes: a major focus for the future. *Hydrological Processes*, *18*(AUGUST), 2183-2186. doi: 10.1002/hyp.5584.

Demissie, F., Yeshitila, K., Kindu, M., & Schneider, T. (2017). Land use/Land cover changes and their causes in Libokemkem District of South Gonder, Ethiopia. *Remote Sensing Applications: Society and Environment*, *8*(April), 224-230. doi: 10.1016/j.rsase.2017.10.001.

Dirzo, R., Young, H.S., Mooney, H.a., & Ceballos, G. (2011). *Seasonally Dry Tropical Forests - Ecology and Conservation*. Island Press.

FAO (Food and Agriculture Organization) (2016). *State of the World's Forests. Forest and agricultural: Land-use challenges and oportunities* (45(12)). FAO. -- Online at www.fao.org/3/a-i5588e.pdf (accessed July 2018).

Farrick, K.K. (2014). *Runoff Generation In A Tropical Dry Forest Watershed : Processes , Patterns And Connectivity*. December.

Finagro (2014). *Infraestructura Regional Y Pobreza Rural*.

Friedman, A.L., & Miles, S. (2006). *Stakeholders: Theory and practice*. Oxford University Press on Demand.

Garcia, L. (1998). *Manejo integrado de los recursos hídricos en América Latina y el Caribe*. -- http://publications.iadb.org/handle/11319/4823.

Garcia, L. (2018). *Modelo de gestión de usos del suelo para la regulación hídrica en cuencas tropicales*.

Garcia, L., Avila, H., & Gutierrez, R.R. (2019). Land-use and socioeconomic changes related to armed conflicts: A Colombian regional case study. *Environmental Science and Policy*, *97*(May), 116-124. doi: 10.1016/j.envsci.2019.04.012.

Geilfus, F. (2008). *80 Tools for participatory development*. Inter-American Institute for Cooperation on Agriculture-IICA.

Geist, H.J., & Lambin, E.F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience*, *52*(2), 143. doi: 10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2.

Guldan, S.J., Fernald, A.G., Ochoa, C.G., & Tidwell, V.C. (2013). Collaborative community hydrology research in Northern New Mexico. *Journal of Contemporary Water Research & Education*, *152*(1), 49-54. -- http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20143131504&site=ehost-live%5Cnhttp://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1936-704X%5Cnemail: sguldan@nmsu.edu%5Cafernald@nmsu.edu.

Gumindoga, W., Rientjes, T.H.M., Haile, A.T., & Dube, T. (2014). Predicting streamflow for land cover changes in the Upper Gilgel Abay River Basin, Ethiopia: A TOPMODEL based approach. *Physics and Chemistry of the Earth, Parts A/B/C*, *76-78*, 3-15. doi: 10.1016/j.pce.2014.11.012.

Hettig, E., Lay, J., & Sipangule, K. (2016). Drivers of Households' Land-Use Decisions: A Critical Review of Micro-Level Studies in Tropical Regions. *Land*, *5*(4), 32. doi: 10.3390/land5040032.

Hewitt, R., van Delden, H., & Escobar, F. (2014). Participatory land use modelling, pathways to an integrated approach. *Environmental Modelling & Software*, *52*, 149-165. doi: 10.1016/j.envsoft.2013.10.019.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, *7*(4), 1-12. doi: 10.1088/1748-9326/7/4/044009.

IAvH Instituo de Investigaciones de Recursos Biológicos Alexander von Humboldt (2014). *El bosque seco tropical en Colombia* (C. Pizano, & H. García (Eds.)). doi: 10.1017/CBO9781107415324.004.

IDEAM (2010). *Leyenda nacional de coberturas de la tierra. Metodología CORINE Land Cover Adaptada para Colombia*. Escala 1:100.000.

IGAC (2009). Estudio general de suelos y zonificación de Tierras. In Departamento de Córdoba.

Johansson, E.L., & Isgren, E. (2017). Local perceptions of land-use change: Using participatory art to reveal direct and indirect socioenvironmental effects of land acquisitions in Kilombero Valley, Tanzania. *Ecology and Society*, *22*(1). doi: 10.5751/ES-08986-220103.

Julio, V., Martínez, B., Adolfo, G., & Parra, C. (2022). Factors influencing the use of non-timber forest products in cattle production under humid tropical conditions. *Economia Agro-Alimentare/Food Economy*, *24*, 1-15. doi: 10.3280/ecag2022oa12566.

Kalácska, M., Calvo-Alvarado, J.C., & Sánchez-Azofeifa, G.a. (2005). Calibration and assessment of seasonal changes in leaf area index of a tropical dry forest in different stages of succession. *Tree Physiology*, *25*(6), 733-744. doi: 10.1093/treephys/25.6.733.

Kalra, N., Groves, D.G., Bonzanigo, L., Molina-perez, E., Ramos, C., Brandon, C., & Cabanillas, I.R. (2015). *Robust Decision-Making in the Water Sector A Strategy for Implementing Lima's Long-Term Water Resources Master Plan*.

Kissinger, G., Herold, M., & De Sy, V. (2012). *Drivers of Deforestation and Forest Degradation*.

Lambin, E.F., Geist, H.J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*(1), 205-241. doi: 10.1146/annurev.energy.28.050302.105459.

Lambin, E.F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, *108*(9), 3465-3472. doi: 10.1073/pnas.1100480108.

Lambin, E.F., Meyfroidt, P., Rueda, X., Blackman, A., Börner, J., Cerutti, P.O., Dietsch, T., Jungmann, L., Lamarque, P., Lister, J., Walker, N.F., & Wunder, S. (2014). Effectiveness and synergies of policy instruments for land use governance in tropical regions. *Global Environmental Change*, *28*(1), 129-140. doi: 10.1016/j.gloenvcha.2014.06.007.

Lovett, A., & Shutidamrong, F. (2008). 'Riding an Elephant to Catch a Grasshopper': Applying and Evaluating Techniques for Stakeholder Participation in Land-Use Planning within the Kae Watershed, Northern Thailand. In: A. Lovett, & K. Appleton (Eds.), *GIS for environmental decision-making* (pp. 149-164). Taylor & F.

Mahecha, L. (2003). Importancia de los sistemas silvopastoriles y principales limitantes para su implementación en la ganadería colombiana. *Revista Colombiana de Ciencias Pecuarias*, *16*(1), 11-18.

Marques, A., Martins, I.S., Kastner, T., Plutzar, C., Theurl, M.C., Eisenmenger, N., Huijbregts, M.A.J., Wood, R., Stadler, K., Bruckner, M., Canelas, J., Hilbers, J.P., Tukker, A., Erb, K., & Pereira, H.M. (2019). Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature Ecology & Evolution*, *3*(4), 628-637. doi: 10.1038/s41559-019-0824-3.

Ministerio de Medio Ambiente y Desarrollo (2014). *Guía Técnica para la formulación de los POMCAS*, 104.

Mitsuda, Y., & Ito, S. (2011). A review of spatial-explicit factors determining spatial distribution of land use/land-use change. *Landscape and Ecological Engineering*, *7*(1), 117-125. doi: 10.1007/s11355-010-0113-4.

Patel, M., Kok, K., & Rothman, D.S. (2007). Participatory scenario construction in land use analysis: An insight into the experiences created by stakeholder involvement in the Northern Mediterranean. *Land Use Policy*, *24*(3), 546-561. doi: 10.1016/j.landusepol.2006.02.005.

Reed, M.S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*(10), 2417-2431. doi: 10.1016/j.biocon.2008.07.014.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., & Stringer, L.C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, *90*(5), 1933-1949. doi: 10.1016/j.jenvman.2009.01.001.

Reilly, K.H., Adamowski, J.F., & John, K. (2017). Participatory mapping of ecosystem services to understand stakeholders' perceptions of the future of the Mactaquac Dam, Canada. *Ecosystem Services*, *30*, 107-123. doi: 10.1016/j.ecoser.2018.01.002.

Robles-Morua, A., Halvorsen, K.E., Mayer, A.S., & Vivoni, E.R. (2014). Exploring the application of participatory modeling approaches in the Sonora River Basin, Mexico. *Environmental Modelling and Software*, *52*, 273-282. doi: 10.1016/j.envsoft.2013.10.006.

Rodriguez, D.A., Tomasella, J., & Linhares, C. (2010). Is the forest conversion to pasture affecting the hydrological response of Amazonian catchments? Signals in the Ji-Paran?? Basin. *Hydrological Processes*, *24*(10), 1254-1269. doi: 10.1002/hyp.7586.

Sanderson, M.R., Bergtold, J.S., Heier Stamm, J.L., Caldas, M.M., & Ramsey, S.M. (2017). Bringing the "social" into sociohydrology: Conservation policy support in the Central Great Plains of Kansas, USA. *Water Resources Research*, *53*(8), 6725-6743. doi: 10.1002/2017WR020659.

Sierra, C.A., Mahecha, M., Poveda, G., Álvarez-Dávila, E., Gutierrez-Velez, V.H., Reu, B., Feilhauer, H., Anáya, J., Armenteras, D., Benavides, A.M., Buendia, C., Duque, Á., Estupiñan-Suarez, L.M., González, C., Gonzalez-Caro, S., Jimenez, R., Kraemer, G., Londoño, M.C., Orrego, S.A., … Skowronek, S. (2017). Monitoring ecological change during rapid socio-economic and political transitions: Colombian ecosystems in the post-conflict era. *Environmental Science and Policy*, *76*(April), 40-49. doi: 10.1016/j.envsci.2017.06.011.

Siyum, Z.G. (2020). Tropical dry forest dynamics in the context of climate change: syntheses of drivers, gaps, and management perspectives. *Ecological Processes*, *9*(1). doi: 10.1186/s13717-020-00229-6.

Smithsonian Tropical Research Institute (2015). *Managing Watersheds for Ecosystem Services in the Steepland Neotropics* (J.S. Hall, V. Kirn, & E. Yaguas (Eds.)). doi: 10.18235/0000163.

UPRA - Unidad de Planificación Rural Agropecuaria (2017). *Departamento de Córdoba*.

Viola, M.R., Mello, C.R., Beskow, S., & Norton, L.D. (2014). Impacts of Land-use Changes on the Hydrology of the Grande River Basin Headwaters, Southeastern Brazil. *Water Resources Management*, *28*(13), 4537-4550. doi: 10.1007/s11269-014-0749-1.

Wassenaar, T., Gerber, P., Verburg, P.H., Rosales, M., Ibrahim, M., & Steinfeld, H. (2007). Projecting land use changes in the Neotropics: The geography of pasture expansion into forest. *Global Environmental Change*, *17*(1), 86-104. doi: 10.1016/j.gloenvcha.2006.03.007.

Wubie, M.A., Assen, M., & Nicolau, M.D. (2016). Patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of lake Tana basin, Northwestern Ethiopia. *Environmental Systems Research*, *5*(1), 8. doi: 10.1186/s40068-016-0058-1.

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