

Environmental Scenario Analysis

Subjects: [Environmental Sciences](#)

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Scenario analysis is a useful tool to facilitate discussions about the main trends of future change and to promote the understanding of global environmental changes implications on relevant aspects of sustainability.

climate change

land use change

models

scenarios

sustainability

watersheds

1. Introduction

In recent decades, changes in land use and climate have had major impacts on the environment at local, regional and global scales [\[1\]\[2\]\[3\]\[4\]\[5\]](#). The high rate of land use change and climate change are now one of the most important environmental problems on regional to global scales [\[2\]\[6\]\[7\]\[8\]](#). Both processes operate simultaneously, with feedbacks at varying spatial and temporal scales.

Given this significant and accelerated process of global change, the need arises to analyze and understand the interactions between human activities and natural resources [\[2\]](#), which leads to the definition of social-ecological systems as a unit of analysis and management. Berkes and Folke (1998) [\[9\]](#) point out that social systems and natural systems are linked at a multi-scale level and that the exclusive delimitation of an ecosystem or the resulting social system is arbitrary and artificial. Janssen and Ostrom (2006) [\[10\]](#) define social-ecological systems as complex adaptive systems in which social and bio-geophysical agents are interacting through multiple spatial-temporal scales. This approach from social-ecological systems will allow to build alternative ways of interaction between society and ecosystems towards sustainability.

Case studies of these types of systems, such as watersheds, are key to understand their functionality and to address the specific problems that threaten them, such as land use change and climate change. This requires a thorough understanding of the causes that determine land use and climate change and the use of simulation tools capable of taking into account the interactions among key factors of socioeconomic and environmental subsystems. This will allow us to explore the consequences in the medium and long-term in aspects relevant to sustainability such as water resources, biodiversity or nature conservation policies. However, the effects of land use change on water resources may not be as obvious, depending on the spatial scale of analysis.

In recent years, advances in research and understanding have led to increased attention to the importance of future scenarios of land use change [\[11\]\[12\]\[13\]](#), with simulation models [\[14\]\[15\]\[16\]\[17\]](#) helping in the analysis of environmental responses.

Scenarios of land use change make possible to explore potential futures and their environmental consequences, as well as potential solutions to environmental problems and thus support decision-making [18]. A scenario is a creative, visionary tool that can support planning for a desired future as well as the preparation for possible undesirable events [19]. Scenarios are best developed not by researchers alone but with stakeholder participation. However, there are many successful and high-profile scenarios that have been developed with little participation from stakeholders [20][21]. Participatory approaches offer a chance to discuss, negotiate, and reach agreement [22][23].

The involvement of stakeholders in designing land use scenarios helps to identify acceptable land use alternatives by reflecting local preferences in land use decisions [24]. It facilitates the understanding of the multifaceted nature of land use issues from the perspective of stakeholders who are directly affected by land use decisions, but with usually limited participation in science and policy discourses [25]. However, development of land use change scenarios which are spatially explicit and detailed remains a complex challenge.

2. Results

Of the 294 articles that were found to include scenario analysis of land use change, nearly half (49%) analyzed the changes at watershed scale. These articles focusing on watersheds are relatively recent, especially when considering the joint study of land use change with climate change and/or analysis of the synergistic effect of both processes (Figure 1). In the last decade of the analyzed period, 79% of the articles on land use change scenarios in watersheds were published. More than half of the publications also discussed the climate change (72%). The synergistic effect of both processes (80%) were published in the last six years (2014–2019). The data indicate that recent advances in research and/or changing research priorities may provide more complete knowledge about the likely trajectories of land use change under different scenarios and their synergistic effect with climate change at a watershed scale.

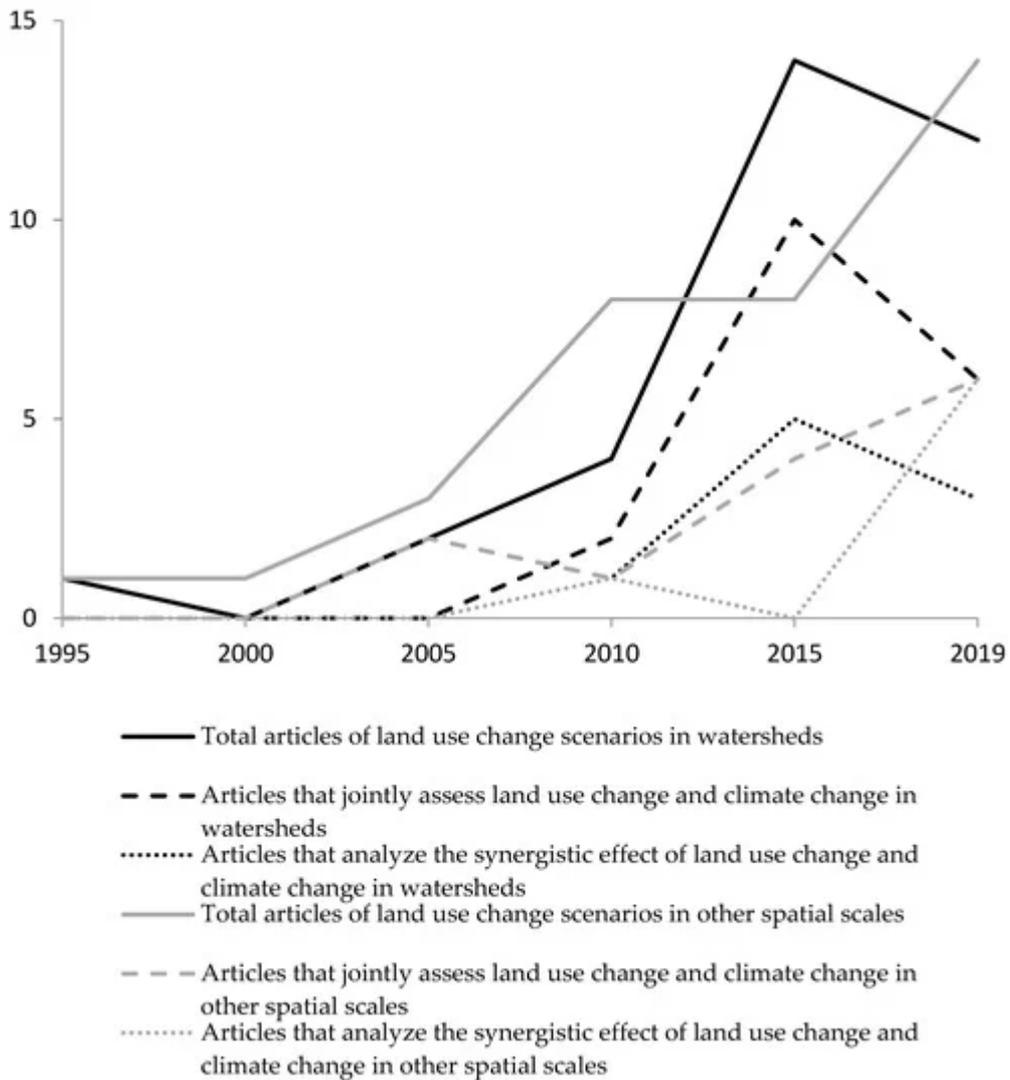


Figure 1. Number of publications in the analysis of land use change scenarios. 1995–2019.

Only 47% of these articles of land use change at the watershed scale also analyzed the process of climate change. In this group, most cases applied regionalized climate change scenarios (68%) compared to global scenarios (32%), possibly due to the increasing availability of regionalized scenarios. Of articles at the watershed scale that also address climate change, more than half (52%) analyzed the synergistic effect between the two processes of global change. Moreover, the evolution over time of these group of articles is rising, although there is a small recession in the last two years (2018 and 2019) (Figure 1).

As for the methodology applied to analyze scenarios of land use changes in watersheds, dynamic spatially distributed models were used more often than spatial statistical models (Table 1). Among the dynamic spatially distributed models the most used were the hydrological models (83%). Specifically, the SWAT model was used in 28% of the reviewed articles. The consideration or lack thereof of climate change did not significantly alter the overall distribution of applied methodological approaches (Table 1).

Table 1. Models classification applied in the analysis of land use change scenarios in watersheds.

| Models Classification | Number of Total Articles in Watersheds | Number of Articles of Land Use Change and Climate Change Jointly Analyzed in Watersheds | Number of Articles of Synergistic Effects of Land Use Change and Climate Change in Watersheds |
|---------------------------------------|---|--|--|
| Non-spatial statistical model | 4 | 0 | 0 |
| Spatial statistical model (e.g., GIS) | 14 | 5 | 5 |
| Aggregated dynamic model | 0 | 0 | 0 |
| Dynamic spatially distributed model | 119 | 59 | 30 |
| Other methodologies | 6 | 3 | 0 |
| Total | 143 | 67 | 35 |

Moreover, in order to know the methodological approach of the models (sectoral or integrated approach), we identified what kind of land use change effects were considered in the reviewed papers, including effects on hydrological dynamics, nutrient dynamics and other different potential environmental effects that may affect the sustainability of the watershed socio-ecological system. Most papers evaluated the hydrological dynamics effects (75%), and there was less frequent analysis of the effects on the dynamics of nutrients (26%) and other environmental attributes (28%), mainly the loss of biodiversity and ecosystem services. Again, the consideration or lack thereof of climate change did not substantially alter the type of analyzed effects.

Most of these publications (86%) evaluated these impacts in the watershed with a sectoral (hydro-ecological discipline) approach. The percentage of articles analyzing the hydrological dynamics effects without considering other possible effects in the watershed were 67%, although the analysis of the effects on the dynamics of the nutrients in the watershed was accompanied by the study of the hydrological dynamics effects in most cases (65%), especially when taking into account the synergistic effect of climate change (91%). Moreover, the study of other environmental effects was accompanied by the study of the hydrological dynamic effects in the 35% of the articles. The analysis of hydrological and nutrient dynamics effects along with other different environmental effects in the watershed was studied in just 2% of the publications, where the watershed was analyzed as a social-ecological system.

These results indicated that there were few integrated approaches, and the analyses were focused primarily on the hydrological dynamics effects of the watershed, versus an integrated and more interdisciplinary approach.

The articles that have analyzed land use changes scenarios in other spatial scales were placed together on a percentage slightly higher to that of watershed (51% of the 294 reviewed publications). More than 50%

(specifically, 53%) of these articles were also published in the period 2014–2019 (Figure 1).

Notably, only 28% of these articles analyzed the process of climate change, a much lower percentage than in the case of watersheds (47%). Moreover, only 48% of these cases used regionalized climate change scenarios. Just as in watersheds, 67% of the publications that took into account both processes of global change, were published in the last six years, from 2014 to 2019 (Figure 1). The study of the synergistic effect of land use change and climate change was discussed only in seventeen studies (39%) and 81% of these studies were published in the last four years (2016–2019) (Figure 1).

In relation to the methodology used in the analysis of scenarios in other spatial scales, it is noteworthy that although the dynamic spatially-distributed models remained the most common method, their use was not as major as in the case of the analysis of land use change scenarios in watersheds (Table 1). The spatial statistical models rose to 59% in the articles analyzing the synergistic effects of land use change and climate change (Table 2).

Table 2. Models classification applied in the analysis of land use change scenarios in other spatial scales to watershed.

| Models Classification | Number of Total Articles in Other Spatial Scales to Watershed | Number of Articles of Land Use Change and Climate Change Jointly Analyzed in Other Spatial Scales to Watershed | Number of Articles of Synergistic Effects of Land Use Change and Climate Change in Other Spatial Scales to Watershed |
|---------------------------------------|--|---|---|
| Non-spatial statistical model | 26 | 4 | 0 |
| Spatial statistical model (e.g., GIS) | 26 | 11 | 10 |
| Aggregated dynamic model | 1 | 0 | 0 |
| Dynamic spatially distributed model | 72 | 24 | 7 |
| Other methodologies | 26 | 4 | 0 |
| Total | 151 | 43 | 17 |

Unlike the analysis of land use change scenarios in watersheds, most of these publications in other spatial scales assessed other environmental effects (87%) compared to the effects of hydrological dynamics (9%) and nutrients (3%). The consideration or lack thereof of climate change did not substantially alter the type of effects analyzed. The approach for the analysis of scenarios in other spatial scales was totally sectorial and cases studies were not

analyzed within the social-ecological framework. Overall, 95% of articles studying other environmental effects on scenario analysis did not take into account the effects on the hydrological dynamics and nutrients.

The participation of stakeholders in the process of building land use change scenarios was only collected in twelve articles (Table 3) and 50% of these articles have been published recently—in the last four years (2016–2019). Most of the articles (95%) developed land use scenarios with researcher-driven approaches [4][28][29][30][31][32][33], where the experts drove scenario development with an objective of providing rigorous descriptions of plausible futures, including details that are well supported by available science.

Table 3. Articles with a participatory approach in the land use change scenarios development.

| References | Spatial Scale | Land Use Change and Climate Change Jointly Analyzed | Synergistic Effect of Land Use Change and Climate Change | Methodology to Study LUC | Effects on Hydrological Dynamic | Effects on Nutrients Dynamic | Other Environmental Effects |
|--|---------------|---|--|--------------------------------------|---------------------------------|------------------------------|-----------------------------|
| Mancosu, E. et al. 2014 [34] | Catchment | YES | NO | Dynamic spatially distributed models | YES | NO | NO |
| Harmácková, Z.V. and Vacka, D. 2015 [18] | Basin | NO | NO | Dynamic spatially distributed models | NO | YES | YES |
| Ronfort, C. et al. 2011 [35] | Watershed | NO | NO | Dynamic spatially distributed models | YES | NO | NO |
| Rickebusch, S. et al. 2011 [36] | Regional | NO | NO | Spatial statistical model | NO | NO | YES |
| Castella, J.C., Verburg, P.H. 2007 [37] | Local | NO | NO | Dynamic spatially distributed models | NO | NO | YES |
| van Noordwijk, M. et al. 2001 [38] | Local | NO | NO | Dynamic spatially distributed models | NO | NO | YES |

| References | Spatial Scale | Land Use Change and Climate Change Jointly Analyzed | Synergistic Effect of Land Use Change and Climate Change | Methodology to Study LUC | Effects on Hydrological Dynamic | Effects on Nutrients Dynamic | Other Environmental Effects |
|----------------------------------|---------------|---|--|--------------------------------------|---------------------------------|------------------------------|-----------------------------|
| Kim, Y.S. et al. 2018 [39] | Local | NO | NO | Dynamic spatially distributed models | YES | NO | YES |
| Lippe, M. et al. 2017 [40] | Local | NO | NO | Dynamic spatially distributed models | NO | NO | YES |
| Sherrouse, B.C. et al. 2017 [41] | Local | NO | NO | Spatial statistical model | NO | NO | YES |
| Benini, L. et al. 2016 [42] | Basin | YES | YES | Dynamic spatially distributed models | YES | NO | NO |
| Trisurat, Y. et al. 2016 [43] | Watershed | YES | NO | Dynamic spatially distributed models | YES | NO | NO |
| Min, F. et al. 2016 [44] | Watershed | YES | NO | Dynamic spatially distributed models | YES | YES | NO |

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