Applied Geography 90 (2018) 106–114

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

From divide to nexus: Interconnected land use and water governance changes shaping risks related to water

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ARTICLE INFO

Keywords:
Land use
Satellite imagery
Risk
Vulnerability
Water management
Water governance

ABSTRACT

Land use changes have been recognized to have considerable impacts on water; and vice versa, changes in water use and governance may have implications on land use and governance. This study analyzes recent land use/land cover (LULC) changes, and how changes in land use and water governance are perceived to affect land use and water-related risks in three case-study areas exposed to frequent flooding and inadequate or deteriorating water quality. The areas studied included the Vantaa basin in Finland, a section of the Grijalva basin in Mexico, and the Lower Xe Bang Fai basin in Laos. We show how there are complex and context-specific interrelationships between land use, water governance, and water-related risks in each study area. In a remote sensing analysis of LULC changes during the past 30 years, we found that LULC changes have been the most dramatic in Xe Bang Fai, Laos in the form of expanding agriculture and built-up areas; however, there has also been an expansion of built-up areas in the two other sites. According to our stakeholder scenario workshop data, analysis of policy documents and field visits, the nexus between land, water and risks is recognized to some extent in each study area. There have been modest shifts toward more integrated land use and water governance in Vantaa and Grijalva, while the integrated governance seems to have been most absent in Xe Bang Fai. Tighter integration of land and water policies is needed in all the three cases to manage the land use changes in a way that their effects on water-related risks will be minimized.

1. Introduction

Water-related problems (e.g. floods, droughts and poor water quality), and vulnerability towards them, are driven by changes in land and water use, as well as by their interconnections. Unsustainable land use changes have been recognized to have considerable implications on water (Delpla, Jung, Baures, Clement, & Thomas, 2009; Foley et al., 2005; Rockström et al., 2009; Steffen et al., 2015), while changes on water use and governance have considerable effects not only on water but also on land use (Alemayehu et al., 2009; Wang et al., 2016). In addition, land and water use changes may significantly increase vulnerability to water-related hazards, such as adverse floods (Lioubimtseva & Henebry, 2009; McCubbin, Smit, & Pearce, 2015).

Land use changes and water-related risks and vulnerability are driven by several factors that include local processes and global political-economic forces (Lambin et al., 2001; Meyfroidt, Lambin, Erb, & Hertel, 2013). Despite universal trends, such as agricultural intensification and expansion of industrial activities and urban settlements (Meyfroidt et al., 2013), the combination of exact drivers of change, their intensities and linkages with water-related risks and vulnerability are contextual and have specific outcomes and meanings in particular sites (Güneralp, Güneralp, & Liu, 2015; Lambin et al., 2001; Rockström et al., 2014). Thus, it is important to understand the similarities and differences in socio-spatial contexts regarding the implications of the land use and water governance changes on water-related risks and vulnerability (Pahl-Wostl, 2015).

By using a mixed-methods approach, we evaluated linkages between changes related to land and water and associated water-related risks and vulnerability in three case studies located in Finland, Mexico and Laos. We quantified land use/land cover (LULC) changes during the past 30 years with the help of Landsat remote sensing data and supervised classification and evaluated (1) to what effect changes in land

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https://doi.org/10.1016/j.apgeog.2017.11.005
Received 5 September 2017; Received in revised form 14 November 2017; Accepted 23 November 2017
0143-6228/

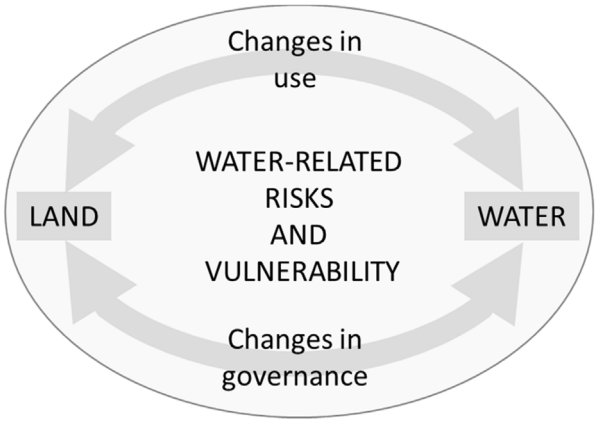

Fig. 1. Analytical framework of the study.

and water use can be tracked using remote sensing. Furthermore, with the help of qualitative data gathered from stakeholder scenario workshops, policy documents, field visits and interviews, we asked what are the institutional perceptions on (2) how changes in land use and governance have affected water-related changes and risks during the past 30 years and how they will affect water during the following 30 years, and (3) how changes in water use and governance have affected and will affect land use and its governance.

2. Water-related risks and their connection to the use and governance of land and water

In the centerpiece of our analysis are water-related risks and vulnerability (Fig. 1). In line with the IPCC (2014), we distinguish risks from vulnerability with the former referring to potential consequences of water-related problems, such as floods, droughts and low water quality, and the latter referring to pre-existing condition of individuals, communities and societies in terms of how heavily they will be affected by water-related problems. For instance, major disparities in social vulnerability often indicate that increasing flood risks and worsening conditions of water quality are socially differentiated (Nygren, 2016; Sze et al., 2009).

Water-related risks and vulnerability are influenced by changes in land and water use, as well as their governance. Furthermore, processes related to land and water are in a bidirectional relationship (Fig. 1), and this interaction has implications for risks. We differentiate land and water use from land and water governance. The former refers to how and where land and water resources are utilized. Governance, on the other hand, refers to the regulation of development and management of land and water resources (c.f. Pahl-Wostl, 2015).

Changes in land use affect both the exposure to flooding (Güneralp et al., 2015; Liu, Wang, & Li, 2014; Sze et al., 2009; de Moel, Aerts, & Koomen, 2011) and flooding patterns by changing the water-flow regimes and runoff generation (Alexakis et al., 2014; Sze et al., 2009; Zhou et al., 2013). In addition to flooding, changes in land use may modify the availability of water, which may have implications e.g. for communities, agricultural livelihoods and energy production (Rahman et al., 2015; Tong, Sun, Ranatunga, He, & Yang, 2012; Zhang, Karthikeyan, Bai, & Srinivasan, 2017). Furthermore, land use changes and increasing human activities have also significant impacts on water quality patterns (Foley et al., 2005; Liu, Long, Li, & Tu, 2015; Rockström et al., 2014; Tu, 2011; Wilson, 2015).

Large-scale water management infrastructure and hydropower projects significantly alter hydrological systems (e.g. streamflow, runoff, storage and infiltration) (Gao, Yang, & Yang, 2013; Lu, Li, Kummu, Padawangi, & Wang, 2014; Muñoz-Salinas & Castillo, 2015), and changes in management and governance of water resources have also implications for land use (Alemayehu et al., 2009; Desta, Lemma, & Gebremariam, 2017; Wang et al., 2016). In many cases, changes in land and water use are clearly intertwined, such as in the embankment and canalization of water for flood protection and to support land conversion to agriculture and built-up areas (Marçal, Brierley, & Lima, 2017; Ritzema & Van Loon-Steensma, 2017). Due to the interconnectedness of land and water, there have been calls for and analyses of the land-water-nexus and integrated land and water management (Benson & Lorenzoni, 2017; Borchardt, Bogardi, & Ibisch, 2016; Chen et al., 2018; Ringler, Bhaduri, & Lawford, 2013; Ritzema & Van Loon-Steensma, 2017; Rockström et al., 2014).

LULC changes have been tracked for decades using remote sensing methods (Singh, 1989; Tewkesbury, Comber, Tate, Lamb, & Fisher, 2015). While remote sensing is sufficient in mapping land cover, for mapping land use, especially its intensity and the changes in its intensity, a combination of remote sensing and other methods is needed (Erb et al., 2013; Kuemmerle et al., 2013; Meyfroidt et al., 2013; Temme & Verburg, 2011). Thus, in order to understand the changes related to land use and link them to social processes, using remote sensing only is not sufficient. For instance, when grasping the multifaceted and contextual interactions between changes related to land, water and associated risks mixed methods are needed (Alemayehu et al., 2009; Desta et al., 2017; Forrester, Cook, Bracken, Cinderby, & Donaldson, 2015; Mapedza, Wright, & Fawcett, 2003; Palmer, Hill, Mcgregor, & Paterson, 2011; Qasim, Hubacek, & Termansen, 2013; Xue, Liao, Hsing, Huang, & Liu, 2015). Here, we combine remote sensing based LULC change analysis with qualitative evaluation of stakeholder perceptions of environmental change. The analysis of the institutional perceptions of the linkages between water, land and risks enabled us to grasp the governance context and the institutional views and values, which form a basis for policy decisions (Forrester et al., 2015; Suckall, Tompkins, & Stringer, 2014).

3. Study areas

The case-study areas included in the study were: the River Vantaa basin in southern Finland, a section of the River Grijalva basin in Tabasco, southeastern Mexico, and the Lower Xe Bang Fai basin in south-central Lao PDR (Fig. 2). We chose study areas which have different socio-cultural, political-economic and environmental contexts, and the combination of three divergent areas thus allows the analysis of how the land-water nexus and associated risks differentiate across three continents in developing, middle-income and developed countries. The study areas have complex land use histories and water-governance policies but they are also exposed to flood risks and to inadequate or deteriorating conditions of water quality, and several strategies have been recently implemented to mitigate these water-related risks. This offers us a good basis to analyze the institutional perceptions of the nexus between land use changes and water-related risks. Instead of a strictly comparative analysis, our purpose is to show the similarities and differences between the drivers of land use changes and their linkages to water-related risks across the cases. A description of the case study areas is given in Supplementary material 1, and the context of water governance in the cases is explained in Räsänen et al. (2017).

4. Methods

4.1. Land use/land cover change analysis

We quantified past changes in LULC using 30 m spatial resolution Landsat images (A more detailed description of the classification approach is given in Supplementary material 2). For each site, we choose three images from different time points (Table 1). The analyzed images were taken approximately during the same time of the year to allow comparison across years. The images were first mosaicked and clipped and after that an object-based classification with Full Lambda Schedule image segmentation in ERDAS Imagine 2014 (Intergraph, Huntsville,