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Research papers

Trajectory analysis of land use and land cover maps to improve spatial–temporal patterns, and impact assessment on groundwater recharge

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ABSTRACT

Land use/land cover (LULC) change is a consequence of human-induced global environmental change. It is also considered one of the major factors affecting groundwater recharge. Uncertainties and inconsistencies in LULC maps are one of the difficulties that LULC timeseries analysis face and which have a significant effect on hydrological impact analysis. Therefore, an accuracy assessment approach of LULC timeseries is needed for a more reliable hydrological analysis and prediction. The objective of this paper is to assess the impact of land use uncertainty and to improve the accuracy of a timeseries of CORINE (coordination of information on the environment) land cover maps by using a new approach of identifying spatial–temporal LULC change trajectories as a pre-processing tool. This ensures consistency of model input when dealing with land-use dynamics and as such improves the accuracy of land use maps and consequently groundwater recharge estimation. As a case study the impact of consistent land use changes from 1990 until 2013 on groundwater recharge for the Flanders-Brussels region is assessed. The change trajectory analysis successfully assigned a rational trajectory to 99% of all pixels. The methodology is shown to be powerful in correcting interpretation inconsistencies and overestimation errors in CORINE land cover maps. The overall kappa (cell-by-cell map comparison) improved from 0.6 to 0.8 and from 0.2 to 0.7 for forest and pasture land use classes respectively. The study shows that the inconsistencies in the land use maps introduce uncertainty in groundwater recharge estimation in a range of 10–30%. The analysis showed that during the period of 1990–2013 the LULC changes were mainly driven by urban expansion. The results show that the resolution at which the spatial analysis is performed is important; the recharge differences using original and corrected CORINE land cover maps increase considerably with increasing spatial resolution. This study indicates that improving consistency of land use map timeseries is of critical importance for assessing land use change and its environmental impact.

1. Introduction

Groundwater is a precious source of fresh water throughout the world. About 2 billion people worldwide depend on groundwater supplies (WWAP, 2015). As the world population continues to grow, more people will rely on groundwater resources, particularly in arid and semiarid areas (Simmers, 1990). However the distribution, quantity, and quality of groundwater are affected by human activity (Gehrels et al., 2001). Therefore, assessing human impacts on the groundwater systems is a major scientific challenge (Tang et al., 2005). Land use change is one of the important human interventions altering groundwater flow systems (Calder, 1993) and will continue in the future to impact recharge dynamics and vadose zone globally (Kim and Jackson, 2012).

Land use change is a complex, dynamic process, which has direct impacts on soil, water and the atmosphere (Meyer and Turner, 1994). Therefore understanding the impacts of land use/-land cover (LULC) change on the hydrologic cycle is needed for optimal management of natural resources (Scanlon et al., 2005). Previous studies have mostly focused on LULC variability impacts over bidirectional feedbacks between surface/subsurface and atmospheric flow processes (Betts, 1999; Pielke et al., 1998; Pitman et al., 2004; Yasunari, 2007). Impacts of LULC change on subsurface hydrology, especially recharge of aquifers is not well studied (Scanlon et al., 2005). Both field experimental (e.g. Scanlon et al., 2005; Zhang and Schilling, 2006) and hydrologic modeling application (e.g. Batelaan et al., 2003; Schilling et al.,2008; Albhaisi et al., 2013) have been previously used to

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investigate LULC change impacts on groundwater hydrology. Spatially distributed hydrologic models have the advantage that they can account for the spatial patterns of the hydrological impact of LULC (Wang et al., 2013a,b). Although, these models can make predictions in the future, few studies take future land use change into account.

To overcome these limitations, land use change models have been developed to predict future land use dynamics (Eshleman, 2004; Verburg et al., 2004). These models have been used in conjunction with hydrologic models but the applications have been limited to surface-runoff and flood prediction (Niehoff et al., 2002; Tang et al., 2005; Tong and Liu, 2006; Lin et al., 2007; McColl and Aggett, 2007). A few recent studies coupled hydrological models with land use change models to assess the impact on groundwater systems (Dams et al., 2008; Poelmans et al., 2010). Dams et al. (2008) coupled a land use change model (CLUE-S) with a water balance model (WetSpass) and a steady-state groundwater flow model (MODFLOW) to estimate the impact of future land use change on the groundwater system of the Kleine Nete basin, Belgium for the period 2000–2020. Results showed that urbanization decreased the average groundwater recharge and consequently the groundwater levels and base flow are reduced. Poelmans et al. (2010) used the same hydrological model (WetSpass) and coupled it with an urban expansion model to study the effect of urban expansion on groundwater systems in Flanders, Belgium for 1976–2050. The study predicts a decrease in groundwater recharge in Flanders with an increase in built-up area.

However, land use change models are suffering from uncertainties, which result from different sources such as land use maps for initialization of the models (Verburg et al., 2013). Hence, there is a need to evaluate the effect of such uncertainty on regional hydrology, as land use/land cover variability affects hydrological processes, including groundwater recharge.

For example, the CORINE Land Cover Project database provides free comparable digital maps of land cover for each European country (CLC, 1990, 2000, 2006). These maps are often used for initialization and/or calibration of land use change models. However, the accuracy of these land cover maps remains uncertain. Willaarts (2012) reported different LULC trends in the Spanish CORINE land cover maps compared to the Forest National Inventory datasets. Based on a case study in Dublin, Ireland Verbeiren et al. (2012) showed that consistent remote sensing derived land use maps are preferred over CORINE land cover maps to avoid overestimation errors and interpretation inconsistencies. Bach et al. (2006) proved that the CORINE land cover map has the lowest accuracy compared to land use maps based on digital topographic maps of Germany (ATKIS), and Landsat 5 TM. Hence, an accuracy assessment approach should be performed before integrating these land cover maps in hydrological impact analyses. There are several accuracy assessment methods, but there is not a standard procedure and the choice of a methodology depends on factors such as time, money and human resources (Caetano et al., 2005). The general approach of accuracy assessment is to compare land use maps with reference information that we assume as true (Caetano et al., 2005). Liu and Zhou (2004) proposed a complementary methodology to evaluate the accuracy of land cover change trajectories where a set of rational rules can be defined to evaluate the land cover change. Powell et al. (2008) developed spatio-temporal rules combined with trajectory analysis to minimize classification errors in satellite imagery.

Zhou et al. (2008) used multi-temporal remotely sensed imagery to derive land cover change trajectories. Wang et al. (2012, Wang et al., 2013a,b) proposed a more advanced approach for spatio-temporal analysis of LULC change by using GIS and satellite imagery. Wang et al. (2012) used LULC trajectories for a large area (Xihe watershed, China) to detect the variability of landscape patterns and their changes. However, they considered only six main LULC classes. Wang et al. (2013a), Wang et al. (2013b) used the same approach and high resolution remote sensing imagery in smaller scale valleys (two sub-watersheds of Xihe watershed, China), considering the full trajectories to compare the spatio-temporal dynamic change characteristics. The above mentioned studies focused on the relationship between change patterns and natural geographic factors, role of human activities in the environmental changes, and assessed the impact of change trajectories in water and soil conservation. However, to our knowledge, no previous study has used full spatio-temporal trajectories to correct the overestimation errors and interpretation inconsistencies in existing land cover maps (i.e. CORINE) in relation to assessing the impact of LULC change on groundwater systems.

In this context the present study aims: (1) to assess the impact of land use data uncertainty on hydrological impact analysis, i.e. estimate how the error in the land cover mapping propagates in the hydrological model (recharge) results; (2) to improve the accuracy of CORINE land cover maps using change trajectory analysis; (3) to identify the spatio-temporal LULC change trajectories; and (4) to quantify effect of the LULC change on groundwater recharge by coupling hydrological models with spatio-temporal LULC change trajectories. The Flanders-Brussels area is taken as an example. It is a highly urbanized region and groundwater is an important resource for drinking water. Therefore quantifying LULC changes is essential for sustainable management of water resources in Flanders.

2. Methodology

The methodology consists of two parts. The first part contains two steps. First the change trajectory analysis is performed for the CORINE land cover maps for Flanders for 1999, 2000, 2006 (CLC 1990, 2000, 2006) and the most recent and detailed land use reference map of Flanders for 2013 (Poelmans et al., 2014). Secondly, the CORINE land cover maps are corrected according to predefined rational change rules. In the second part, the corrected land cover maps are integrated in the spatially distributed hydrological model WetSpass to calculate the seasonal and annual evapotranspiration, surface runoff and groundwater recharge.

2.1. Study area and data

The Flanders and Brussels region extends in northwestern Europe with a surface area of 13,700 km^2, constituting a nearly flat region. It is one of the most densely populated areas in Europe with a total population of 6.4 Million (Economie, 2014). Groundwater accounts for approximately 60% of public water supply (Dassargues and Walraevens, 2014). Flanders has three major river catchments: the Scheldt, Meuse and Yser, these consist of 11 regional catchments and 103 sub-catchment (Fig. 1).

The mean annual long-term precipitation varies spatially between 675 and 995 mm/yr, while the average yearly long-term potential open water evaporation varies between 662 and 675 mm/yr (Batelaan et al., 2007). The summer potential evaporation typically constitutes about 85% of the total yearly amount. The northern part of Flanders has mainly sand (26%) and loamy sand soils (18%), while in the south silty loam (18%) and sandy loam (13%) dominate. The coastal area is characterized by the presence of clay, while the polders are characterized by heavy clay. The main land use types are built-up area (24%), meadow (22%), agriculture (30%), forest (11%), and lakes and rivers (2%) (Poelmans et al., 2014).