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Research papers

An inverse method for watershed change detection using hybrid conceptual and artificial intelligence approaches

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ABSTRACT

Land Use and Land Cover (LULC) changes intrinsically lead to various hydrological impacts especially on the outflow rate of the watersheds. This research investigated LULC changes and its effect on outlet runoff by detecting LULC changes location and severity via an inverse method for the Little River Watershed, USA. For this purpose, the Clark's conceptual Rainfall-Runoff model was applied to the delineated sub-watersheds of the basin to generate different outflows by altering the Storage Coefficient (*SC*) of the model for each sub-watershed as the representative of LULC. Then, the relation between *SC* values and outflow time series was simulated by Artificial Intelligence (AI) based models of artificial neural network and least square support vector machine. In this way, in order to ignore redundant information and reduce the dimension of input vector, Wavelet-Entropy (*WE*) values of the outflow sub-series were computed and used as the inputs of the AI model to compute *SCs* of the sub-watersheds as the outputs. The trained multi-output AI model as an inverse method could be then used to predict the *SC* values (as representative of LULC) of the sub-watersheds using the observed time series of runoff at the outlet. The obtained results showed that the proposed inverse method could reliably detect not only the location but also the severity of LULC changes by prediction of *SC* values in the coming future years. For validation of the method, a comparison was also performed between the obtained results and recorded changes via normalized difference vegetation index (*NDVI*) and land use classification, extracted from Landsat images. The comparison approved the ability of the proposed method for LULC change detection in a way that deforestation and cropland increasing of the sub-watersheds from 1990 to 2013 were aligned with the *SC* reduction e.g., 26% decrease of *SC* for downstream sub-watershed versus 53% decrease and 21% increase of forest and crop lands, respectively.

1. Introduction

Land Use and Land Cover (LULC) change of a watershed is a major challenge in hydro-environmental studies to extent of which is affected by numerous factors inside and outside the watershed. Unsuitable practices of LULC such as deforestation, uncontrolled and unnecessary pasturing, agriculture development, and urban expansion are deteriorating watershed conditions, at different temporal and spatial scales (Agaton et al., 2016). LULC changes in watersheds could have undeniable effects on the quantity and quality of water as well as the ecosystem of the basin, which in turn can impact the human life. Detection of LULC changes at different spatio-temporal scales is a complicated task affected by different anthropogenic and natural factors. Various studies have been conducted regarding the watershed change analysis through different methods mostly using satellite imaginary, Remote Sensing (RS) and Geographic Information System (GIS) tools (e.g. see, Oñate-Valdivieso and Bosque Sendra, 2010; Persendt and Gomez, 2016; Welde and Gebremariam, 2017; Diamantini et al., 2018). Haque and Basak (2017) and Choudhary et al. (2017) detected the LULC changes of watersheds via distributed models and *NDVI*. One of the main hydrological responses of a watershed to such LULC changes can be seen in the outlet flow (e.g. see, Nie et al., 2011; Saeidifarzad et al., 2014; Niraula et al., 2015; Nourani and Saeidifarzad, 2016). Although the utilization of satellite data, as a forward problem, is a commonly used method for LULC change detection, this method may include some deficiencies such as the blurbification of images due to cloudy weather, cost/time-consuming procedure of the RS productions or from the temporal point of view, sometimes, it is possible that the satellite images are not available. In this condition, inverse solution of the problem can be considered as an alternative.

Generally, the scientific procedures to investigate physical systems can be divided into the following three types (Tarantola, 2005):

I. Parameterization of the system: detection of a minimal group of

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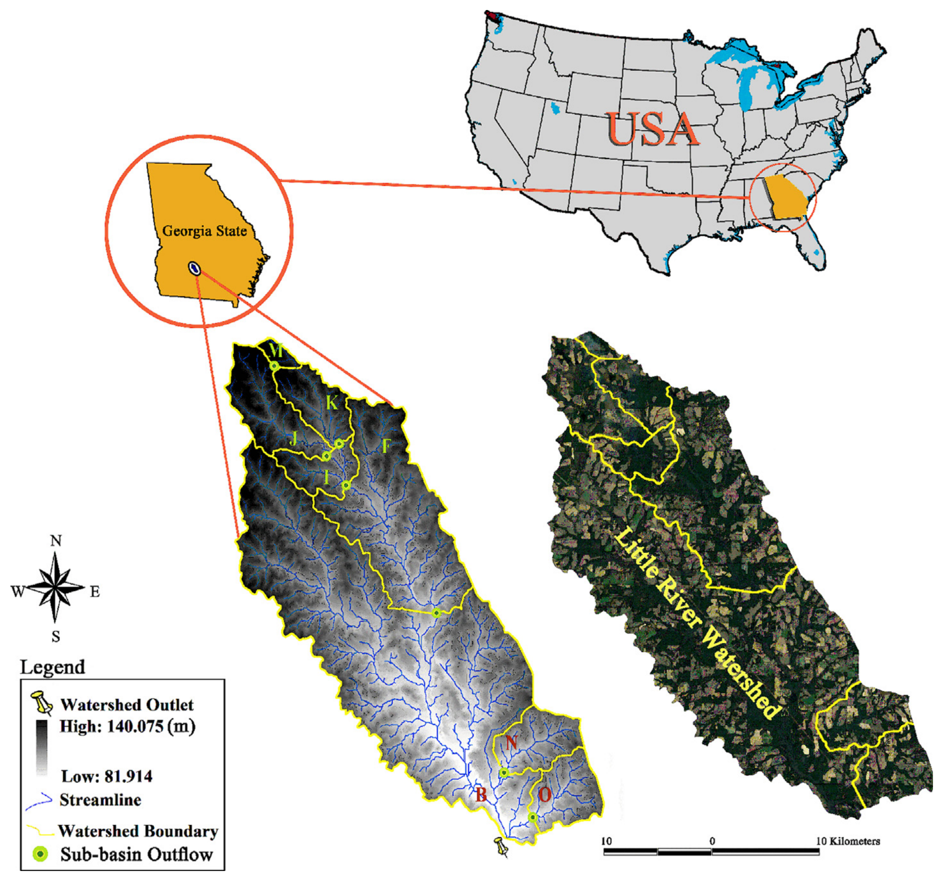

Fig. 1. Location map of the LRW in Georgia, USA.

model factors whose values fully describe the system (from a given point of view).

II. Forward problem: discovery of the physical laws allowing us, for given values of the model parameters, to make predictions on the outcomes of measurements on some observable parameters.

III. Inverse problem: use of the real outcomes of some measurements of the observable parameters to infer the actual values related to the model parameters.

The inverse problem is subjected to determine the unknown model parameters using the experiential state data. The inverse technique is one of the key methods at different fields such as structural damage detection (e.g., see, Fang et al., 2005; Wang et al., 2017), physics (e.g., see, Meng et al., 2015; Davin et al., 2017), hydrogeology (e.g., see, Zhou et al., 2014), hydraulic and hydrology (e.g., see, Kretzschmar et al., 2014). Bhattacharjya (2011) presented a simple spreadsheet cell-oriented methodology for solving a groundwater flow inverse problem. Pan and Wood (2013) developed a methodology to invert the routing process, i.e., to derive the spatially distributed runoff from streamflow by inverting a linear routing model using fixed interval. Kretzschmar et al. (2014) combined a continuous-time transfer function model with regularized derivative estimates obtained using a recursive method for estimation of catchment sub-hourly rainfall from the measured streamflows. In some hydrological studies, the parameters of a model that converts the rainfall to runoff are assumed to be constant over time. But in practice, these parameters may be altered due to LULC changes over time. In other words, there is a need for a method to analyze the input-output relationship of Rainfall-Runoff (R-R) and to identify physical changes within the watershed by solving an inverse problem and without conducting direct observations. In this study, a novel method is introduced to determine the location and severity of LULC changes in the Little River Watershed (LRW). To the best of our knowledge, there is not any inverse method using the distributed, semi-distributed or black box models for LULC change detection. In this regard, Artificial Intelligence (AI) based methods of Artificial Neural Network (ANN) and Least Square Support Vector Machine (LSSVM) are used to extract the relationship between LULC changes and outflows of the watershed. Firstly, R-R modeling is performed via Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) using Clark's conceptual model and extracted geomorphologic information for the LRW as a linear reservoir. Then by altering Storage Coefficient (*SC*) values of sub-watersheds in the Clark model (*SC* is considered as a lumped parameter that represents LULC of each sub-watershed, such presumption that considers a lumped parameter as representative of the LULC of the hydrologic units of the watershed has been proposed in some other studies e.g., Bronstert, 2005; Dwarakish and Ganasri, 2015; Si et al., 2017), different outflow time series are generated. In the next step, the relationship between generated outflows time series and related *SCs* is created by the multi-output AI models to estimate the severity and location of LULC variations (represented by *SC* values). To prevent imposing a large amount of information (whole outflow time series), Wavelet-Entropy (*WE*) values of each time series are computed and imposed into the AI models instead of whole outflow time series. Finally, the trained model can be used to detect the LULC changes of the LRW for the future years. Therefore, by this proposed inverse method, LULC changes will be detectable just by analyzing runoff time series in the coming years. For the validation purpose, the obtained results are also compared with the recorded changes via *NDVI* and land use classification, extracted from the Landsat images because *SC* and *NDVI* values do not have same order (and dimension), in the validation step, the validation rate of each with regard to the base year is computed and compared with together.