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Editorial

Geo-Spatial Analysis in Hydrology

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Abstract: With the increasing demand for accurate and reliable hydrological information, geo-spatial analysis plays a more and more important role in hydrological studies. The development of the geo-spatial technique advances our understanding of the complex and spatially heterogeneous hydrological systems. Meanwhile, how to efficiently and effectively process and analyze multi-source geo-spatial data has become more challenging in the fields of hydrology. In this editorial, we first review the development and application of geo-spatial analysis in three major topics in hydrological studies, namely the scaling issue, extraction of basin characteristics, and hydrological modelling. We hence introduce the articles of the Special Issue. These studies present the latest results of geo-spatial analysis in different topics in hydrology, and improve geo-spatial analytic methods for better accuracy and reliability.

Keywords: hydrology; geo-spatial analysis; scaling issue; basin characteristic extraction; hydrological modelling

1. Introduction

With the rapid development of geo-spatial technology and the increasing demand for accurate and reliable hydrological information, geo-spatial analysis plays a more and more important role in hydrological studies, such as hydrological monitoring, water resources assessment, and water-related decision making. The applications of geographical data acquiring, storing and analytic technique in hydrology provide more detailed (e.g., finer resolution) and more extensive (e.g., larger spatial and temporal coverage) information of the distribution, movement, and dynamic of water components, such as precipitation, surface runoff, soil moisture, and groundwater. These geo-spatial data and techniques advance our understanding of the complex and spatially heterogenous hydrological systems especially in ungauged regions such as arid and semi-arid areas. Meanwhile, how to efficiently and effectively mine, process and analyze multi-source geo-spatial data has become more challenging in the fields of hydrology.

Geo-spatial analytic methods have been widely adopted in hydrological studies. The applications of geo-spatial analysis in three fundamental issues in hydrology are briefly reviewed in this editorial, namely the scaling issue, extraction of basin characteristics, and hydrological modelling.

(1) Scaling issue of hydrometeorological variables

Traditional in situ measurements of hydrometeorological variables, such as precipitation, temperature, streamflow, and soil moisture, are at the site scale, while some hydrological studies require basin-scale analysis [1]. Therefore, how to solve the scaling mismatch issue has been one of the most fundamental issues in hydrology [2]. Various spatial interpolation techniques have been developed to interpolate point-scale observations to the areal scale, such as Thiessen Polygons, Inverse Distance Weighting, and Ordinary Kriging [3]. Hydrological variables such as precipitation are highly heterogeneous in space and time, and their spatial distributions are strongly affected by topographic factors. In order to improve the skill of the interpolation methods, especially in the regions with complex terrain, topographic factors are considered as secondary predictors in certain interpolation methods, such as Thin Plate Smoothing Splines [4] and Kriging with External Drift [5]. Besides spatial interpolation techniques, Areal Reduction Factor, a ratio between the areal average value and the point-scale value, is another popularly used strategy to deal with the scaling issue of precipitation in hydrological risk analysis and design [6]. Moreover, different types of statistical downscaling methods have been developed to downscale future projections from coarse Global Climate Models to a fine resolution [7,8]. Statistical downscaling methods are based on the statistical relationship between values at a coarse resolution and a fine resolution in a selected training period.

(2) Extraction of basin characteristics

Basin characteristics, such as elevation, slope, basin area, river channel, and land cover land use, are the most basic and essential information for hydrological studies such as hydrological modelling [9]. Geo-spatial methods have been developed to extract these key characteristics from grid-based Digital Elevation Models (DEM) [10]. For instance, to acquire terrain parameters for hydrological studies at various spatial scales, DEM may need to be generalized or reconstructed using geo-spatial techniques such as triangulated irregular network (TIN). However, the reliability of basin characteristics extracted depends on DEM accuracy, data structure, and derivation algorithm [11,12]. For example, flow routing extracted from DEM can be affected by the choice of extraction algorithms [13]. A number of studies have been conducted to improve the accuracy and reliability of basin characteristics extracted from geo-spatial data. Zhou and Chen [9] proposed a compound method to integrate the point-additive and feature-point methods to construct a TIN. The compound method is capable of keeping the major terrain features while significantly reducing the elevation data points. To overcome the complication of flow divergence/convergence in traditional raster-based methods for estimating surface flow paths, Zhou et al. [14] developed a triangular facet network algorithm. They found that the facet-based algorithm outperforms the traditional methods with better representation and more consistent outcomes.

(3) Hydrological modelling

The advancement of geo-spatial techniques and the increasing availability of multi-source geographical data facilitate the development of hydrological models. Remote sensing provides a variety of hydrometeorological (e.g., precipitation, evapotranspiration, and soil moisture) and land surface data (e.g., DEM and land use land cover) with extensive spatial coverage for hydrological models as inputs or as reference for model calibration and validation [15,16]. A data assimilation technique has been developed to couple instrumental observations (more accurate but lacking spatial representativeness) and hydrological models (better spatial representativeness but limited by model errors and uncertainties), such as the popularly used Global Land Data Assimilation System (GLDAS) [17]. The resolutions of hydrological models have become higher and more physical processes have been incorporated in the state-of-the-art models, making hydrological modelling more computationally demanding. More recent studies focused on improving the computation efficiency of hydrological modelling, such as those using the parallel computing strategy. Spatial domain decomposition is a parallel strategy that partitions a basin into a number of sub-basins and conducts hydrological simulations in different sub-basins among multiple processors [18]. Zhang and Zhou [19] developed a particle-set strategy to parallelize the flow-path network model to achieve higher performance in the simulation of flow dynamics. Compared to previous partition-based strategy, the strategy developed by Zhang and Zhou [19] focused on dynamic water flows instead of statistic basin units.

In addition to the topics introduced above, there are many other hydrological topics in which geo-spatial analysis plays a crucial role, such as water quantity and quality evaluation for sustainable management [20,21]. Given the increasing importance of geo-spatial analysis in hydrological studies, the Special Issue aimed to seek studies in a wide range of topics related to the development and application of geo-spatial analysis in hydrology.

2. Content of the Special Issue

This Special Issue was set up for exchange of the latest ideas, methods, and results of hydrological studies using geo-spatial analytic technique. The articles of the Special Issue cover a variety of topics in hydrology, including flood modelling, extraction of basin characteristics, and the monitoring of water quantity and quality for sustainable management using geo-spatial methods.

Floods are one of the costliest and deadliest natural hazards in the world. Flood simulation and visualization with acceptable accuracy and reliability are crucial for flood monitoring, forecast, and management. Effective and efficient policy and decision making for flood prevention and control require not only high-quality and fine-resolution hydrological data, but also timely processing and visualization of geo-spatial information. Geo-spatial technique is the key for flood simulation and decision support system to store, process, and visualize hydrological data and flood risks. Wu et al. (2019) integrated one- (1D) and two-dimensional (2D) hydrodynamic models with a spatio-temporal Geographic Information System (GIS) to dynamically simulate flood risks. In this decision support system, a three-dimensional (3D) model of the study area and hydraulic engineering facilities can be quickly established using the photography-based 3D modeling technology. Based on this framework, a multi-source spatio-temporal data platform for flood risk simulations was developed for the Xiashan Reservoir in the Weihe River as a case study. The model assessment results in Wu et al. [22] showed that the integration of spatio-temporal GIS and hydrodynamic models can improve the efficiency of flood risk simulations for decision support, such as dam-break flood simulations and dynamic visual simulations. Munir et al. [23] integrated a hydrological model and a hydraulic model based on remote sensing and GIS-derived estimates to simulate torrential streamflow response to flash flood events in Pakistan. The study made use of the integration of GIS and remote sensing technique to derive different hydrological parameters for the models at a pixel level. The integration of the models was found to be able to simulate flash flood conditions and extents more accurately. These two studies indicated that the integration of models with geo-spatial analytic methods can improve the efficiency and accuracy of flood simulations for flood management.

The second group of studies focused on using geo-spatial technique to improve the accuracy of extraction of basin characteristics. Li et al. [24] proposed a new method of watershed delineation for flat terrain based on Sentinel-2A images with the Canny algorithm on Google Earth Engine (GEE). Using the traditional DEM for water delineation in local-scale plains may not obtain realistic drainage networks primarily because of large depressions and subtle elevation differences. In their study, Sentinel-2A images were first used to identify water bodies such as rivers, lakes and reservoirs to compose the drainage network. Afterward, catchments were delineated based on the flow direction of these water bodies. The proposed method was applied in the Taihu Basin of the Yangtze River basin as an example. The catchment characteristics extracted from the Sentinel-2A images were compared with those based on DEM. Their results showed that the catchment delineation based on the Sentinel-2A images can more precisely represent drainage networks and catchments especially in the plain areas. In another paper of this Special Issue, a level of confidence approach was proposed to quantify the confidence and improve the accuracy of the bathymetry [25]. The quantification of the confidence of satellite-derived bathymetry is challenging because of the lack of in situ data for validation. This proposed approach considers multiple satellite-derived bathymetry techniques, i.e., empirical, classification, and photogrammetric (including automatic and manual). They found that the proposed approach increases the overall accuracy of the satellite-derived bathymetry. Furthermore, certain levels of uncertainties in bathymetry were removed in the proposed method.

The evaluation of water quality and crop water budgeting are two important issues in water resources management for achieving sustainable development of society and ecosystems. Remotely sensed data and geo-spatial methods have been widely used by researchers and policy makers to monitor water quality and estimate crop water deficit. However, the commonly used moderate resolution sensors hardly fulfill the monitoring requirements for small-sized water bodies. Avdan et al. [26] introduced the high-resolution RapidEye satellite data to assess water quality parameters in a small dam, such as electrical conductivity, total dissolved soils, water turbidity, suspended particular matter, and chlorophyll-a. Their results showed that almost all of the water quality parameters have correlations with Rapid Eye reflection higher than 0.80. In Javed et al. [27], a remote sensing technique was used to estimate crop water deficit. Crop classification was determined by NDVI using crop cycles based on reflectance curves. The crop water deficit was defined as the difference between potential and actual evapotranspiration derived from the reflectance-based crop coefficients. Their results showed strong correlations between evapotranspiration, temperature, and rainfall. Crops in summer suffered a higher water deficit than in winter, because of the higher evapotranspiration demand due to higher temperature. Both studies demonstrated that remote sensing and geo-spatial methods are important tools for small-scale water quality assessments and agricultural water consumption evaluations for sustainable water management.

3. Closing Remarks

The articles in this Special Issue presented the latest results of geo-spatial analysis in different topics in hydrology, and developed new methods to improve the accuracy and reliability of the results of geo-spatial analysis. These studies showed that the integration of traditional hydrological/hydraulic models with geo-spatial techniques can improve the efficiency and performance of flood simulations for decision making. The needs of high-resolution hydrological data for scientific studies and practical operations at the local scale have been increasing. The results of these studies demonstrated the reliability of using geo-spatial techniques to acquire high-resolution hydrological parameters at a small spatial scale. In summary, geo-spatial analysis has been an essential and important element in a wide range of research topics in hydrology.

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