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Editorial

Recent Advances in Geographic Information System for Earth Sciences

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1. Introduction

Geographic Information System (GIS) is a computer-based technology and methodology for collecting, managing, analyzing, modeling, and presenting geospatial data for a wide range of applications. GIS plays a vital role in Earth sciences by providing a powerful means of observing the world and various tools for solving complex problems. The scientific community has used GIS to reveal fascinating details about the Earth and other planets.

This special issue on recent advances in GIS for Earth sciences includes 12 publications from esteemed research groups worldwide. The research and review papers in this special issue belong to the following broad categories: Earth science informatics (geoinformatics), mining, hydrology, natural hazards, and society.

2. GIS for Geoinformatics

GIS is an important tool used to solve complex spatial problems in geoinformatics. Several articles dealing with basic algorithms for spatial data analysis are included in this special issue. Zhou et al. [1] propose an efficient parallel algorithm for polygon overlay analysis. Overlay analysis is a fundamental operator in spatial data analytics and is widely used in Earth science applications. The proposed algorithm includes procedures for active-slave spatial index decomposition for intersection, multi-strategy Hilbert ordering decomposition, and parallel spatial union. The application of their new parallel algorithm to a land-use map of China consisting of multiple polygons with 15,615 elements and 886,547 points shows that the algorithm can perform polygon overlay analysis with high efficiency. Therefore, the study contributes to geoinformatics by allowing the processing of large scale spatial data for spatial data analytics.

Vector maps in GIS have been widely used in various fields, including Earth science. Currently, huge volumes of vector map data can be easily stolen and distributed without permission from the original data providers. Pham et al. [2] propose a random encryption algorithm based on multi-scale simplification and the Gaussian distribution to encrypt vector map data before it is stored and transmitted. Their experiment using vector maps of Scotland at different scales shows that the proposed algorithm provides higher security and computational efficiency of storage and transmission of vector map data than previous methods. Therefore, the algorithm can be applied to improve the security of online and offline Earth science map services.

QGIS [3], an open-source GIS software, has been utilized in the Earth science community. Dobesova [4] assesses the visual notation of QGIS's Processing Modeler, a graphical editor for workflow design, using the Physics of Notations theory in combination with eye-tracking measurements. The results from this study provide several practical recommendations to improve the effective cognition of the QGIS Processing Modeler, including changing the fill color of symbols, increasing the size and variety of inner icons, removing functional icons, using a straight connector line instead of a curved line, and providing a supplemental preview window for the entire model.

Geo-sensor networks produce large amounts of Earth science data that can be processed using GIS for different purposes and for intelligent decision making. Malik and Kim [5] propose a geo-sensor framework that can be used by multiple clients to deploy their own geo-sensor networks, bind their sensor objects to desired locations, generate geo-sensor services for the uploaded networks, and manage the services with a geo-sensor composite toolbox. The framework is implemented based on the RESTful and SOAP web services [6]. Performance analysis shows that the lightweight RESTful web service is the best choice for ease of implementation and access.

3. GIS for Mining

Systematic and strategic mine planning, operation, and environmental management are necessary to improve mineral productivity, operational efficiency, and stability in the mining environment. To accomplish these objectives, GIS has been effectively used to design and optimize mine development. Choi et al. [7] review GIS-based methods and applications utilized in mine development, especially for mine planning, operation, and environmental management. They observe that GIS-based methods, including database management, spatial analysis, mapping, and visualization, are effectively used for all stages of mine development at global, regional, and local scales. In the mine planning phase, GIS-based methods are adopted for ore reserve estimation, open-pit boundary optimization, mine infrastructure design, and potential conflict analysis. Various mine operation systems based on GIS have been implemented in mining sites for ore haulage operations, wireless communication, ore management, safety monitoring, underground ventilation, and drainage systems. Moreover, various GIS applications have been developed to support decision-making in mine reclamation planning and re-utilization designs.

As an example of a GIS application for mining, Liu et al. [8] present a spatiotemporal model tightly coupled with GIS for simulating methane emissions in underground coal mines. Such a tight coupling approach is achieved by developing a lattice Boltzmann method (LBM)-based turbulent model with an underlying shared FluentEntity model within the GIS. A case study demonstrates that the proposed GIS-based model is capable and effective in providing functionalities for lattice domain decomposition, simulation, visualization, and analyses, as well as improving computational efficiency compared with traditional computational fluid dynamics (CFD) methods. The tight coupling approach for integrating GIS and simulation models is applicable to underground coal mine disasters.

4. GIS for Hydrology

In hydrological studies, GIS has facilitated the development of a dynamic model for analyzing runoff phenomena as well as a distributed parameter model that considers spatial variability in parameters related to the runoff process. The topography-based hydrological MODEL (TOPMODEL) is a distributed parameter model that uses a digital elevation model (DEM) in GIS. However, TOPMODEL is affected by the resolution of the DEM used. A reliable DEM grid-size resolution that exhibits low sensitivity to changes in input parameters during runoff simulations is investigated by Park et al. [9]. A case study in the Dongkok and Ieemokjung watersheds in South Korea shows that the efficiency of TOPMODEL rarely changes up to a DEM grid-size resolution of approximately 40 m, but changes more noticeably with coarser resolution. The findings of this study are important for understanding and quantifying the modeling behaviors of TOPMODEL under the influence of varying DEM resolution.

Social media data collected through Twitter, Facebook, Flicker, and Weibo can be used to improve understanding of urban hydrology. Wang et al. [10] examine rainstorm-related micro-blogging activities in response to rainstorms in an urban environment at fine spatial and temporal scales. The study collected hourly precipitation data and a total of 3.32 million Weibo blogs geotagged with Beijing, China from June to September 2017. The consistency between rainfall amount and human activities can be explained by the distribution of water ponding sites and major transportation hubs. The results show that human responses to the rainstorm event are consistent, though with certain time lags, in virtual and physical spaces at both grid and city scales.

5. GIS for Natural Hazards

Advances in GIS have popularized its application to spatial analysis of natural hazards. In particular, GIS has been widely used for landslide susceptibility mapping. Landslide susceptibility maps generated by GIS can be effectively used for future land planning and monitoring. Dikshit et al. [11] review studies of rainfall-induced landslides in the Indian Himalayan region to provide a reference point for the first time for researchers working in this region, and a summary of the improvements most urgently needed to better address landslide hazard research and management. Their study reveals that the inclusion of climate change factors and the acquisition of basic input data of the highest quality for computational models is critical for landslide susceptibility mapping.

Zhao and Chen [12] present an example of GIS-based landslide susceptibility mapping using ensemble techniques of functional tree-based bagging, rotation forest, and dagging (functional trees (FT), bagging-functional trees (BFT), rotation forest-functional trees (RFFT), and dagging-functional trees (DFT)). A landslide inventory map with 263 landslide events is established for Zichang County, China, and 14 landslide conditioning factors selected to analyze the correlation between the conditioning factors and the occurrence of landslides. The results show that the prediction rate of the BFT model is the highest when compared with the accuracy of the four ensemble models.

6. GIS for Society

GIS plays an important role in society, especially for land-use planning. The land is a complex system providing food, fresh water, and other material resources for humans. It is essential for habitation, transport, leisure, and other activities. For land-use planning, various factors such as topography, soil, hydrology, biology, and climate will be considered simultaneously. Xiang et al. [13] use GIS to assess the spatiotemporal dynamic multi-functionality of land use and to analyze obstacle indicators in Xiangxi, China using two methods (analytic hierarchy and hierarchical weighting). The study finds that spatial heterogeneity of land use in Xiangxi is increasingly clear. The production function of land use in Xiangxi is slowly increasing, with more rapid growth in the southern and central regions than in the northern regions. Three types of obstacles preventing efficient land use in Xiangxi are identified by GIS-based spatial analysis.

Different land uses are connected by transport networks to improve accessibility for human activities. Yu et al. [14] analyze the traffic flow network using GIS to understand the properties of spatial connectivity, spatial aggregation, and spatial dynamics. The study conducted a series of experiments to explore the transport system in Beijing city using taxi trajectory points recorded by the global positioning system (GPS). The results indicate that the interactions of land use show different characteristics over different time periods. Aggregation patterns of functional areas are dynamic over time and are strongly associated with the travel behaviors of residents in the city.

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