Methods for the Modeling and Visualization of Regional Scale 3D Vegetation: A Case Study of the Qinghai Lake Basin

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Abstract: Geospatial data with attribute tables serve as the foundation for spatial analysis, data sharing and exchange, and application services on the regional scale. GIS models based on 3D spatial data have been widely applied in related fields such as urban planning, landscape management, and ecosystem monitoring. However, due to the unique 3D structure and physiological characteristics of plants, there is a lack of systematic and standardized modeling and visualization methods for 3D vegetation. This study proposed 2.5D and 3D modeling methods of 3D vegetation at the regional scale based on OGC standards and GIS platforms, including 2.5D vector models, 2.5D raster models, 3D geometric models, and 3D Billboard models. Then, by taking the Qinghai Lake Basin as a case study, different kinds of vegetation models were built and visualized to test the rapid generation and visualization of large-scale vegetation in 3D scenes and the geospatial attribute integration on the WebGIS platform. This study could provide a reference for vegetation modeling and analysis at the regional scale and offer a pathway to support public participation and collaborative sharing with intuitive 3D interactive vegetation models on the WebGIS platform.

Keywords: 3D vegetation model, geospatial database, Qinghai Lake Basin

1 Introduction

With the rapid development of the 3D geographic information system (GIS), 3D spatial models have been widely used in urban planning, landscape management, and ecosystem service evaluation (XU et al. 2021). The 3D GIS applications for buildings and other types of gray infrastructure are relatively well-developed. However, compared to other geometries, such as buildings and bridges, the 3D geometries of plants have significant differences, which include complex branching structures, dynamic growth, and seasonal changes (OKURA 2022), making it a challenge for the visualization and computation process. The current computational data of vegetation in GIS is primarily limited to 2D space, with a noticeable absence of systematic modeling methods in 3D space. 3D vegetation models with geospatial attributes serve as the foundation of spatial analysis, data sharing, exchange, and interactive visualization (FU et al. 2024). Therefore, it is essential to establish a specific geospatial modeling and visualization method that can integrate with current geospatial modeling standards and datasets.

Moreover, in landscape research and practice, the expansion of study areas and the increasing computational demands for vegetation space necessitate standardized modeling and exchange methods for 3D geospatial data (RANTANEN et al., 2023). The Indexed 3D Scene Layers (I3S), proposed by ESRI and adopted by the Open Geospatial Consortium (OGC), is a set of visualization standards for 3D geospatial data that facilitates the production, exchange, transformation, and publication process (LIANG et al. 2023). I3S supports techniques such as

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Level of Detail (LOD), geometric compression, texture compression, and node index pages, which enables high performance and scalability for 3D spatial data.

The geospatial datasets generally are represented by 2D vector graphics or raster images for geospatial statistics analysis in specialized research domains (MAHDAVI-AMIRI et al. 2015). There is a lack of application for intuitive and realistic visualization approaches for non-professionals and the general public. Current 3D digital twin models in the industry are often rendered with game engines such as Unity or Unreal Engine, which perform well in 3D visualization but lack integration with attribute information and do not support interactive data analysis or collaboration.

With the increasing public accessibility needs of geospatial datasets and the growing demand for public participation in GIS mapping, the development of intuitive and easy-to-use geospatial databases has become a pressing need. Additionally, there is an urgent demand for solutions based on WebGIS that enable the structured data storage, visualization, and collaborative editing of 3D geospatial data.

This study selected the Qinghai Lake Basin, a critical ecological sanctuary in China, as a case study. Leveraging multi-source datasets, we proposed a standardized method to construct 2.5D and 3D vegetation models, as well as corresponding attributes to generate a geospatial database. These efforts could support public participation and collaborative sharing in the Qinghai Lake National Park planning and development process.

2 Research Methods

2.1 Research Area

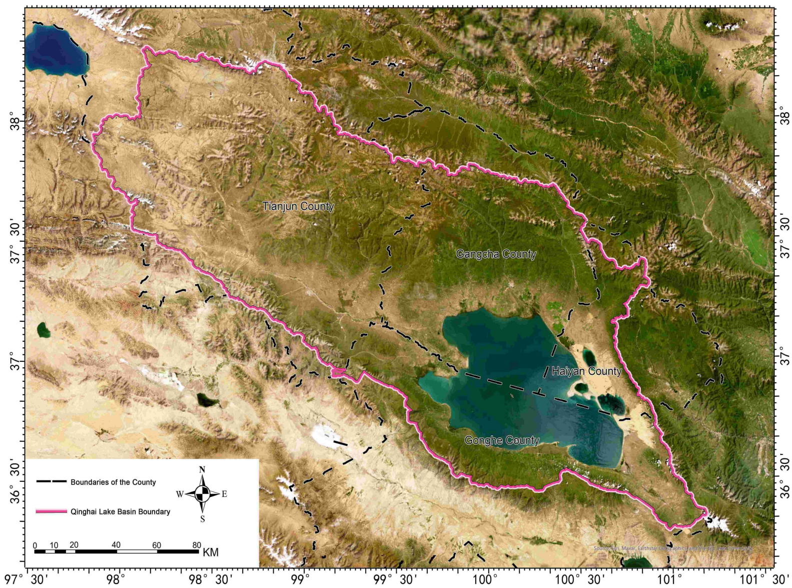

Fig. 1: Boundary of Qinghai Lake Basin

The Qinghai Lake Basin is an inland lake basin located in the northeastern part of Qinghai Province, China. The basin measures approximately 300 km in length from east to west and about 220 km in width from north to south, covering a total area of 29,661 km² (Fig. 1). As a part of the Qinghai Lake National Park planning, conducting a comprehensive survey of various natural resources and establishing a WebGIS Platform will facilitate a systematic assessment of the natural ecological environment, important natural resources, and socio-economic conditions of the Qinghai Lake Basin (ZHAO et al. 2024; LAN et al. 2020).

2.2 Data Sources

The construction and visualization of a vegetation geospatial database require various data sources, including plant species, regional distribution, and morphological and physiological features.

The datasets of vegetation regional distribution include the geographic location of vegetation and related attribute information, such as land cover, ownership, vegetation type, canopy density, and dominant plant species. The datasets were obtained from land resource or forestry surveys. The vegetation coverage data used in this study are based on the Third National Land Resource Survey, which includes various vegetation types and their attribute information.

Plant morphological data used to construct 3D geometric features includes attributes such as crown width, height, and shape of individual trees. Certain data types, such as crown height, can also be acquired through remote sensing and field sampling. This study utilized the global canopy height data collected in 2020 at a 10-m resolution, derived from the Global Ecosystem Dynamics Investigation (GEDI) mission and fused with Sentinel-2 satellite imagery.

The attribute information expresses the physiological characteristics of plants. At the regional scale, remote sensing data serve as a crucial source for acquiring vegetation physiological data, including the Leaf Area Index (LAI) and vegetation coverage. The LAI is derived from the MuSyQ GF-series 16m/10-days Leaf area index product (ZHANG et al. 2021). The dataset was generated by fusing the high spatial and temporal resolution of the GF-1 satellite and a 3D radiative transfer model. The FVC is obtained from the MuSyQ GF-series 16m/10-day vegetation cover product (ZHAO et al. 2021). The product took advantage of the high spatial and temporal resolution of GF-1. It was created using the gap probability theory for forest type and the dimidiate pixel model based on normalized difference vegetation index (NDVI) for other vegetation types.

2.3 Modeling Procedures

This study introduces 2.5D and 3D modeling methods for vegetation models. Each method contains two kinds of sub-type modeling approaches. 2.5D models includes 2.5D raster model and 2.5D vector model, and 3D models includes 3D geometric model and 3D billboard model. Each model includes geometric features and attribute tables. These methods were developed based on the ArcGIS Pro geospatial database and tailored to meet various application requirements.

The 2.5D and 3D model data conform to the I3S standard for scene layer services, enabling data exchange via scene layers. Additionally, the data can be packaged into SLPK (Scene Layer Package) format for data transmission and web service publication.

2.3.1 2.5D Vegetation Models

The 2.5D vegetation model represents the 3D geometry of plants based on vertical indicators. In this study, two types of 2.5D vegetation models were established: a 2.5D raster model and a 2.5D vector model, to express the geometric feature information of plants from different perspectives.

The 2.5D raster model represents the plant model through a continuous surface formed by a number of grid cells. The height of a cell indicates the average tree height inside the cell area, while the color intensity of the cell expresses the average leaf area density (LAD) of the vegetation contained. The 2.5D raster grids could be set to different resolutions corresponding to different scales. In the Qinghai Lake Basin case study, a grid size of 1000m × 1000m was utilized for the watershed area, while a finer grid size of 160m × 160m was applied to focus on specific local regions. Multi-source attributes at different scales are connected to the corresponding grids by the spatial join. In the vertical direction, the vegetation heights were stretched according to the canopy height attributes, while in the horizontal direction, the color variations were displayed based on leaf area density (Fig. 2).

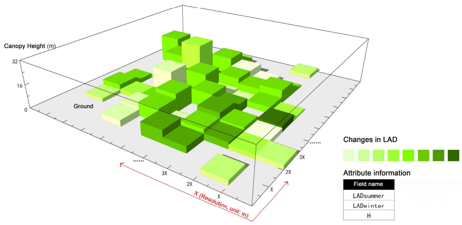

Fig 2: 2.5D raster model

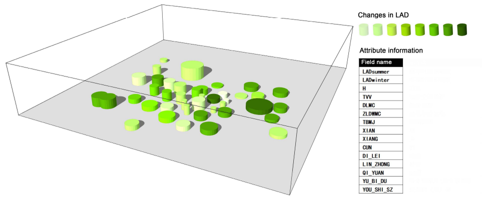

Fig 3: 2.5D vector model

The 2.5D vector model visualizes crown height and LAD information for scattered individual trees. The individual tree locations and crown diameter information of each tree were obtained by processing remote sensing images and various vector datasets. The 2D crown vector shape of each tree was then stretched in a z-axis based on tree height to generate a cylindrical 3D plant model, with the plant model's color density indicating the value of each tree's LAD (Fig. 3).

2.3.2 3D Vegetation Models

The 3D vegetation models are designed to represent the 3D geometry of individual trees. To balance the modeling details and rendering performance, this study proposed two different 3D vegetation modeling approaches: 3D geometric models and billboard models.

The 3D geometric models were generated based on 3D triangulated mesh solids of different trees. Different types of 3D vegetation models were constructed based on the geometric forms of various plants, with some of the models referenced from the OpenStreetMap ArcGIS 3D Tree Library. The plant models generated by the modeling software were exported in .dae format and imported into ArcGIS Pro. Based on the location map of each tree, the size of the 3D vegetation models was set by the geometric attributes, including crown height and crown width, and rendered with the terrain model in the global scene of ArcGIS Pro (Fig. 4).

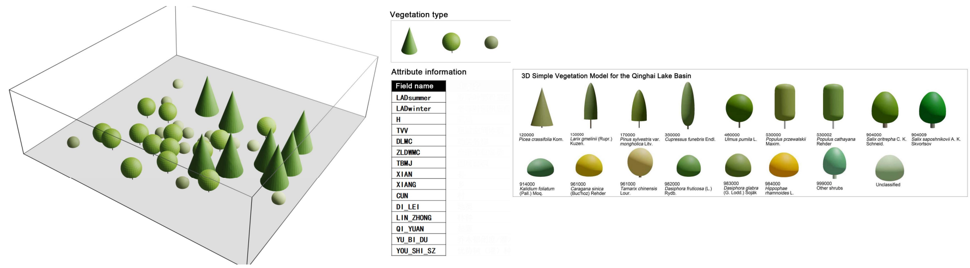

Fig 4: 3D geometric model

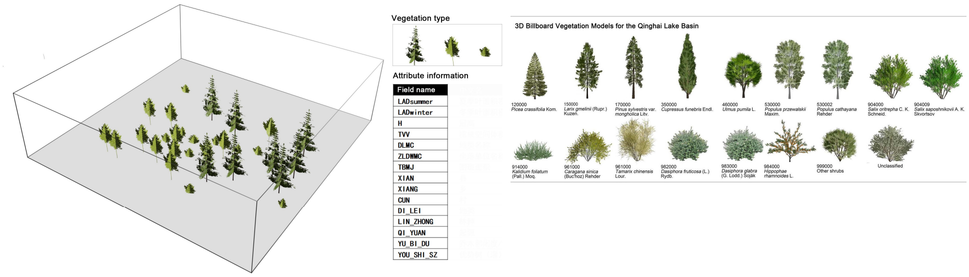

Fig 5: 3D billboard model

The 3D billboard models were generated with cross-intersected profile images of each tree species through cross-sectional modeling. Some of these models were referenced by plant models from the OpenStreetMap 3D Tree Library. The 3D billboard plant models generated by the modeling software were exported in .dae format and then imported into ArcGIS Pro. Based on the location map of each tree, the sizes of the 3D vegetation models were set by the geometric attributes, including crown height and crown width, and rendered with the terrain model in the global scene of ArcGIS Pro (Fig. 5).

3 Results

The spatial data of different types of 3D vegetation was stored in a file geodatabase and visualized in ArcGIS Pro (Fig. 6-9). The data can also be exported in SLPK format for the model exchange between different software and platforms.

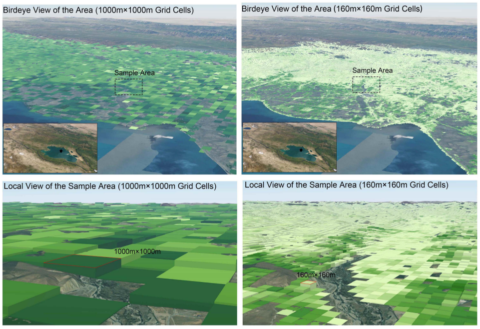

Fig. 6: 2.5D raster vegetation model

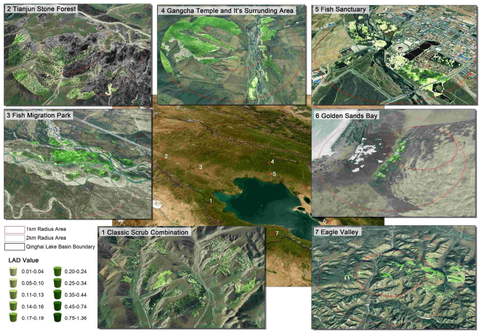

Fig. 7: 2.5D vector vegetation model

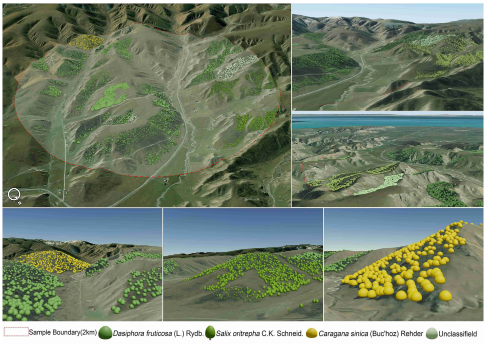

Fig. 8: 3D geometric vegetation model

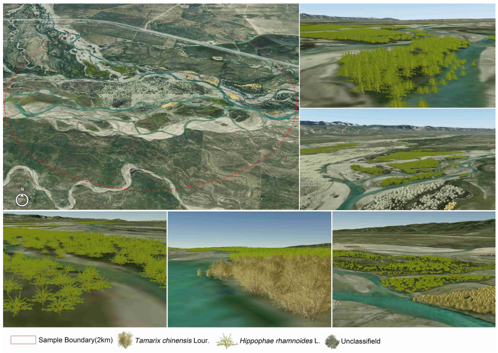

Fig. 9: 3D billboard vegetation model

The generated SLPK file, derived from the I3S standard, was then published as a web service on ArcGIS Online, which could provide intuitive visualization rendering, query statistics, and spatial analysis functionalities to the public, as well as to serve as a tool for education and information retrieval for the Qinghai Lake National Park. The WebGIS service could support public engagement and participation in the national park's planning and design process.

3.1 Visualization

Based on the 3D model, different 3D visualization effects can be rendered on the WebGIS platform, which could provide an intuitive and easily understandable data visualization pipeline for the general public.

3.2 Information Query

The vegetation information model contains geospatial attributes from multiple data sources, which enables the support to query and analyze various vegetation data in the WebGIS platform, allowing users to quickly search, locate, and retrieve different information (Fig. 10).

3.3 Multidimensional Spatial Analysis

Based on the 3D data model, WebGIS can perform multidimensional spatial processing and analysis, including 2D analysis, such as buffer and overlay, as well as 3D analysis, such as skyline, sunlight exposure, and visibility. These analyses could provide data support for macro-level regional planning and management. Figure 11 shows the sunlight analysis in the web scene.

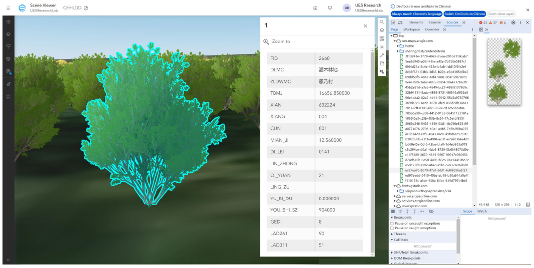

Fig 10: Query on ArcGIS Online

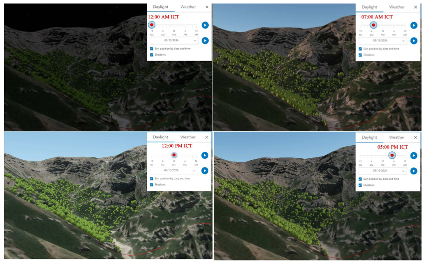

Fig 11: Sunlight Analysis

4 Discussion

Different application requirements correspond to various GIS modeling needs. The 2.5D and 3D models can express the spatial structure of the trees from different perspectives to meet special demands.

The 2.5D raster vegetation model is a continuous grid model that incorporates the height of the vegetation cover, enabling the expression of vegetation volume distribution at a regional scale. Additionally, it can utilize its color density or other symbolic information to represent ecological indicators such as leaf area density, making it suitable for depicting vegetation biological attributes in broad-scale areas. The 2.5D vector vegetation model is based on the 2D morphology of individual plants, integrating 2D crown shape stretched with corresponding tree height, which is appropriate for illustrating the spatial locations of the trees in a regional context.

The 3D simple geometric models, based on the 3D canopy shapes of different plant species, can more accurately represent the 3D spatial distributions among various plants. The 3D billboard models can express the vertical profiles and textures of different plants, making them suitable for visualization and rendering of geospatial vegetation data.

In addition to geometric features, the constructed vegetation models are GIS-based and can be incorporated with various attributes, which can be used for landscape pattern and ecological structure analysis.

This study still has certain limitations. The high-precision 3D modeling data at the regional scale currently faces challenges in achieving rapid visual rendering processes due to the performance constraints in the ArcGIS Pro platform. Future efforts may involve optimizing the rendering performance of 3D plant models in large-scale environments by implementing an adaptive level of details during the rendering process of the 3D models.

5 Conclusion

This study summarized the geospatial vegetation modeling types and methods at the regional scale. Based on I3S and ArcGIS Pro, different 2.5D and 3D modeling approaches were proposed to enable rapid publishing through web scenes on ArcGIS Online or scene layer packages. This approach facilitates efficient rendering and exchanging across different platforms, supporting visualization and public sharing via WebGIS. By taking the Qinghai Lake Basin as a case study, we examined different modeling approaches and established a vegetation geodatabase for the Qinghai Lake Basin. The modeling and visualization pipeline could provide a reference for 3D vegetation at the regional scale, which can be used for regional planning and natural resource management.

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