The Impact of DEM Uncertainty and Error on Flood Simulation

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1. Introduction

Climate change is intensifying extreme rainfall and storm-surge events. Low-lying coastal areas are often affected first because flooding there is strongly controlled by tidal boundaries and the condition of coastal levees. Reliable simulations of inundation driven by levee breaches and storm surges are therefore essential for developing effective regional disaster-mitigation strategies. However, hydrodynamic models are highly sensitive to terrain elevation. In practice, airborne- or satellite-derived digital elevation models (DEMs) are commonly used as terrain inputs, but their accuracy is influenced not only by observation conditions (e.g., cloud cover) but also by systematic biases over vegetated and water-covered surfaces. Coastal wetlands and intertidal zones are characterized by a mosaic of vegetation and water bodies, which can amplify DEM errors in critical areas and, in turn, affect estimates of flood extent and water depth. Although high-precision elevation data can be obtained using tools such as RTK (Real-Time Kinematic) surveys and unmanned aerial vehicles (UAVs), it is often impractical to fully cover the entire study area due to constraints on manpower, time, budget, and site accessibility. To address this limitation, this study develops a DEM correction workflow that uses locally surveyed RTK data and applies regression kriging to estimate and correct DEM errors over a larger region, thereby improving the reliability of terrain representation in wetland-dominated areas.

2. Methods

The study area is the Qigu Saltpan Wetland in Qigu District, Tainan City, Taiwan. The baseline terrain input is an airborne LiDAR–derived DEM with a 5 m × 5 m resolution. We collected 1,125 high-precision RTK elevation points within the wetland area and defined the DEM error as y = DEM − RTK. We then applied regression kriging to correct the DEM. Specifically, slope and terrain convexity were used to build a regression-based trend component of the error. A semi-variogram was computed for the regression residuals and fitted with a spherical model, and ordinary kriging (OK) was used to capture the spatial correlation of the residuals. The final error prediction was obtained by combining the trend and kriged residual terms, and the DEM was corrected accordingly.

To link the corrected DEM to a disaster-focused application, this study used it as the terrain input for a two-dimensional unstructured-grid hydrodynamic model based on the shallow-water equations. A levee-breach boundary was prescribed with a breach length of 80 m, a width of 2.5 m, and a breach-bottom elevation of 0.45 m. The boundary forcing was derived from hourly tide levels (H) from 04:00 to 09:00 on 2025/07/23 (0.64, 0.85, 1.05, 1.24, 1.40, 1.35m), which were converted into an hourly inflow hydrograph using $Q = 1.705 \cdot 80 \cdot (H - 0.45)^{\frac{3}{2}}$ as the boundary condition.

3. Results

The semi-variogram of the regression-kriging residuals was fitted with a spherical model using weighted least squares (WLS), yielding a nugget of 0.0127, a sill of 0.0855, and a range of 118 m. The fit was strong ($wR^2 = 0.988$), indicating that DEM error residuals in the wetland exhibit short-range spatial correlation on the order of 100 m. For independent validation, we evaluated terrain accuracy using 29 RTK check points distributed across the entire study area. The RMSE of the original DEM was 1.3614 m, which decreased to 0.4536 m after correction. This corresponds to an absolute RMSE reduction of 0.9078 m (about 66.7%). These results (Fig. 1) show that, even when only local high-precision measurements are available, the proposed deterministic regression-kriging DEM correction workflow can substantially improve overall terrain accuracy and provide a more reliable topographic basis for subsequent inundation simulations under levee-breach and storm-surge scenarios.

In the scenario simulations, the levee-breach discharge converted from tide levels reached a maximum of 126.3 m³/s and an average of 74.62 m³/s during the simulation period, with the peak occurring at 5hr. Compared with the results based on the original DEM, the breach-induced inundation simulation using the corrected DEM (Fig. 2) shows that the maximum inundated area changed from 3.83 km² to 3.12 km², corresponding to a change of −3.895%.

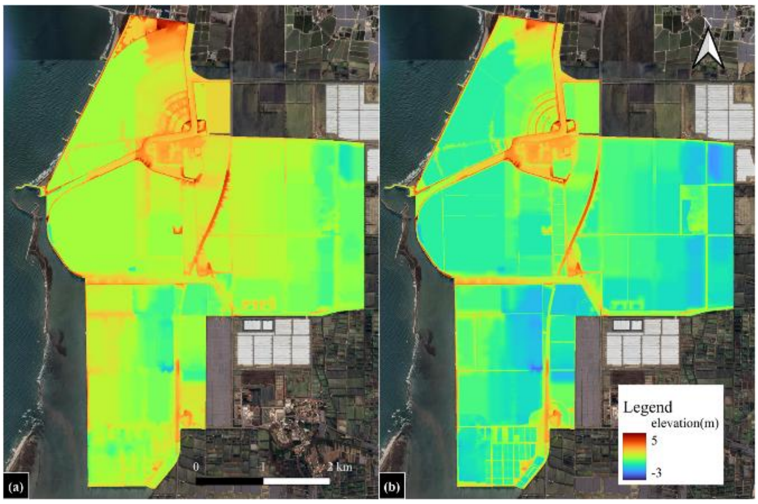

Fig.1. (a) Original DEM; (b) Corrected DEM

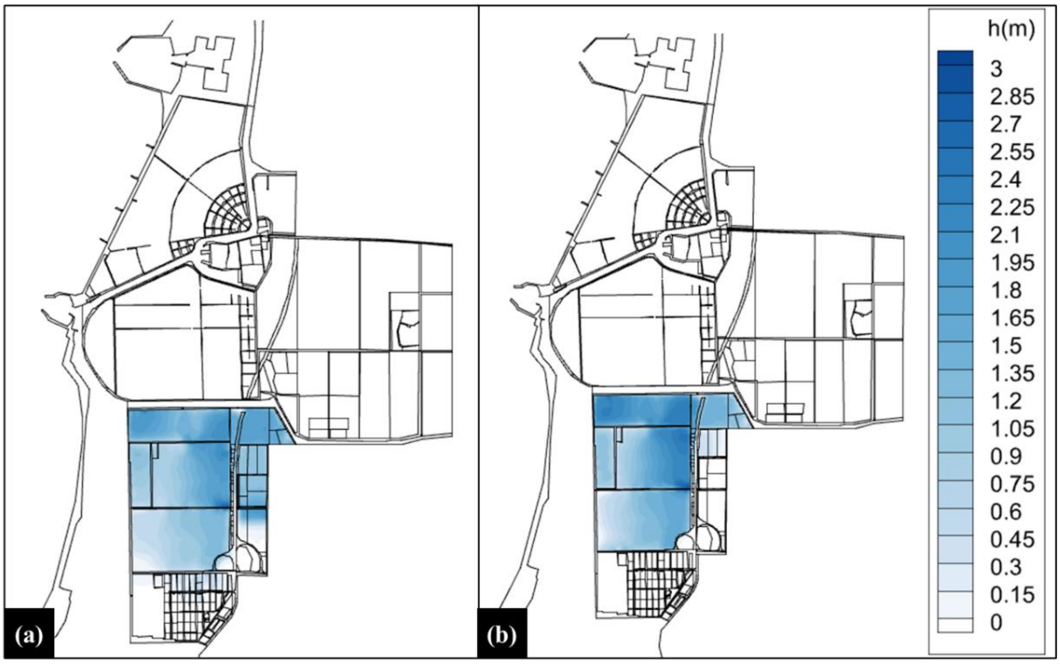

Fig.2. (a) Original DEM with model simulation; (b) Corrected DEM with model simulation