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Ph.D. DISSERTATION DEFENSE

Candidate:	Zhoobin Rahimi
Degree:	Doctor of Philosophy
School/Department:	Charles V. Schaefer, Jr. School of Engineering and Science / Department of Civil, Environmental & Ocean Engineering
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Title:	Applications of InSAR in Urban Coastal Areas: Toward Scalable Land Subsidence Assessment, Monitoring, and Prediction
Chairperson:	Dr. Jon Miller, Dr. Matthew Janssen (co-chair), Department of Civil, Environmental & Ocean Engineering, Stevens Institute of Technology
Committee Members:	Dr. Carlo Lipizzi, Department of Systems Engineering, Stevens Institute of Technology Dr. Reza Marsooli, Department of Civil, Environmental & Ocean Engineering, Stevens Institute of Technology Dr. Brian Harris, U.S. Army Engineer Research and Development Center (ERDC)

ABSTRACT

Land subsidence is a slow-moving but consequential geohazard, particularly in dense urban environments where natural sediment compaction interacts with groundwater extraction and aging infrastructure. Despite its widespread occurrence, the relative contributions of these drivers remain difficult to quantify, largely because hydrogeological, infrastructural, and climatic processes interact in complex, nonlinear ways that conventional monitoring alone cannot disentangle. This dissertation develops a progressive, three-stage framework that uses Interferometric Synthetic Aperture Radar (InSAR) observations to identify, model, and ultimately forecast urban land subsidence, with applications across coastal areas of New Jersey and New York.

The first stage addresses the role of infrastructure deterioration, a factor often overlooked relative to groundwater-driven mechanisms. Using Sentinel-1 InSAR data, land subsidence was mapped across Hoboken, New Jersey, and a Land Subsidence Severity Index (LSSI) was developed using the Analytic Hierarchy Process (AHP) to integrate hydrogeological factors with a newly incorporated Risk of Infiltration (RI) index representing sewer network deterioration. The combined index assigned 70% weight to hydrogeological susceptibility and 30% to sewer infiltration risk, highlighting the importance of infrastructure-related factors in urban subsidence susceptibility assessment. However, the AHP-based framework relies on linear weighted aggregation, limiting its ability to capture nonlinear interactions among contributing factors and restricting the direct transferability of its assigned weights to other urban areas.

The second stage addresses this limitation through a Random Forest (RF) machine-learning framework that integrates hydrogeological and geological factors with land cover and population density, the latter serving as an indirect proxy for urbanization and infrastructure-related pressures. Using feature importance and

sensitivity analysis, population density emerged as the highest-ranked predictor at the county level, with a permutation importance score of 0.91, followed by groundwater fluctuation (0.61) and land cover (0.59). Despite strong county-wide predictive performance under random validation ($r = 0.97$), dividing the study area into four geographically distinct quadrants revealed substantial spatial variability in predictor importance. Spatially independent validation yielded considerably lower predictive performance (pooled $R^2 = 0.193$), highlighting spatial heterogeneity as a significant limitation to the geographic generalization of machine-learning models for urban subsidence assessment.

Building on this framework, the third and culminating stage introduces a spatiotemporal deep learning model, NARX-LSTM, integrating InSAR time series with hydro-meteorological and static geological variables to model and forecast the spatial and temporal evolution of land subsidence. Applied to Nassau County, New York, the model achieved an RMSE of 0.25 mm, R^2 of 0.87, and correlation coefficient of 0.93, outperforming the conventional LSTM model (RMSE = 0.40 mm, $R^2 = 0.81$, $r = 0.90$).

Together, these three stages demonstrate the importance of incorporating infrastructure-related factors into urban subsidence susceptibility assessment, reveal the spatial variability of influential subsidence predictors and the limitations of their geographic transferability, and establish the potential of spatiotemporal deep learning for forecasting future land deformation under interacting environmental and geological conditions.