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50 Years of Water Body Monitoring: The Case of Qaraaoun Reservoir, Lebanon

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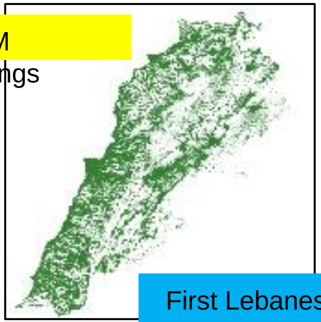
GEOspatial Artificial Intelligence (GEOAI) group

- Lebanese National Center for Remote Sensing - CNRS
- established in April 2015
- rely on openly available satellite imagery
- geogroup.ai
- know-how (deep learning, time-series imagery, in-house python library)
- GEOAI offers: AI-based solutions for Earth Observation (EO) across several verticales.

GeoUrban-AI

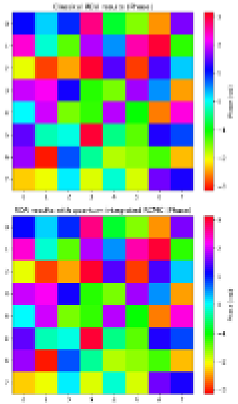
~1MM buildings



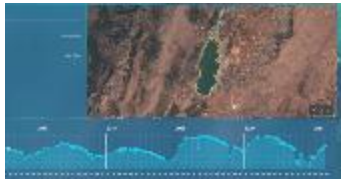
First Lebanese footprints Map

Solar rooftop potential map

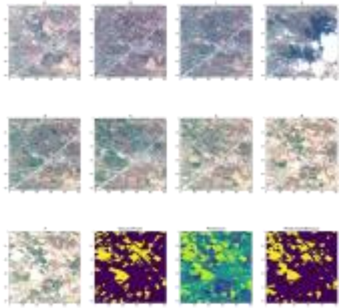
Quantum EO



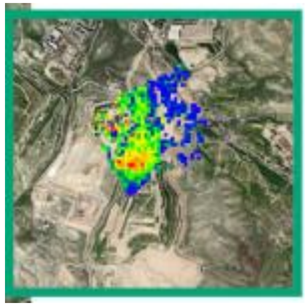
Water Body Assessment



Crop Monitoring



Methane Mapping



Background and Problem Definition

Reliable reservoir volume monitoring is essential for hydrological analysis, water security, and climate impact assessment.

In practice, long-term in-situ monitoring is often unreliable due to sensor failure, maintenance limitations, and data gaps, particularly in developing regions.

This creates discontinuities and inaccuracies in historical water volume records, limiting operational and scientific use.

Research Gap and Contribution

Most solutions estimate surface water extent but still rely on ground sensors for volume estimation.

This work proposes a **fully sensor-independent pipeline** that directly infers reservoir volume from satellite-derived water surface information.

Main contributions:

- A novel **Weighted Composite Water Index (WCWI)** for robust water segmentation
- A **nonlinear SVR-based inference model** linking surface area to volume
- A **50+ year continuous volume time series** derived exclusively from satellite data

Overall Algorithmic Pipeline

1. Multi-sensor satellite image acquisition (Landsat , Sentinel).
2. data preprocessing.
3. Water surface extraction using the proposed WCWI and Otsu adaptive thresholding.
4. Surface area computation and normalization.
5. Support Vector Regression inference to estimate relative water volume.

Water Segmentation Challenge

Accurate segmentation is the critical bottleneck, as surface errors propagate nonlinearly into volume estimates.

The Qaraaoun Reservoir presents difficult conditions:

- Turbid water
- Vegetation and wet soil confusion
- Seasonal shadows from surrounding mountain chains

Standard indices exhibit under-segmentation and false positives under these conditions.

Proposed Weighted Composite Water Index (WCWI)

WCWI combines the strengths of NDWI and $AWEI_{nsh}$ using a weighted linear formulation.
The index enhances water–non-water separability across seasonal and spectral variability.

WCWI consistently reduces under-segmentation in shallow and narrow reservoir sections.
Segmentation accuracy exceeds 95% along the shoreline when validated against manually labeled ground truth.

Ground Truth and Data Preparation

Bathymetric survey data from the Litani River Basin Management Support program used as reference.

Survey data digitized, georeferenced, and interpolated into a DEM.

Simulated water levels used to generate a level–surface–volume relationship.

Training dataset constructed using surface area and corresponding volumes.

Machine Learning Model Design

Reservoir filling dynamics are inherently nonlinear due to basin geometry.
Support Vector Regression selected for its robustness in modeling nonlinear relationships with limited overfitting.

Input feature: normalized water surface percentage.
Target variable: relative reservoir volume.
RBF kernel adopted to capture nonlinear surface–volume behavior.

Model Training and Optimization

- Data split into training and testing subsets.
- Min–Max normalization applied to stabilize convergence.
- Hyperparameters optimized via GridSearchCV with cross-validation.

Final model configuration achieves high stability across sensors and years without sensor-specific recalibration.

Quantitative Performance

Coefficient of determination consistently above 0.98
Mean Absolute Percentage Error below 6%
Root Standard Deviation Ratio approximately 0.2
Error remains below 1.5% of total reservoir capacity, exceeding established hydrological modeling benchmarks

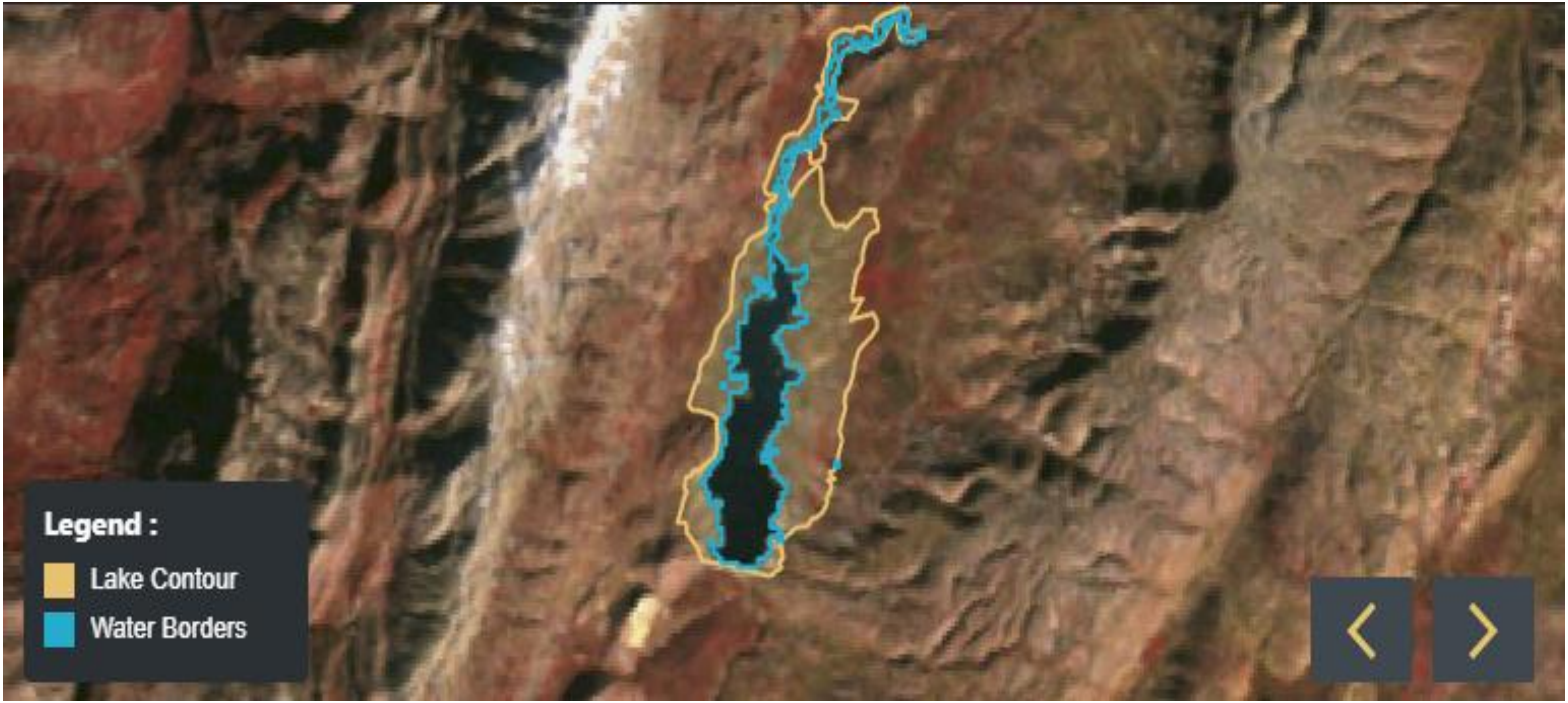
Results are consistent across Landsat and Sentinel platforms.

Long-Term Monitoring Results (1973–2025)

The proposed pipeline reconstructs over five decades of reservoir dynamics.
Accurately captures historical extremes, including near-empty conditions in the early 1980s.
Recent years reveal a pronounced declining trend, with record-low volumes observed in 2025.

The method prioritizes **temporal consistency and trend fidelity**, which is critical for climate analysis.

January 17 1982 – Historical Minimum



Limitations and Future Directions

Atmospheric effects and sensor noise may still affect segmentation under extreme conditions.
Index weighting may require local calibration for different environments.

Future work includes integration of satellite-derived water quality indicators and real-time automation.

Conclusion

This study demonstrates that accurate, long-term reservoir volume monitoring can be achieved using satellite imagery and machine learning alone.

The proposed WCWI–SVR framework offers a robust, cost-effective alternative to traditional sensor-based monitoring.

The approach is well suited for large-scale environmental monitoring and climate change impact studies.