Improving capacity for SDG Monitoring with Earth Observation (2024-2026)

Groundwater Resources Related SDG Indicators for Finland: SDG 6.6.1

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Keywords

- Semi-automated processing pipelines
- Transparency, reusability
- New data sources
- Spatial aggregations
- Time-series harmonization

SDG Indicators

- **6.3.2 Proportion of bodies of water with good ambient water quality**
- **6.6.1 Change in the extent of water related ecosystems over time**
- 11.3.1 Ratio of land consumption rate to population growth rate
- **14.1.1a Index of coastal eutrophication**
- **15.3.1 Proportion of land that is degraded over total land area**
- 15.4.2 Mountain green cover index

Timeline

- 2024: Proof-of-Concept, review of methods and data, adaptation and “beta-testing”
- 2025: Full implementation of 4 indicators (bolded), development of processing pipelines, evaluation, indicator reporting.

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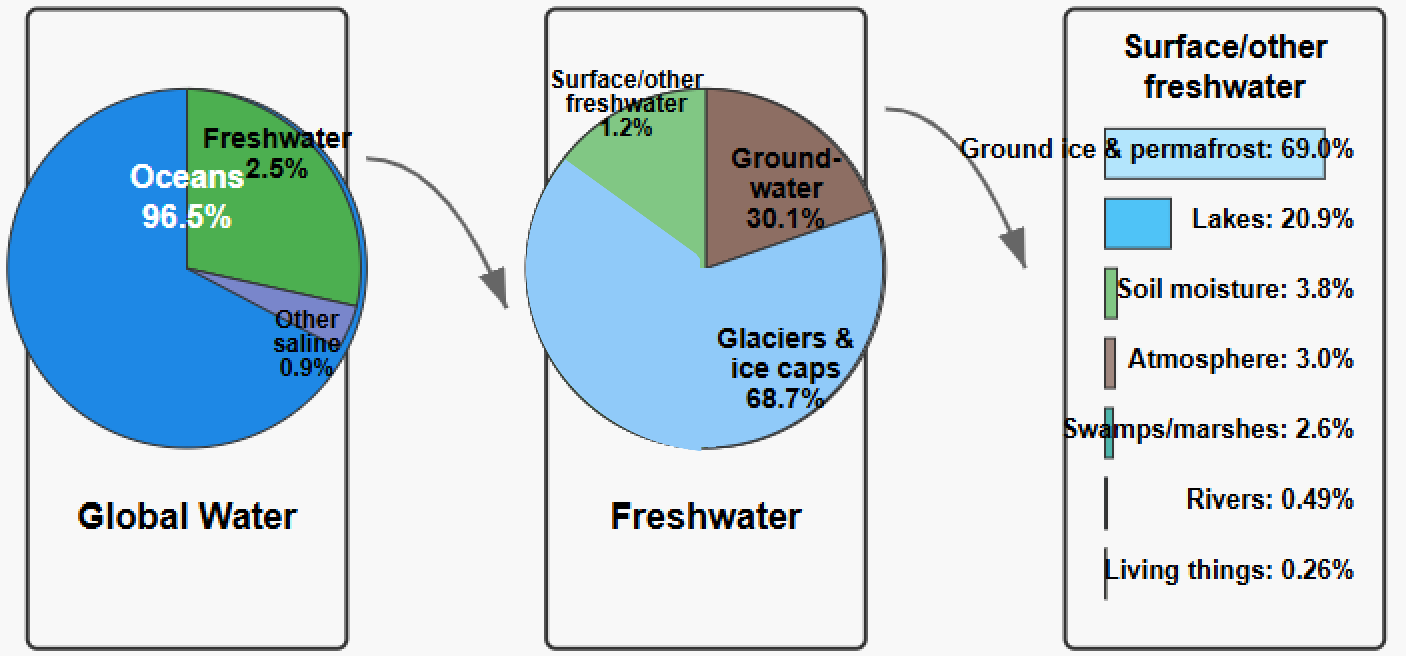
Global Groundwater Context

- 97.5% of Earth's water is saltwater, mostly in oceans (96.5%)
- Only 2.5% is freshwater, with 68.7% of that locked in glaciers and ice caps
- Groundwater represents 0.75% of Earth's total water (30.1% of all freshwater)
- Lakes and rivers combined make up less than 0.01% of total water
- Approximately 0.76% of Earth's water is potentially available for human use
- Half of the world's drinking water comes from groundwater sources

Earth's Water Distribution



Data based on: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

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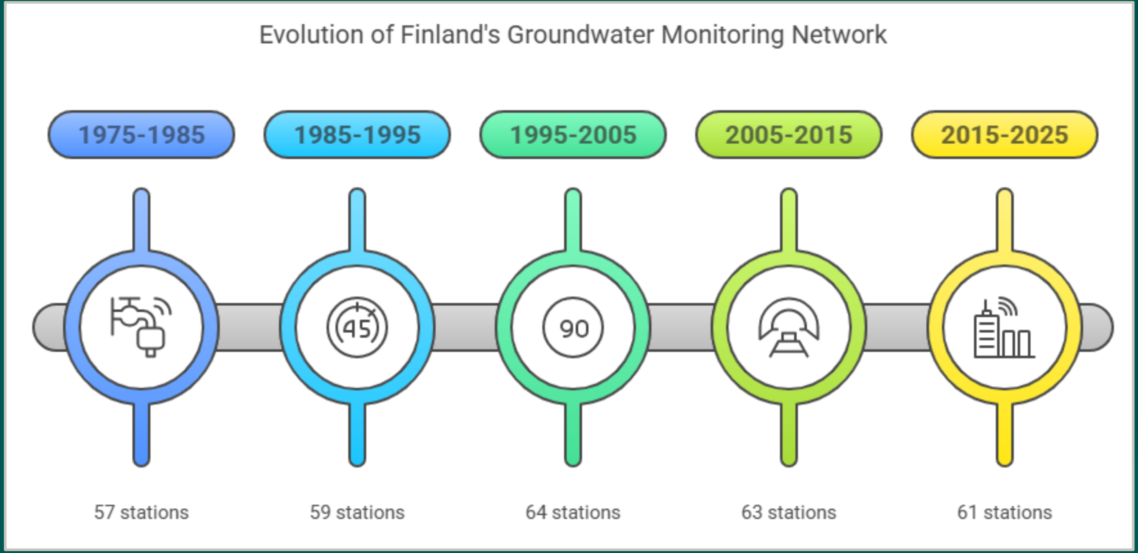
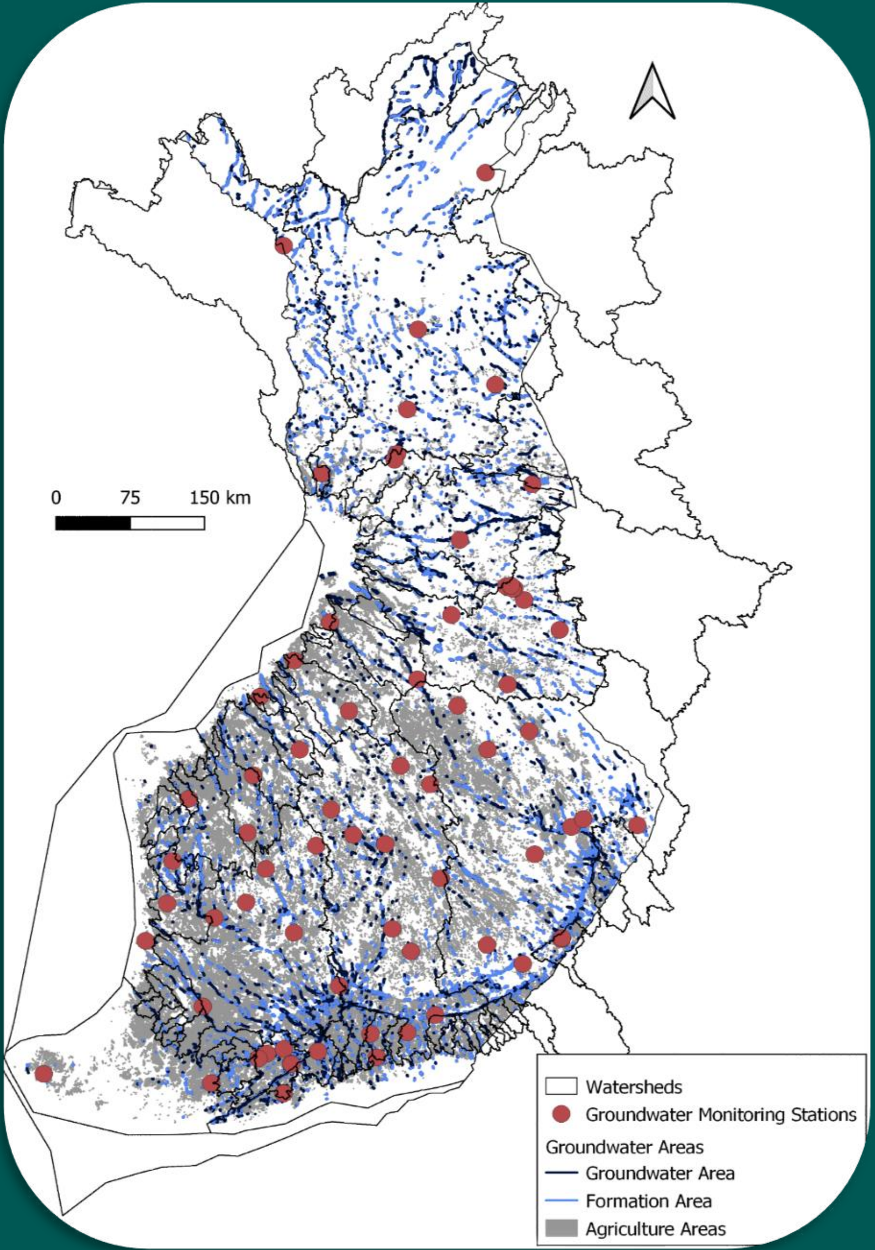
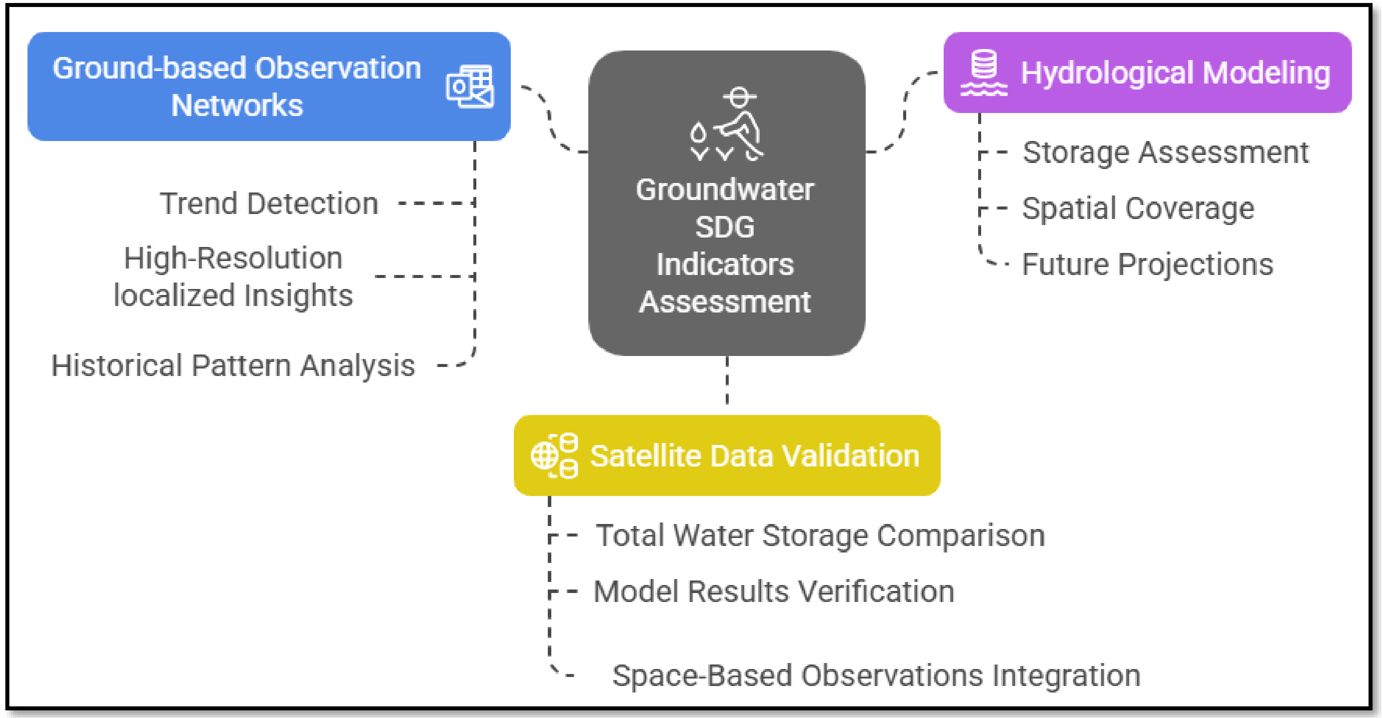
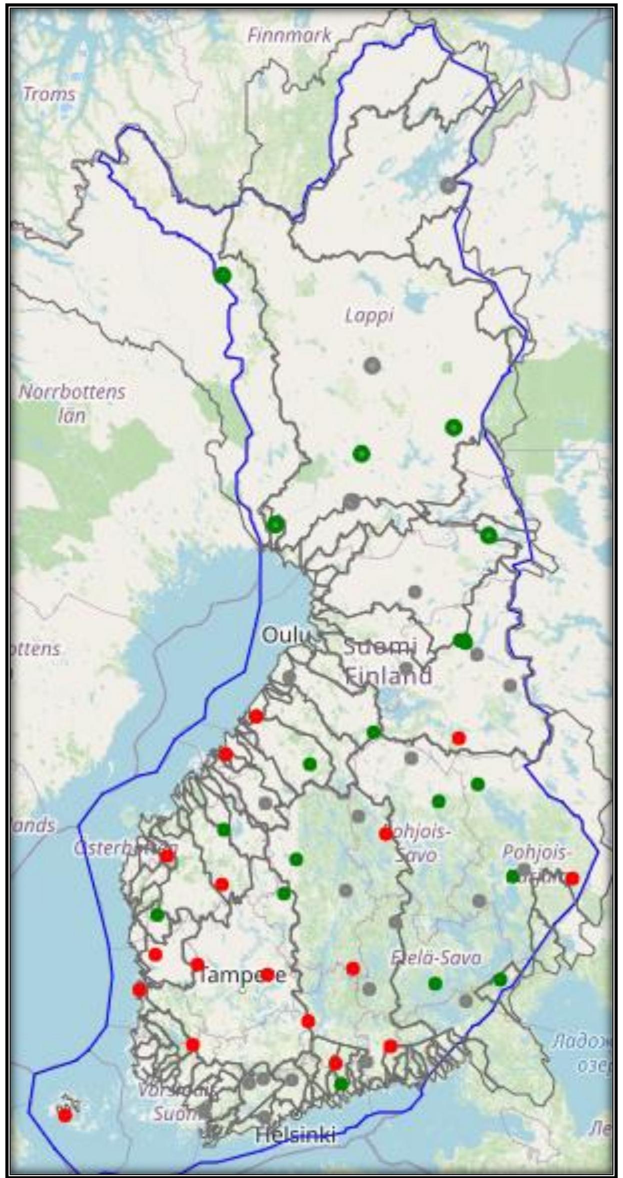
Groundwater in Finland





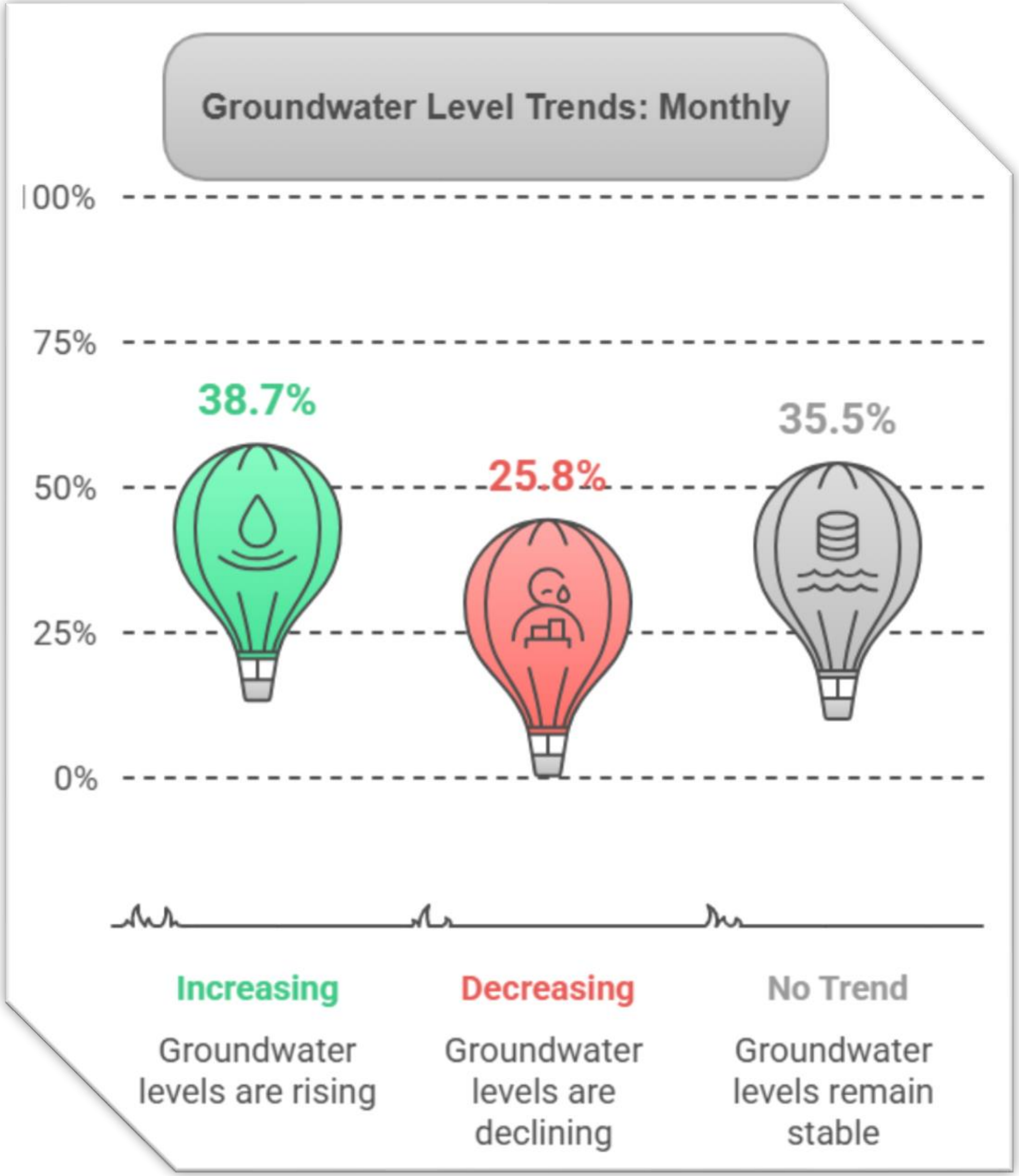
Complementary Methods for Groundwater SDG Assessment

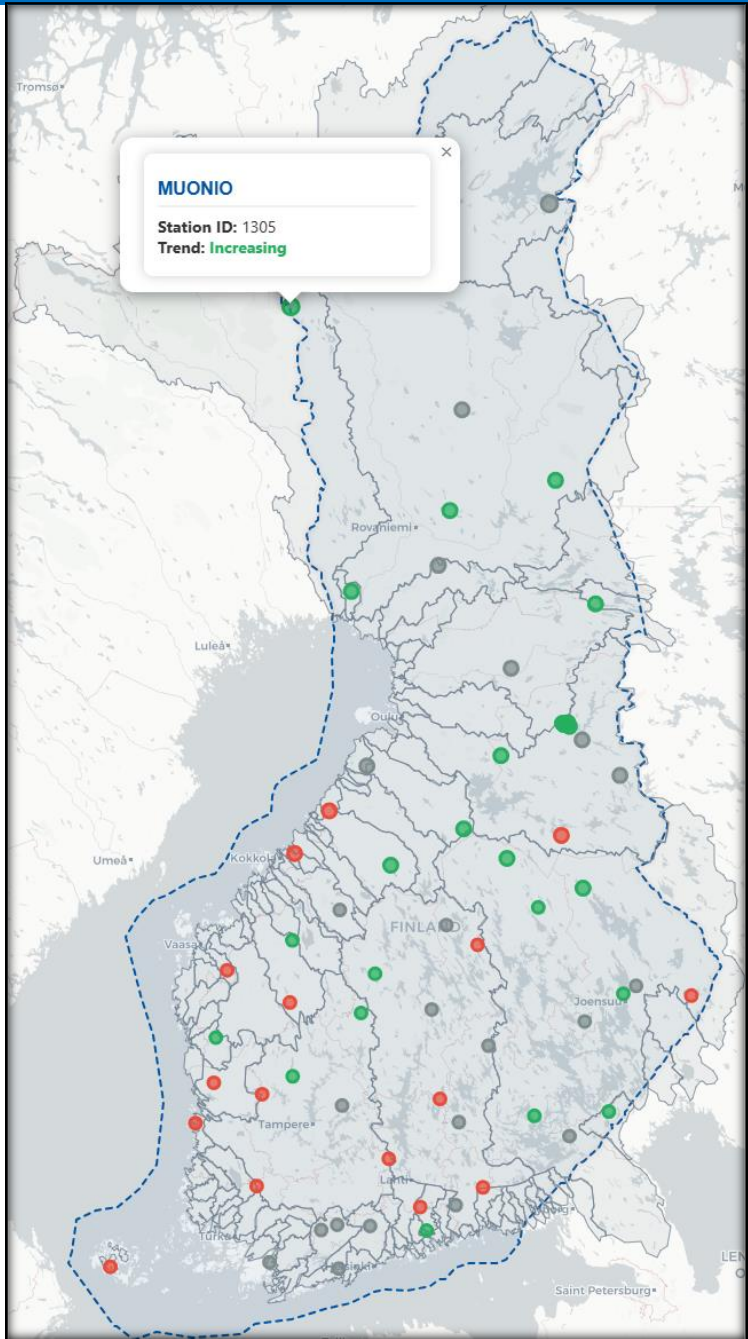




1. **Ground-Based Observations:**
   - Syke's Finland national groundwater monitoring network
   - Mann-Kendall analysis: monthly variability, seasonal impacts, long-term trends
2. **Hydrological Modelling (WSFS)**
   - Computed nationwide storage anomalies
   - Key inputs for WSFS: hydrometeorological, surface water, geohydrological data
   - Model utilizes satellite SWE/SCA data for improved accuracy
     - Prevents false snow melt predictions
3. **Satellite Data (GRACE) Comparison**
   - We computed Total Water Storage Anomalies for Finland-wide coverage
   - Multi-scale trend analysis (seasonal/yearly/long-term) performed
   - Compared the GRACE total water storage anomalies with WSFS model outputs

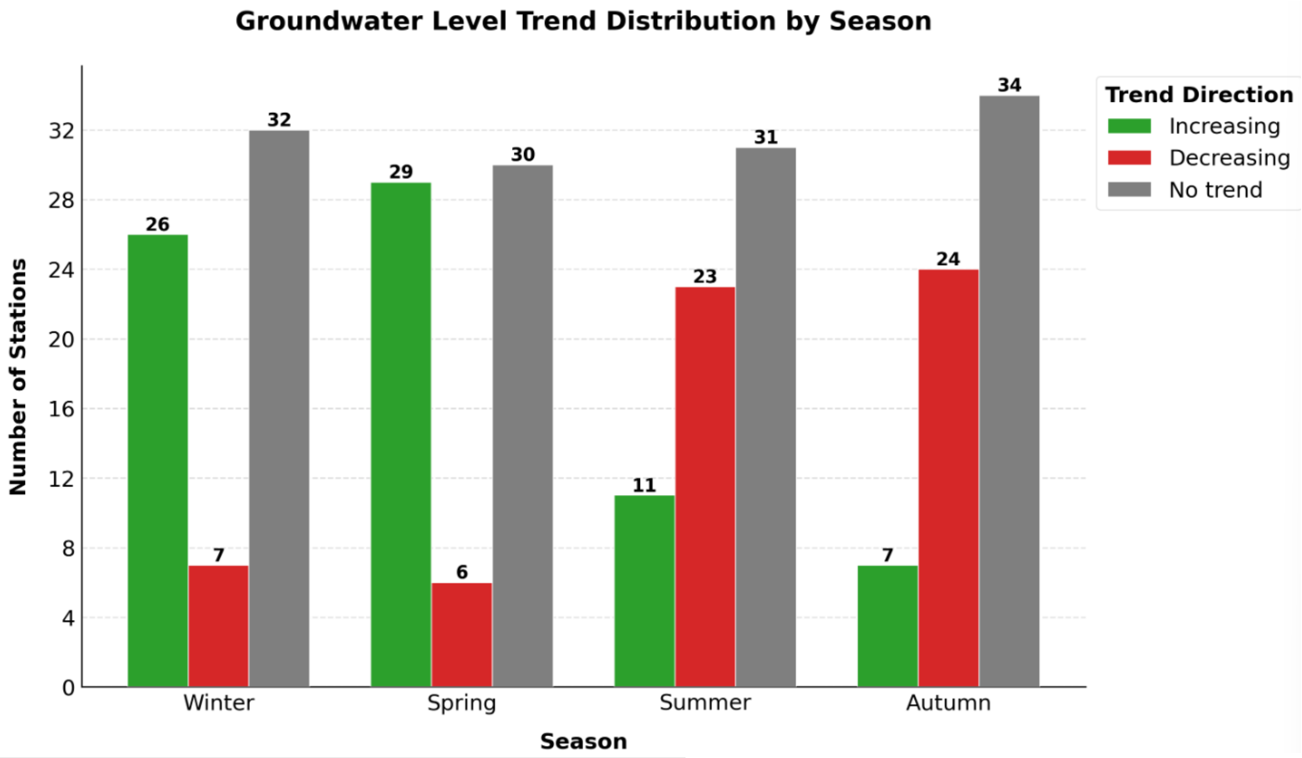
Monthly Groundwater Level Trends Across Finland (1970 – Pres.)





Global Groundwater Context
Groundwater in Finland
Framework & Methodology
Results: Ground-based Observations - Monthly
Results: Ground-based Observations - Seasonal
Results: Ground-based Observations - Decadal
Results: Hydrological Modelling - WSFS
Results: Satellite-based Data
Results: Satellite vs. WSFS Model Comparison: Monthly
Results: Satellite vs. WSFS Model Comparison: Seasonal & yearly
Summary

Seasonal Patterns in Finnish Groundwater Levels (1970-Present)



Summer:

17.7% increasing trends, 37.1% decreasing trends, & 45.2% no trend.

Autumn:

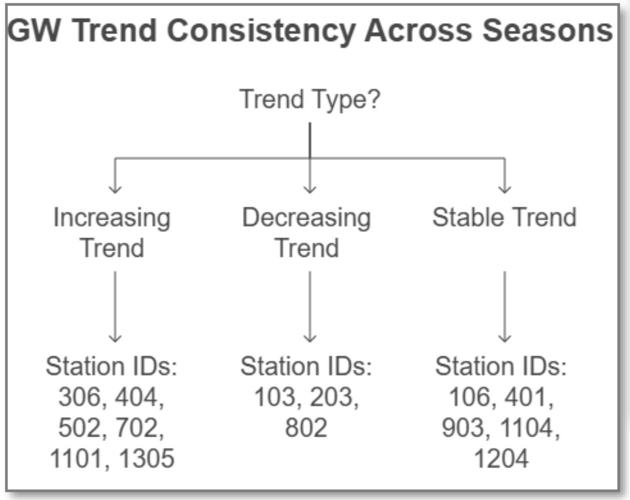
11.3% increasing, 35.5% decreasing, and 53.2% no trend.

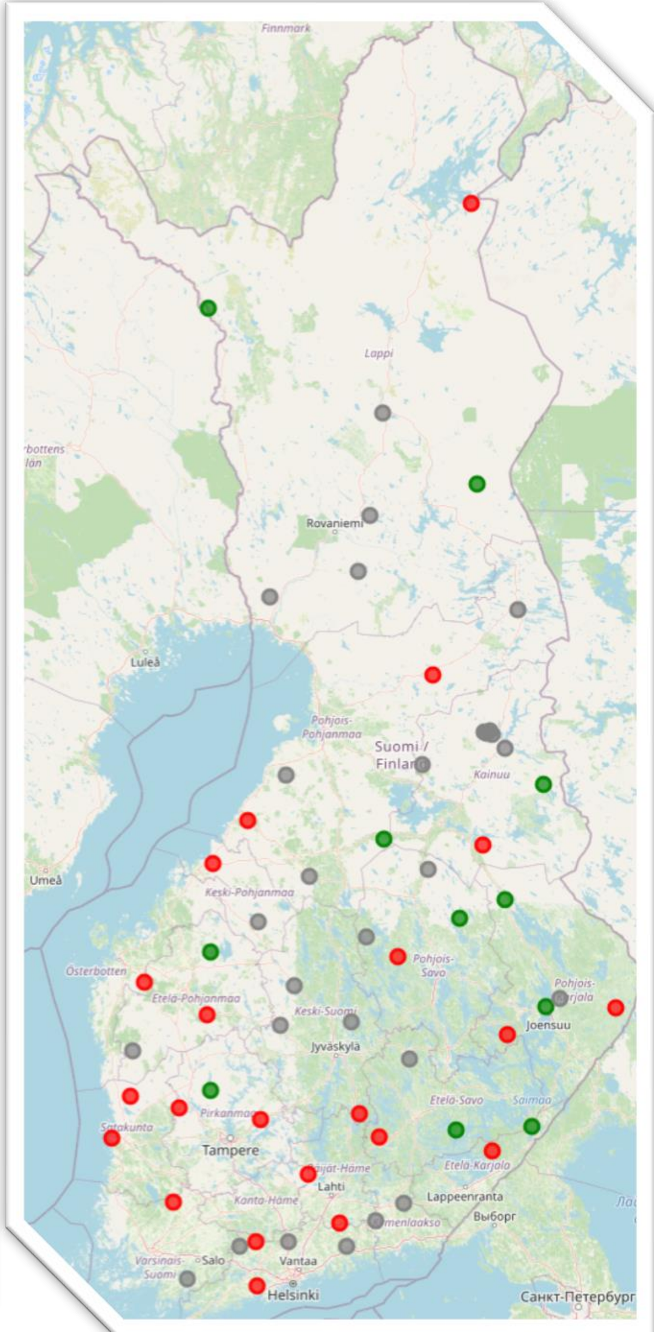
Winter:

40.3% increasing, 11.3% decreasing, and 48.4% no trend.

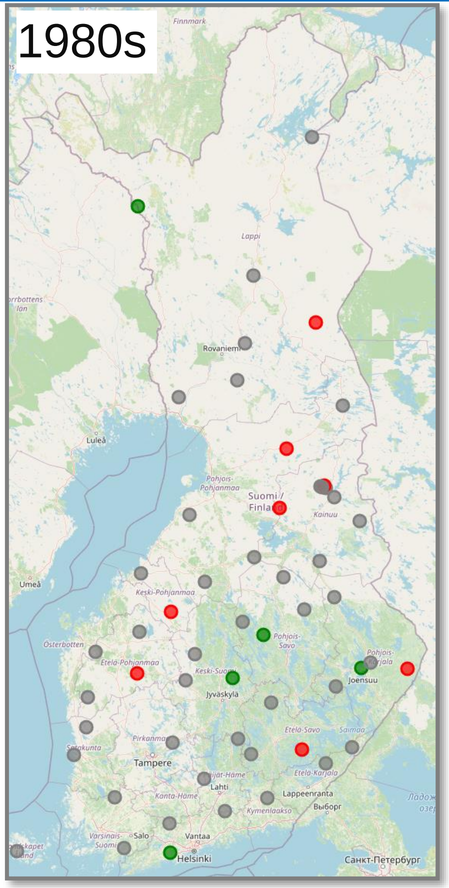
Spring:

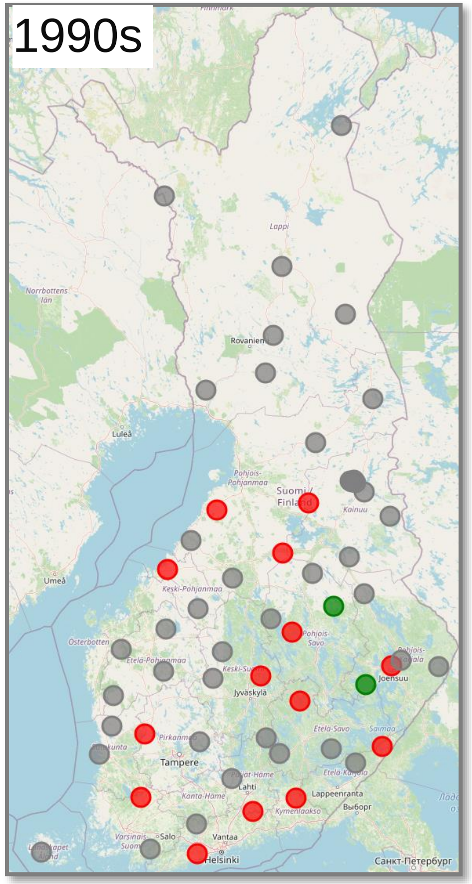
45.2% increasing trends, 9.7% decreasing trends, and 45.2% no trend.

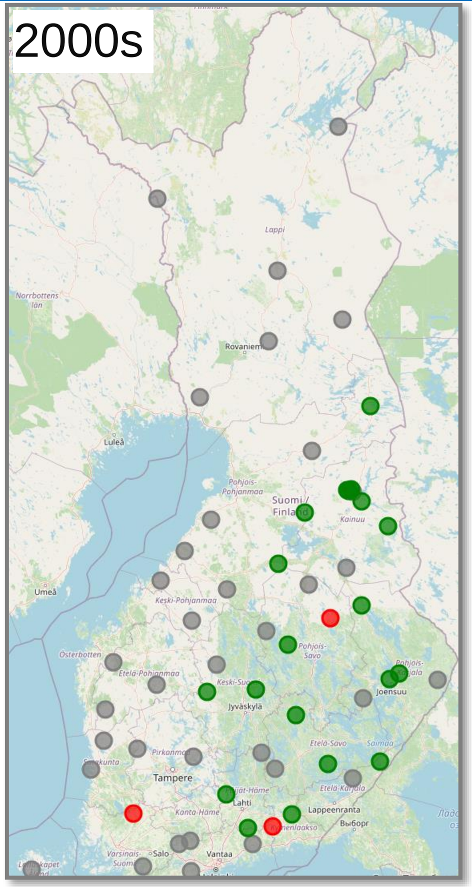


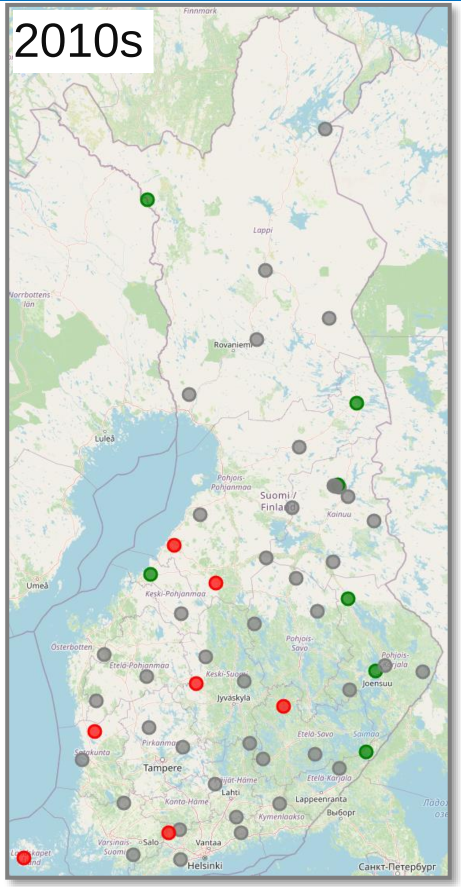


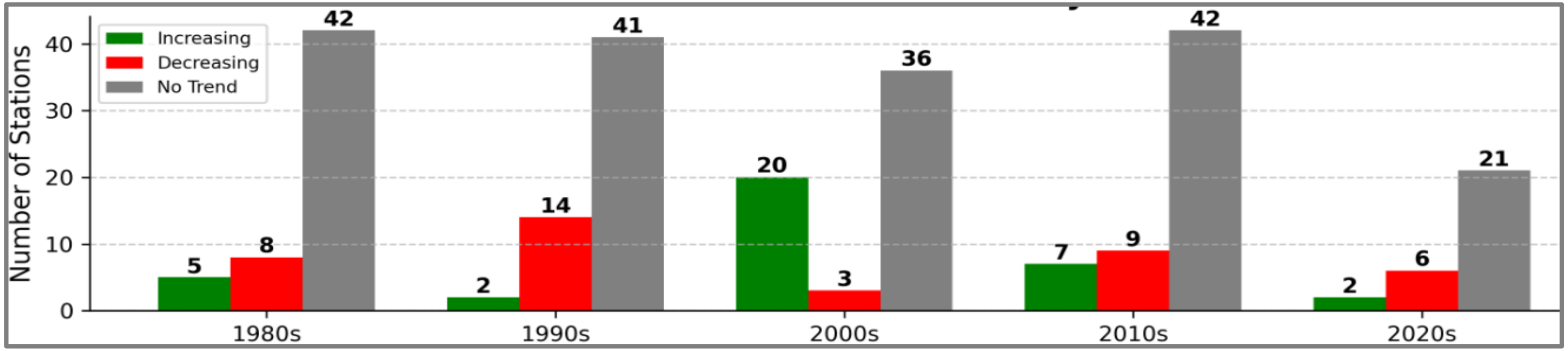
Long-term Decadal Changes in Groundwater Resources











WSFS Model: Status of Groundwater resources in Finland

Relative Groundwater Storage in Finland

Baseline: All values relative to August 1, 1961 (0mm reference point)

Winter: Recent years (2022-2024) had improved groundwater recharge compared to historical median:

- *likely due to increased winter precipitation as rain rather than snow*

Spring: Recent year showed significantly higher groundwater recharge compared to the historical median:

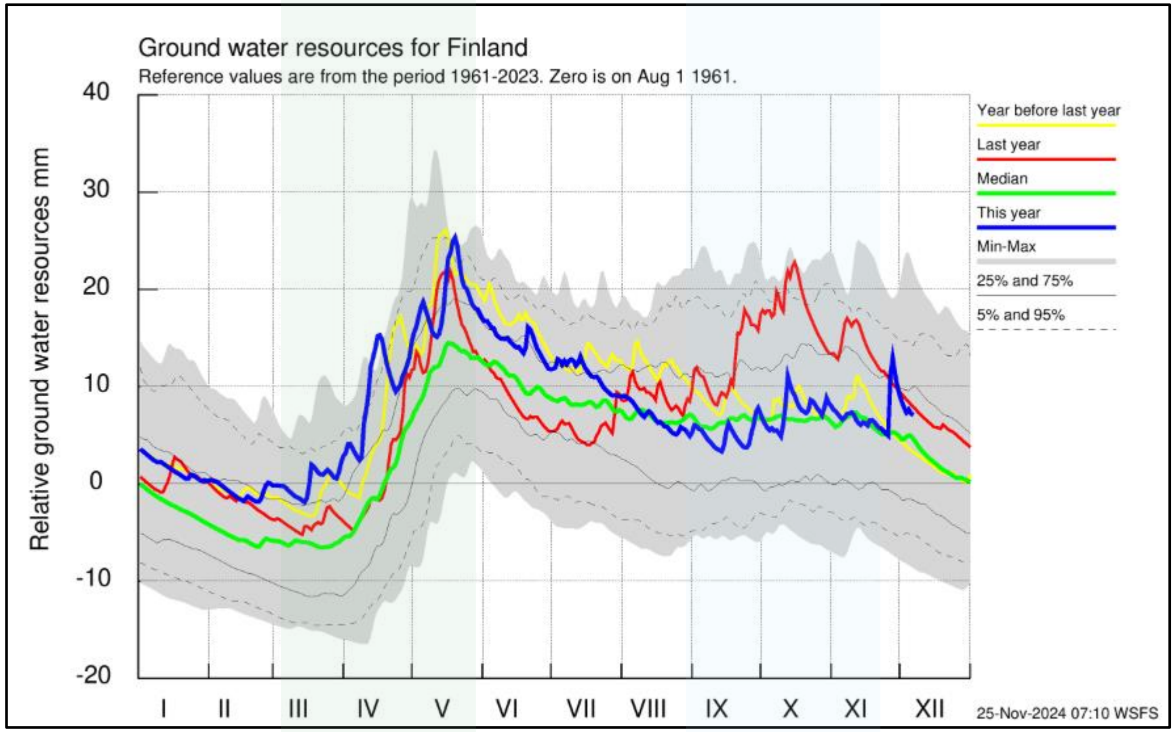
- *possibly due to rapid snow melt events combined with increased spring rainfall*

Summer: Years 2022 and 2024 had higher recharge compared to historical median:

- *could be due increased ppt intensity, despite warming temperatures*

Autumn: Exceptionally high potential groundwater storage for year 2023:

- *could be due to shifting precipitation patterns toward wetter autumns*



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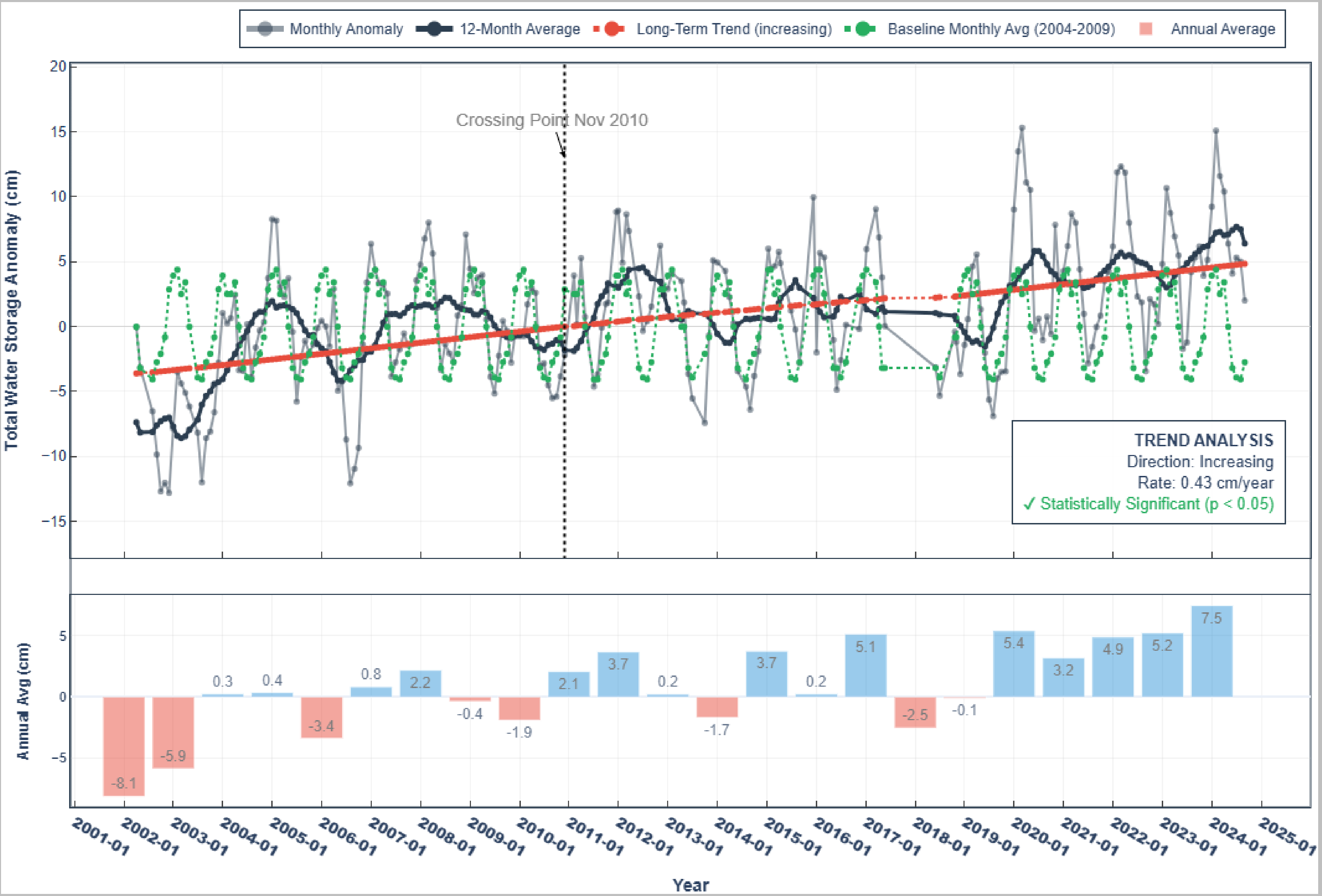
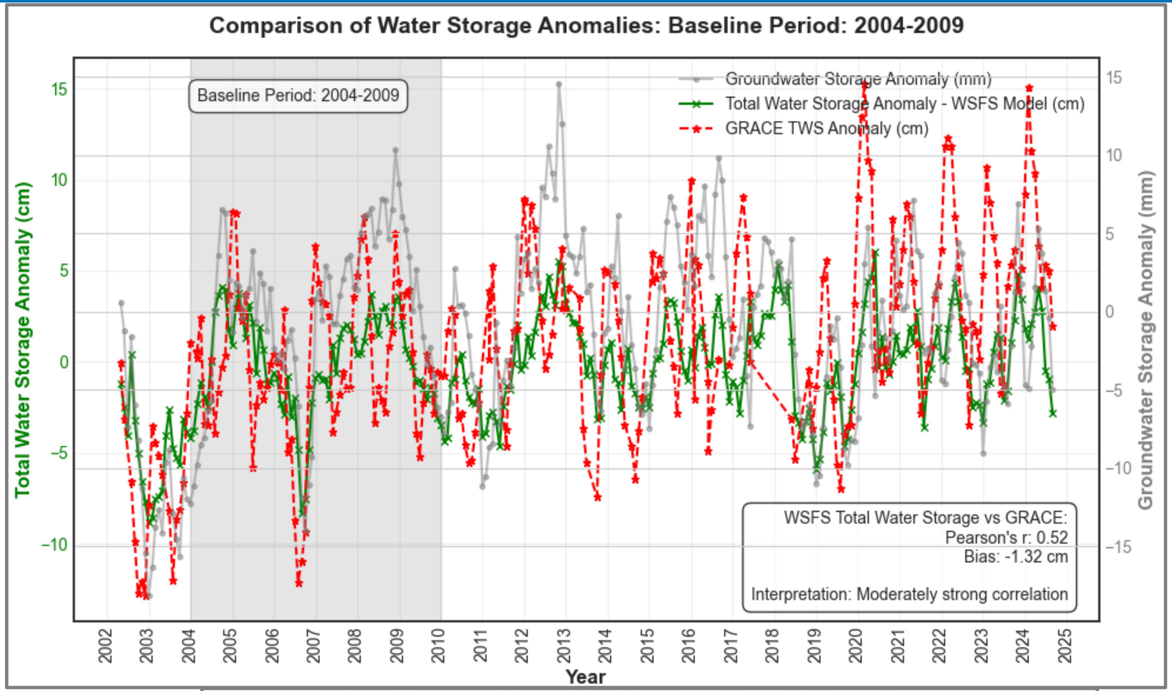
GRACE Satellite Data: Total Water Storage Changes in Finland

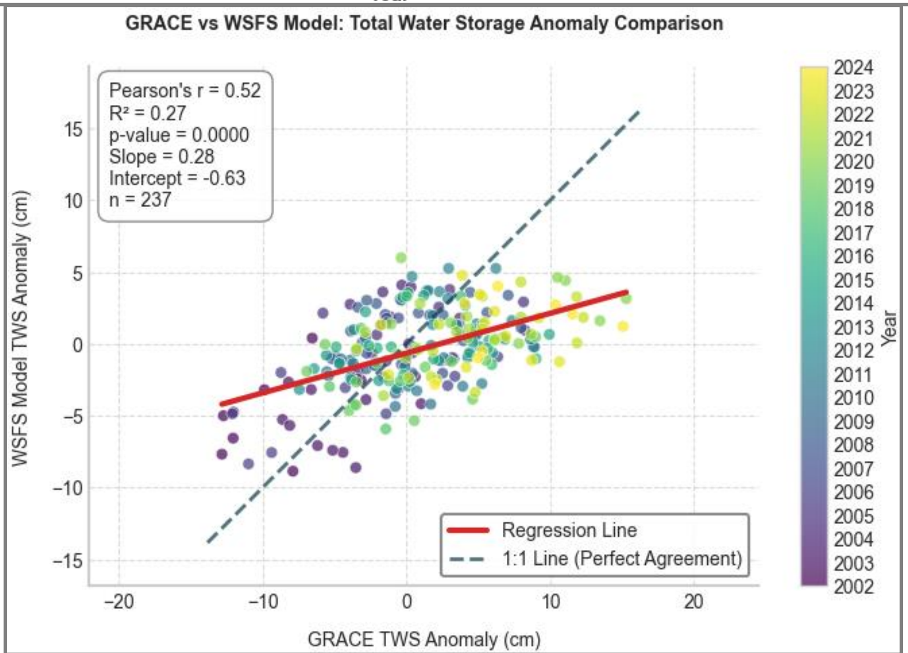


Comparison of Total Water Storage Anomalies: GRACE vs WSFS

WSFS vs GRACE: Monthly-Data

- Baseline period (**2004-2009**) was used as reference for anomaly calculations
- Time series plot shows WSFS and GRACE follow similar seasonal patterns
- Moderately strong positive correlation between GRACE and WSFS model (Pearson's r = 0.52)
- Coefficient of determination ($R^2 = 0.27$): indicates only 27% of the variability in WSFS anomalies could be explained by GRACE anomalies
- Positive relationship, but WSFS underestimates variability (slope = 0.28 vs ideal 1:1 line)
- Despite moderate correlation, GRACE data provides valuable model validation, especially at times when the disagreements are significant





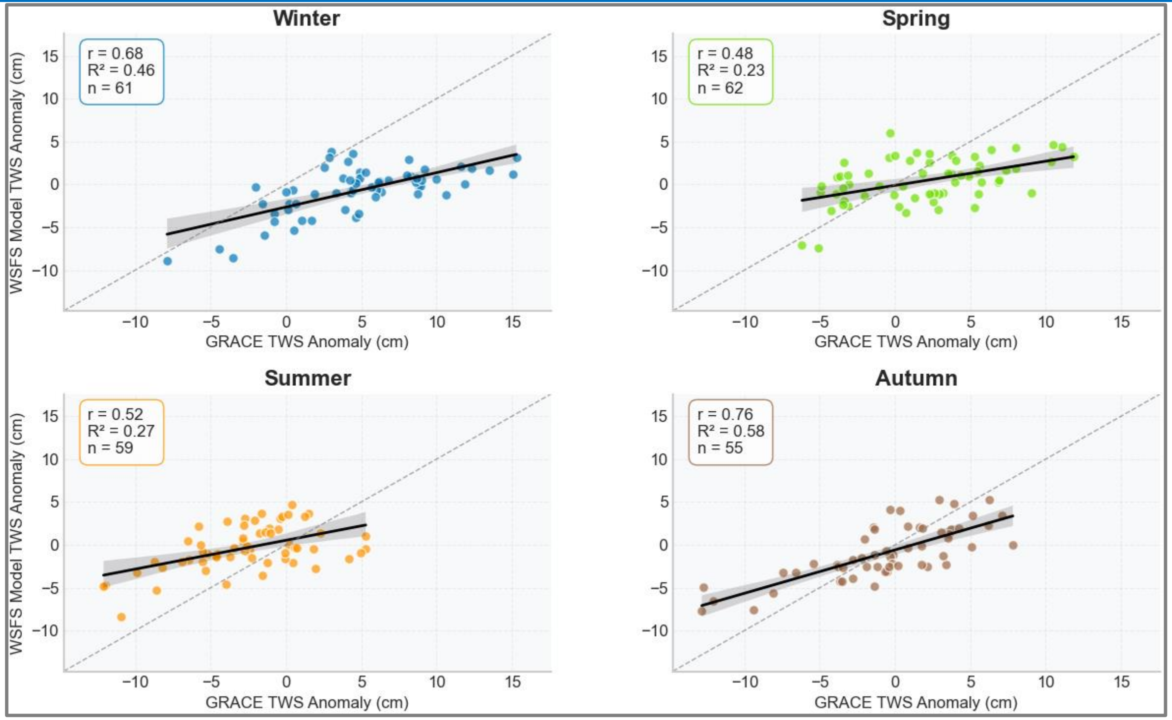
Comparison of Total Water Storage Anomalies: GRACE vs WSFS

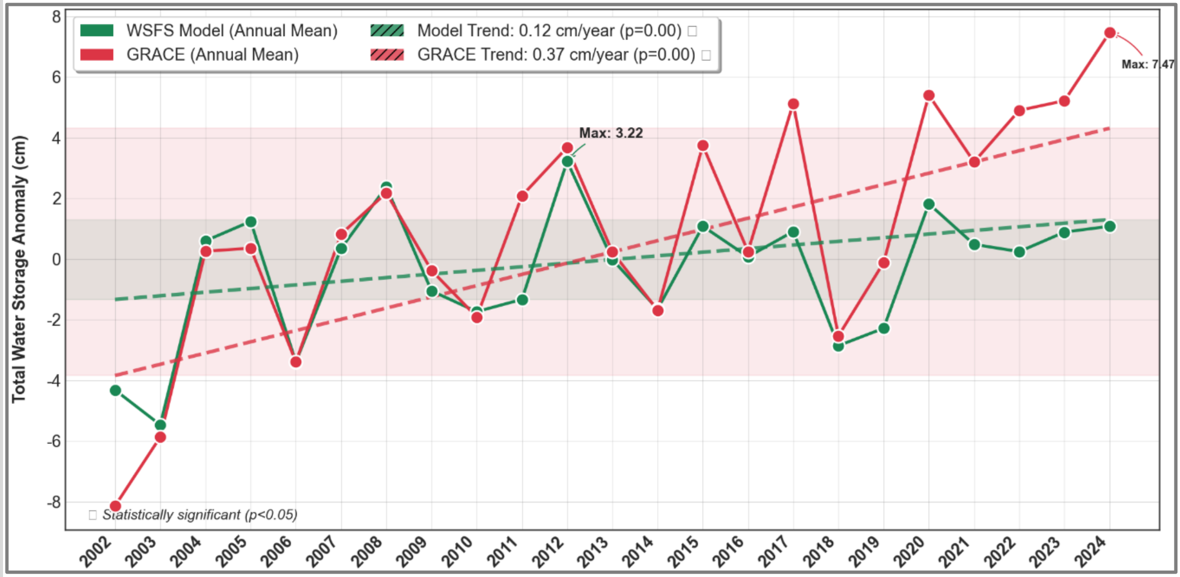
WSFS vs GRACE: Seasonal

- **Autumn** & **Winter**: strongest correlation
- **Spring** shows weakest correlation: suggesting WSFS model limitations during snowmelt period: e.g.,
  - Increasing temperatures could alter traditional melt timing and patterns
  - Variable soil frost/thaw conditions could as well affect infiltration rates
  - Changing precipitation types (rain vs. snow) complicates runoff calculations
- **Summer** correlation matches overall average
- WSFS underestimates extreme anomalies across all seasons

WSFS vs GRACE: Yearly

- Both trends are statistically significant (*p=0.00*)
- Grace data shows stronger increasing trend with **0.37 cm/year** compared to WSFS model (**0.12 cm/year**)
- Gap between GRACE and WSFS widens in recent years (2020-2024): maximum discrepancy in 2024
- WSFS captures pattern timing, but underestimates magnitude of water storage changes





Summary: Groundwater quantity SDG assessment for Finland

- Combining **ground observations**, **hydrological modelling**, & **satellite data** provided comprehensive groundwater assessment
- Groundwater trends vary spatially across Finland
- **Summer/Autumn** showed more stations with decreasing trends while **winter/spring** showed more increasing trends
- Specific stations showed persistent declines across all seasons (IDS: 103, 203, 802)
  - These stations might need targeted action
- WSFS underestimated total water storage changes compared to GRACE satellite data
  - Poorest correlations during spring highlight the need for improved snowmelt and frost-thaw modelling in WSFS
- **Climate signals**?: recent years (2022-2024) showed improved winter recharge, potentially due to increased rain vs. snow precipitation
- GRACE revealed stronger increasing trend (0.37 cm/year) compared to WSFS (0.12 cm/year)
- **The 1990s were a stress period** for Finland's groundwater - we had 14 stations declining, about 25% of all monitoring stations, with only 2 showing increases
- **2000s was a recovery decade:** Showed a surge in increasing trends (20 stations) suggesting groundwater recovery.