Finland Total Water Storage Anomaly (TWSA) Analysis Report

Executive Summary

This report presents an analysis of Total Water Storage Anomaly (TWSA) in Finland from 2002 to 2024. The analysis reveals that Finland is experiencing a significant positive trend in water storage, gaining approximately 1.24 gigatons of water annually. This trend represents a critical insight into Finland's changing hydrological conditions, with notable extreme years identified in 2002, 2003 (extremely dry), and 2024 (extremely wet). The findings highlight important shifts in Finland's water resources that have implications for water management, ecosystem health, and climate adaptation strategies.

Introduction

Total Water Storage Anomaly (TWSA) represents the deviation of the total amount of water stored in a region from a long-term average. This includes surface water (lakes, rivers), soil moisture, groundwater, snow, and ice. TWSA measurements provide valuable information about hydrological changes and are increasingly important for monitoring climate change impacts on water resources.

Methodology

This analysis utilized time series data of TWSA measurements over Finland spanning from 2002 to 2024. A linear regression model was applied to determine the trend in water storage changes over time. Statistical analysis was performed to identify extreme years and seasonal patterns. Water volume changes were converted to mass (gigatons) to quantify the annual water gain or loss across Finland's territory.

Results and Analysis

Linear Regression Results

Table 1 presents the key statistical parameters from the linear regression analysis of TWSA data.

Table 1: Linear Regression Statistical Parameters

Parameter	Value	Units
Slope	0.00102308	cm/day
Intercept	-3.1739	cm
R-squared	0.2259	-
P-value	8.106437e-15	-
Standard Error	0.00012327	cm/day

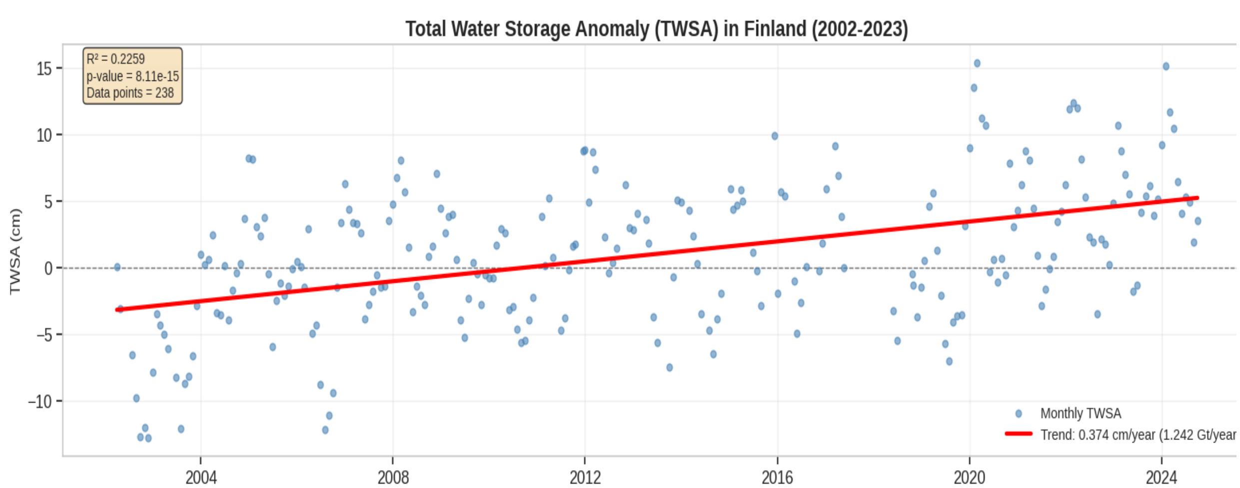
Water Storage Change

The linear regression results translate to significant annual water storage changes in Finland, as summarized in Table 2.

Table 2: Annual Water Storage Change in Finland

Parameter	Value	Units
Rate	+0.3737	cm/year
Volume change	+1.24 × 10^9	cubic meters/year
Mass change	+1.2415	gigatons/year
Status	**GAINING**	-

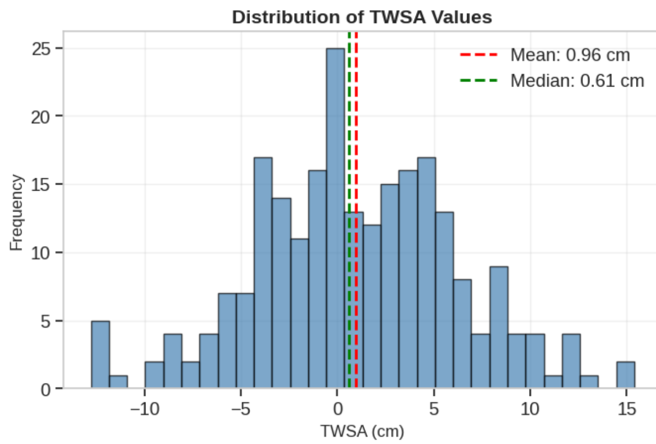
Long-Term Trend in Water Storage



Total Water Storage Anomaly (TWSA) in Finland (2002-2024)

The scatter plot with trend line demonstrates the positive trend in monthly TWSA values over the study period. The red line represents the linear trend with a slope of 0.374 cm/year (1.242 Gt/year). Despite considerable monthly variability, the overall upward trend is statistically significant.

Distribution of TWSA Values

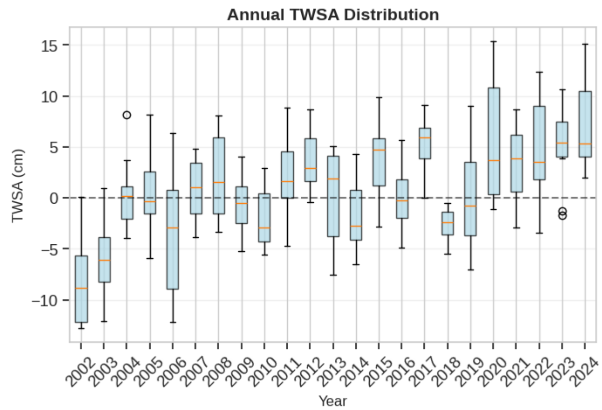


Distribution of TWSA Values

The histogram shows the frequency distribution of all TWSA measurements across the study period. The data follows a roughly normal distribution with: - Mean value: 0.96 cm - Median value: 0.61 cm

The slight positive skew indicates that positive anomalies (wetter conditions) tend to be more extreme than negative anomalies (drier conditions).

Annual TWSA Distribution



Annual TWSA Distribution

The box plot illustrates the distribution of TWSA values for each year from 2002 to 2024. This visualization effectively shows: - The progression from predominantly negative anomalies in the early 2000s to increasingly positive anomalies in recent years - The interannual variability in water storage - The extreme dry years (2002-2003) and wet years (particularly 2024) - The increasing median values over time, consistent with the positive trend

Annual Statistics

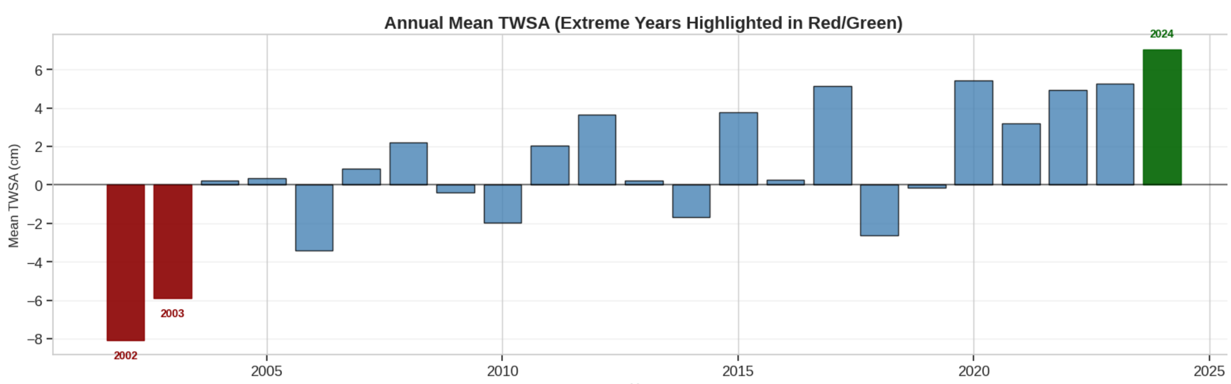
Table 3 provides detailed statistics for each year in the study period.

Table 3: Annual TWSA Statistics (2002-2024)

Year	Mean TWSA (cm)	Min TWSA (cm)	Max TWSA (cm)	Std Dev (cm)	Sample Count	Z-score
2002	-8.078845	-12.774193	0.055535	4.709453	8	-2.379395
2003	-5.875520	-12.108413	0.994061	3.516977	11	-1.794842
2004	0.233297	-3.946094	8.196609	3.424759	12	-0.174144
2005	0.362718	-5.893318	8.170953	3.612083	12	-0.139808
2006	-3.403026	-12.152193	6.336295	6.056175	12	-1.138878
2007	0.855826	-3.858342	4.787235	3.093847	12	-0.008984
2008	2.197574	-3.323671	8.047807	4.106038	12	0.346988

Year	Mean TWSA (cm)	Min TWSA (cm)	Max TWSA (cm)	Std Dev (cm)	Sample Count	Z-score
2009	-0.395350	-5.263106	4.011717	2.923921	12	-0.340927
2010	-1.955706	-5.610892	2.926909	3.126836	11	-0.754897
2011	2.025323	-4.723881	8.841202	4.418276	11	0.301289
2012	3.665656	-0.402035	8.663173	3.024232	10	0.736477
2013	0.210891	-7.502654	5.056659	4.810840	9	-0.180088
2014	-1.684189	-6.497492	4.327534	3.715379	8	-0.682862
2015	3.766401	-2.832237	9.927838	3.807874	9	0.763206
2016	0.251773	-4.892674	5.693908	3.541476	9	-0.169242
2017	5.153008	-0.026067	9.122780	3.462423	5	1.131079
2018	-2.608256	-5.448954	-0.490465	1.851524	6	-0.928021
2019	-0.155078	-7.001589	8.990013	4.980491	12	-0.277182
2020	5.437322	-1.110934	15.386979	5.997484	12	1.206509
2021	3.216047	-2.866744	8.724628	3.766872	12	0.617194
2022	4.943202	-3.435083	12.375948	5.136570	12	1.075417
2023	5.246705	-1.740358	10.678953	3.771680	12	1.155937
2024	7.053064	1.946551	15.118986	4.380347	9	1.635173

Extreme and Record Years



Annual Mean TWSA (Extreme Years Highlighted)

The bar chart highlights years with extreme TWSA values. Table 4 summarizes the extreme years identified in the analysis.

Table 4: Extreme Years (z-score > 1.5 or < -1.5)

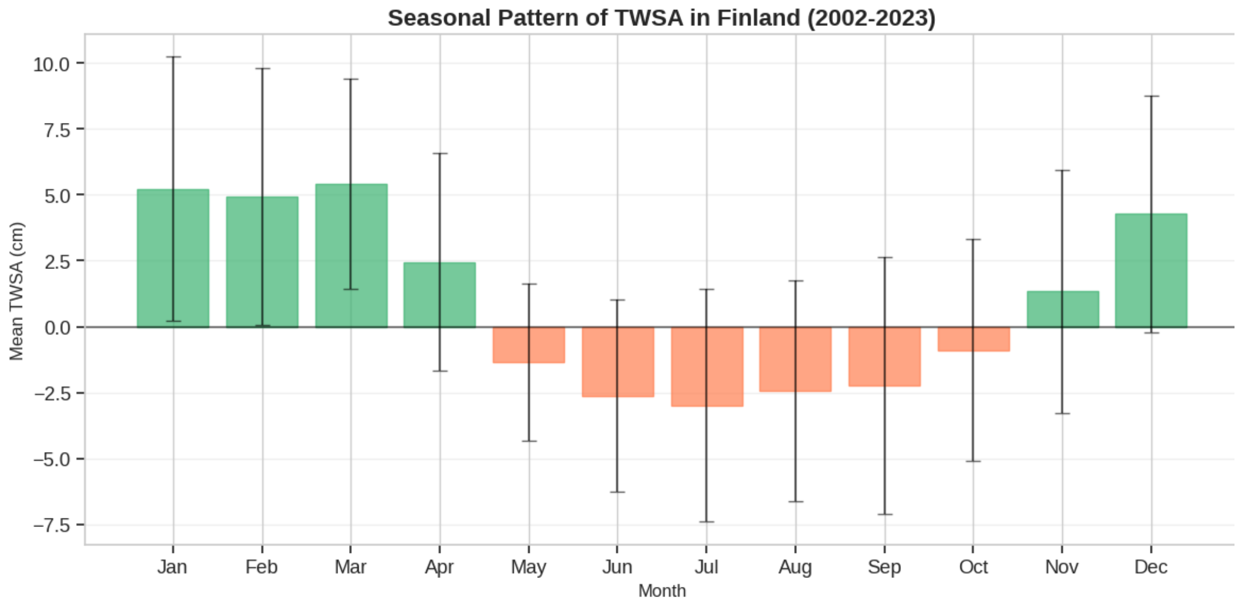
Year	Condition	Mean TWSA (cm)	Z-score	Standard Deviation (cm)
2002	EXTREMELY DRY	-8.08	-2.38	4.71
2003	EXTREMELY DRY	-5.88	-1.79	3.52
2024	EXTREMELY WET	7.05	1.64	4.38

Table 5: Record Years

Condition	Year	Mean TWSA (cm)
Wettest Year	2024	7.05
Driest Year	2002	-8.08
Difference		15.13

The difference between the wettest year (2024) and the driest year (2002) is 15.13 cm of water equivalent thickness, representing a dramatic shift in water storage conditions over the study period.

Seasonal Pattern



Seasonal Pattern of TWSA in Finland

The bar chart illustrates the seasonal cycle of water storage in Finland, with key seasonal characteristics summarized in Table 6:

Table 6: Seasonal Pattern Highlights

Season	Months	TWSA Condition	Notable Values
Winter-Spring	January-March	Highest positive anomalies	Peak in March: 5.42 cm
Summer	June-September	Lowest values	Minimum in July: -2.99 cm
Autumn	October-December	Recovery period	Gradually increasing values

This pattern aligns with Finland's hydrological cycle, where snow accumulation during winter, spring melt, summer evapotranspiration, and autumn precipitation play key roles in water storage dynamics.

Data Quality Summary

Table 7: Data Quality Metrics

Metric	Value	Notes
Total observations	238	Monthly data points
Time span	22.5	years
Regression R^2	0.2259	Trend explains 22.6% of variance

Discussion

Climate Change Implications

The observed trend of increasing water storage (+1.24 Gt/year) may reflect several aspects of climate change in Finland:

1. **Increased Precipitation**: Climate models predict higher precipitation in northern Europe under warming scenarios, which could contribute to the observed water storage gains.

2. **Changes in Seasonal Patterns**: While total water is increasing, the seasonal distribution may be shifting, potentially affecting ecosystems and water resource management.

3. **Contrast with Global Trends**: The positive trend in Finland contrasts with water loss trends observed in many other regions globally, highlighting the spatial heterogeneity of climate change impacts.

Hydrological Cycle Changes

The dramatic shift from extremely dry conditions in 2002-2003 to extremely wet conditions in 2024 suggests potential intensification of hydrological extremes. This pattern is consistent with climate change projections that indicate more variable precipitation and intensified hydrological cycles.

Data Considerations

The R-squared value of 0.2259 indicates that while the trend is statistically significant, approximately 77% of the variance in TWSA is explained by factors other than the linear trend.

This suggests complex interactions between climate oscillations, land use changes, and other environmental factors.

Conclusion

This analysis demonstrates that Finland is experiencing a significant increase in total water storage at a rate of approximately 1.24 gigatons per year. The transition from record dry conditions in the early 2000s to record wet conditions in recent years represents a substantial shift in Finland’s hydrology.

These findings have important implications for:

1. **Water Management**: Infrastructure planning may need to account for increasing water availability and potential flooding risks.

2. **Ecosystem Management**: Changes in water availability will affect forest health, wetland ecosystems, and aquatic habitats.

3. **Climate Adaptation**: Understanding these trends is essential for developing appropriate climate adaptation strategies.

Further research is recommended to investigate the specific drivers of this trend, regional variations within Finland, and projections for future changes in water storage under different climate scenarios.

Summary of Key Findings

Table 8: Summary of Key Results

Finding	Value	Units
Annual water gain	1.2415	gigatons/year
Rate of TWSA change	0.3737	cm/year
Mean TWSA (2002-2024)	0.96	cm
Median TWSA	0.61	cm
Wettest year	2024 (7.05 cm)	-

Finding	Value	Units
Driest year	2002 (-8.08 cm)	-
Extreme wet-dry difference	15.13	cm
Highest monthly TWSA	March (5.42 cm)	-
Lowest monthly TWSA	July (-2.99 cm)	-