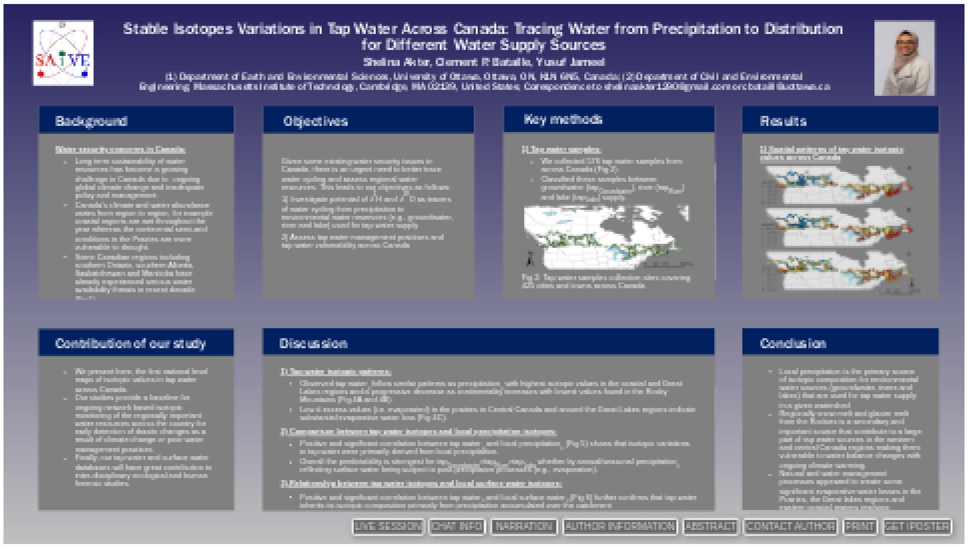
Stable Isotopes Variations in Tap Water Across Canada: Tracing Water from Precipitation to Distribution for Different Water Supply Sources



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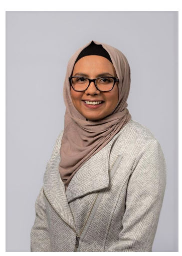

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BACKGROUND

<u>Water security concerns in Canada:</u>

- Long term sustainability of water resources has become a growing challenge in Canada due to ongoing global climate change and inadequate policy and management.
- Canada's climate and water abundance varies from region to region, for example coastal regions are wet throughout the year whereas the continental semi-arid conditions in the Prairies are more vulnerable to drought.
- Some Canadian regions including southern Ontario, southern Alberta, Saskatchewan and Manitoba have already experienced serious water availability threats in recent decade (Fig1).

- Yet, regionally important water resources that supply tap water to public and their vulnerability are largely unknown.

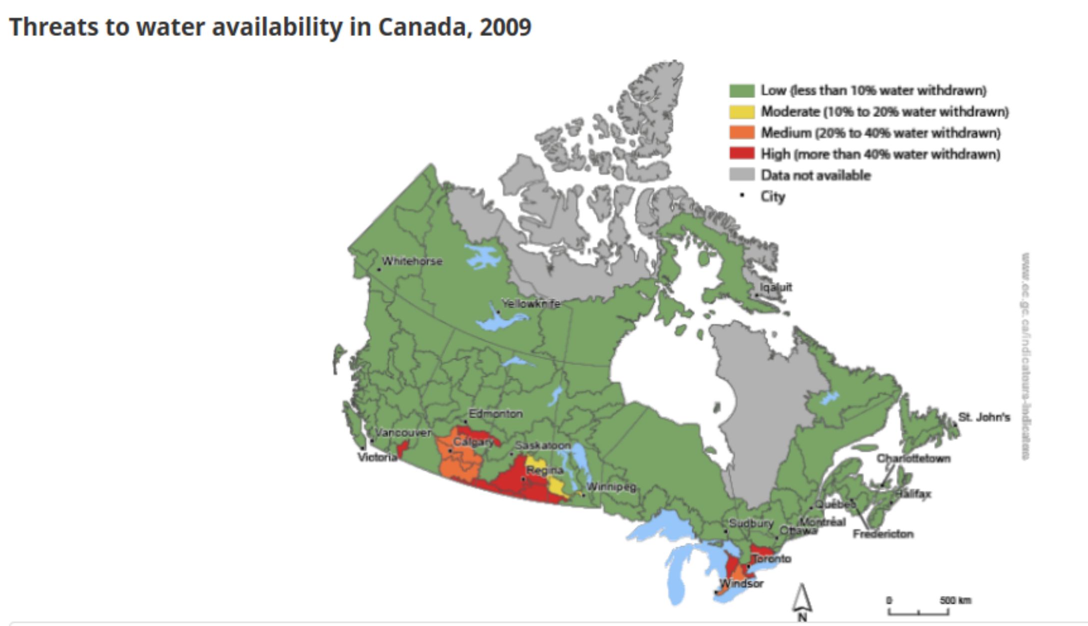

Fig1:Threats to water availability in Canada, 2009 (Government of Canada, 2017)

OBJECTIVES

Given some existing water security issues in Canada, there is an urgent need to better trace water cycling and assess regional water resources. This leads to our objectives as follows:

1) Investigate potential of δ^2H and δ^{18}O as tracers of water cycling from precipitation to environmental water reservoirs (e.g., groundwater, river and lake) used for tap water supply

2) Assess tap water management practises and tap water vulnerability across Canada

KEY METHODS

1) Tap water samples:

- We collected 576 tap water samples from across Canada (Fig 2).
- Classified these samples between groundwater ($tap_{Groundwater}$), river (tap_{River}) and lake (tap_{Lake}) supply.

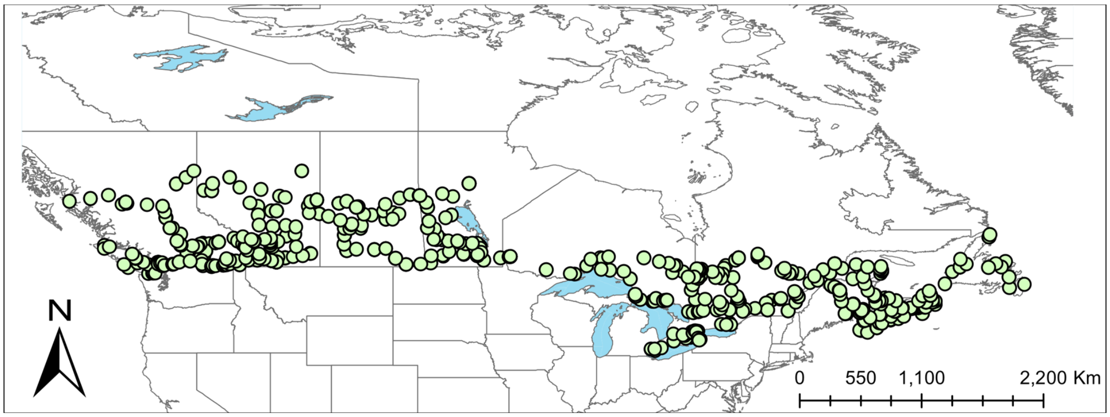

Fig 2: Tap water samples collection sites covering 425 cities and towns across Canada

2) Comparison between tap water isotopes and local precipitation isotopes: provides primary insights into water cycling

- Used precipitation δ^2H and δ^{18}O isoscapes from the RCWIP model (Regionalized Cluster-based Water Isotope Prediction) to extract precipitation isotopes values at each tap water collection site
- Explored correlation between the observed isotopic values in tap water (tap $water_\delta$) and interpolated isotopic values in local precipitation ($precipitation_\delta$)

3) Comparison between tap water isotopes and local surface water isotopes: provides further insights into water cycling (e.g.,post-precipitation processes) and water management practices

- Constructed a series of water balance models (Table 2) to predict annual and seasonal δ^2H and δ^{18}O values in local surface water (surface $water_\delta$)
- Explored correlation and residuals between the observed tap $water_\delta$ and predicted local surface $water_\delta$.

3.1) Water balance modelling to predict surface water isotopes across Canada:

Table 1: List of existing geospatial data used for the water balance modelling

ID	Description	Resolution
Precipitation Monthly & Annually (mm/yr)	Annual and monthly global gridded precipitation data (between 1970-2000)	$1km^2$
Evapotranspiration (ET) Monthly & Annually (mm/yr)	Annual and monthly evapotranspiration (ET) data (between 1982 and 2013)	$8km^2$
δ^2H and $\delta^{18}O$ Isotopes in precipitation	Long-term average mean annual and mean monthly δ^2H and $\delta^{18}O$ values for global precipitation were downloaded from the GNIP website	$\sim 10km^2$
Digital topography map with drainage direction	North American flow direction raster	$1km^2$

Table 2: Equations used to calculate discharge and isotopic flux at 1^2 km grid cell to be accumulated downstream

ID	Discharge	Isotopic flux (Discharge * δd^2H or $\delta^{18}O$)
Annual model (annual average)	Q = P	δQ = annual P * annual δP
Annual ET model (annual average)	Q = P – ET	δQ = annual (P-ET) * annual δP
Annual ET model (monthly weighted)	Q = P – ET	δQ = (Jan (P-ET) * Jan δP) +….(Dec (P-ET) * Dec δP)
Summer model (monthly weighted)	Q = P	δQ = (May P *May δP) +….(October P * October δP)
Summer ET model (monthly weighted)	Q = P – ET	δQ = (May (P-ET) *May δP) +….(October (P-ET) * October δP)
Winter model (monthly weighted)	Q = P	δQ = (November P * Nov δP) +….(April P * April δP)
Winter ET model (monthly weighted)	Q = P – ET	δQ = (November (P-ET)*November δP) +….(April (P-ET)*April δP)

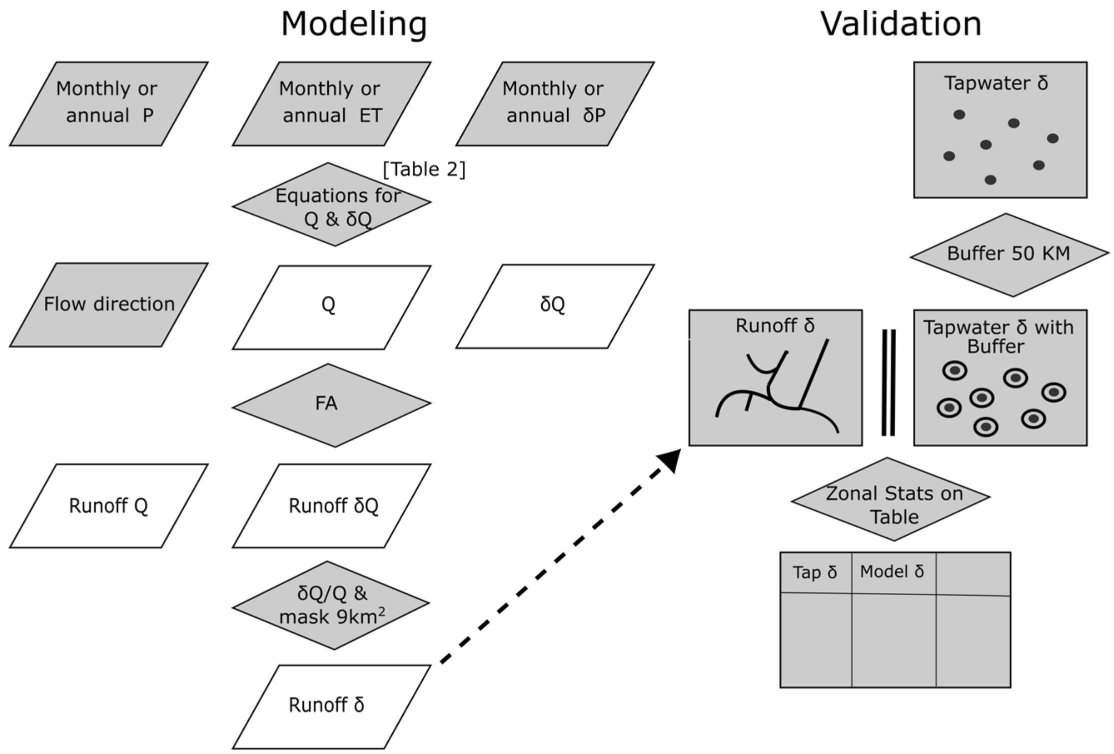

Fig 3: Workflow for GIS based water balance modeling modified from Bowen et al. 2011. Diamond = operations and rectangular (shaded) = input raster data sets. P = precipitation; ET = evapotranspiration; δP = isotopic composition of precipitation; FA = flow accumulation; Q = discharge, and δQ = isotopic flux associated with discharge.

RESULTS

1) Spatial patterns of tap water isotopic values across Canada

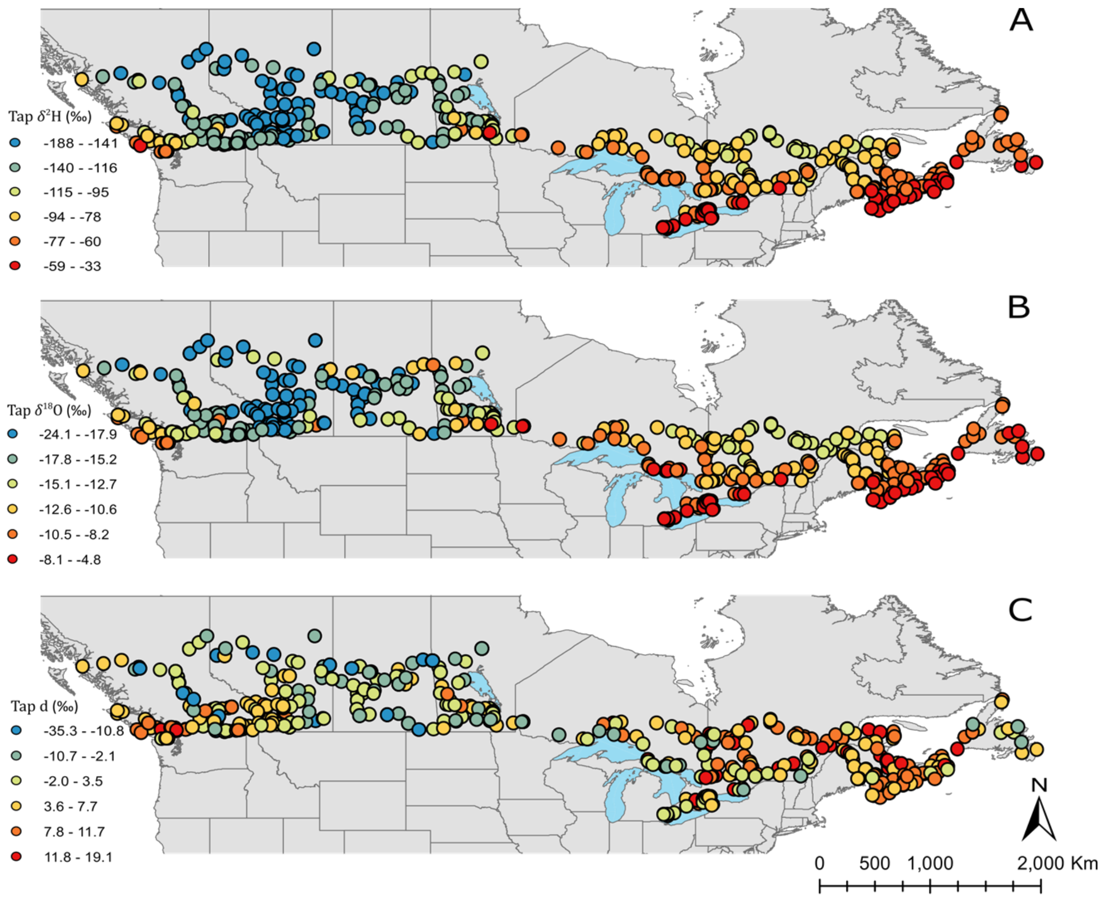

Fig 4: Isotopic values in tap water across Canada. A= δ^2H variability (n=576). B = δ^{18}O variability (n=576) and C= d-excess (n=576).

2) Relationship between tap water isotopes and local precipitation isotopes

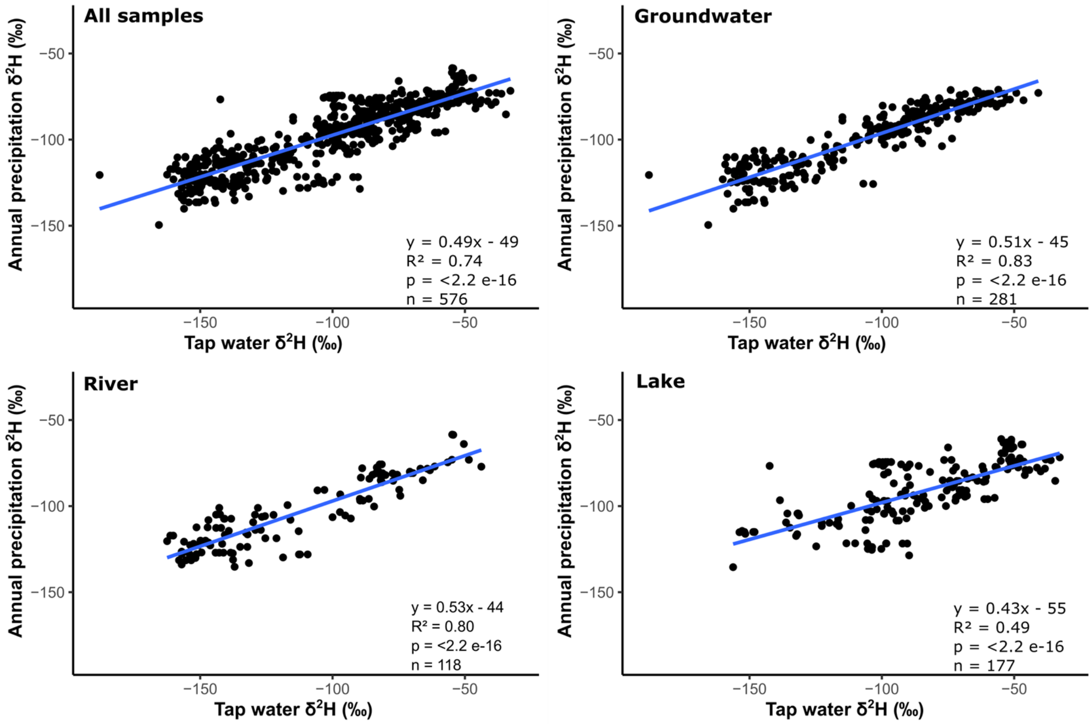

Fig 5: Correlation between tap water δ^2H (sourced from groundwater, river and lake) and local precipitation δ^2H

3) Relationship between tap water isotopes and local surface water isotopes

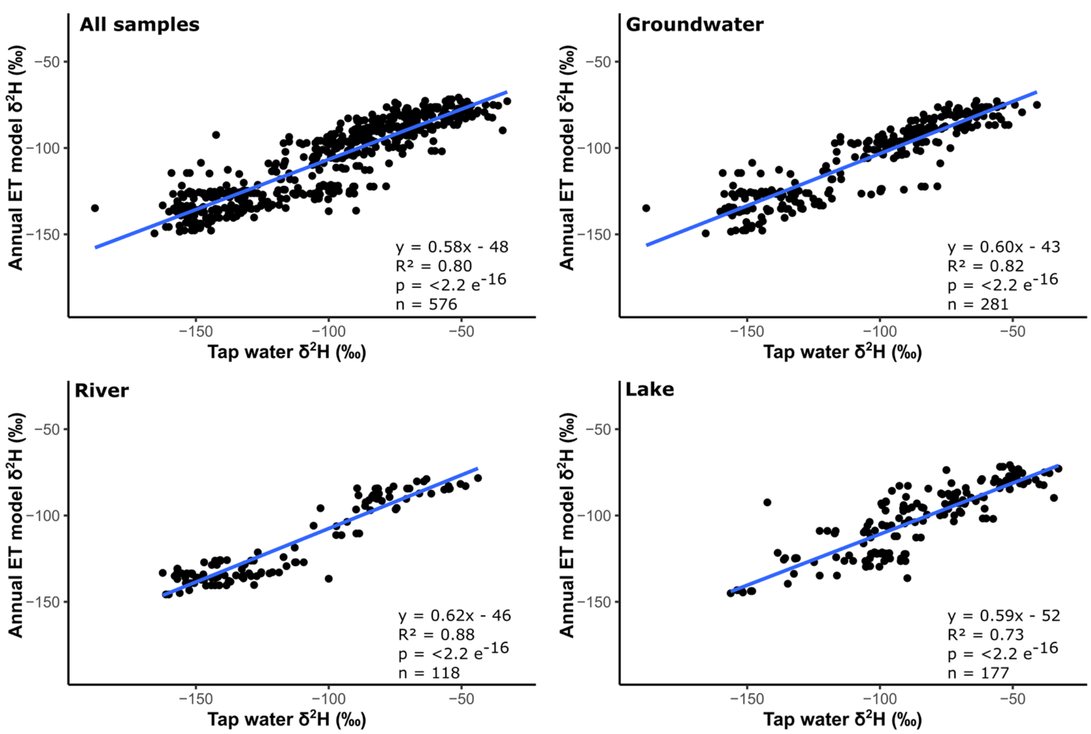

Fig 6: Correlation between tap water δ^2H (sourced from groundwater, river and lake) and modelled surface water δ^2H

4) Residuals map: isotopic values (tap water – local surface water)

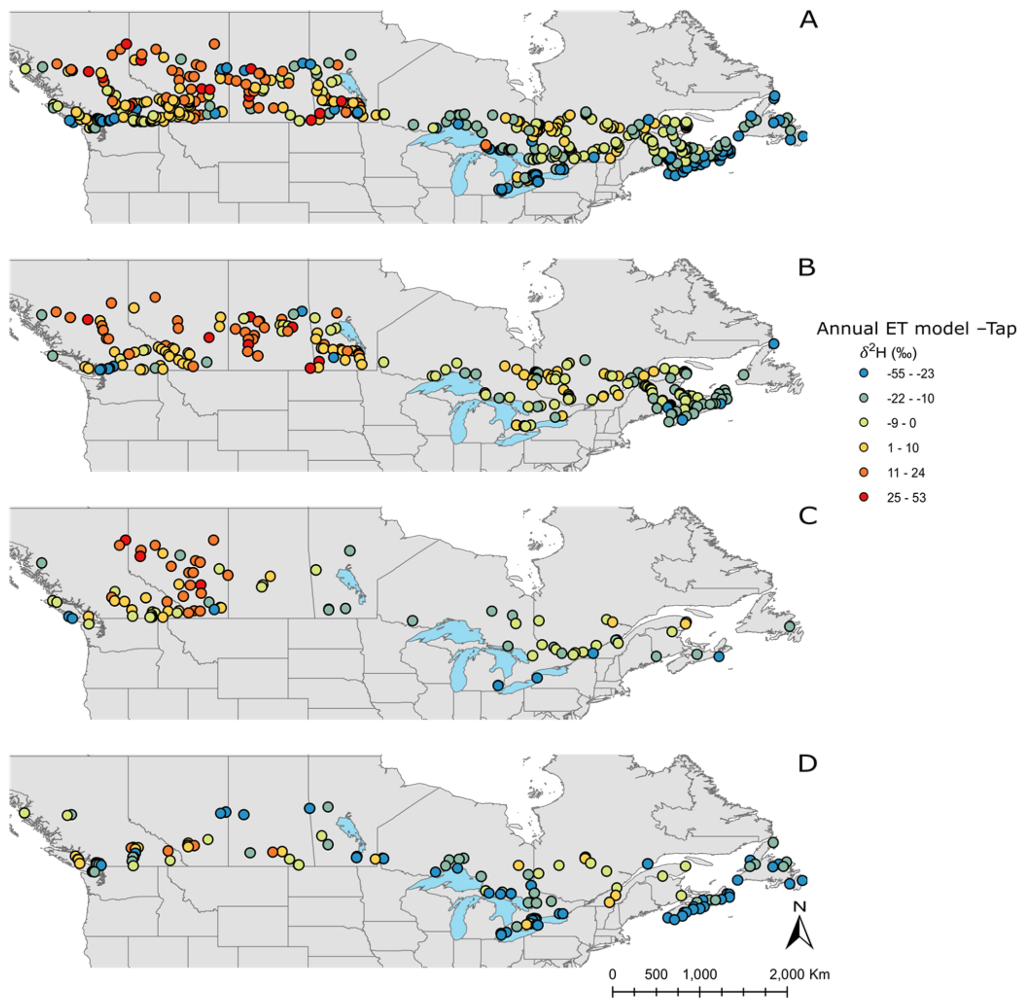

Fig 7: δ^2H (local surface water– tap water) residuals patterns: (a) tap water from all sources combined (b) tap water sourced from groundwater (c) tap water sourced from river (d) tap water sourced from lake.

CONTRIBUTION OF OUR STUDY

- We present here, the first national level maps of isotopic values in tap water across Canada.
- Our studies provide a baseline for ongoing network based isotopic monitoring of the regionally important water resources across the country for early detection of drastic changes as a result of climate change or poor water management practices.
- Finally, our tap water and surface water databases will have great contribution to inter-disciplinary ecological and human forensic studies.

DISCUSSION

1) Tap water isotopic patterns:

- Observed tap water$_{\delta}$ follow similar patterns as precipitation$_{\delta}$ with highest isotopic values in the coastal and Great Lakes regions and a progressive decrease as continentality increases with lowest values found in the Rocky Mountains (Fig 4A and 4B).
- Low d-excess values (i.e. evaporated) in the prairies in Central Canada and around the Great Lakes regions indicate substantial evaporative water loss (Fig 4C).

2) Comparison between tap water isotopes and local precipitation isotopes:

- Positive and significant correlation between tap water$_{\delta}$ and local precipitation$_{\delta}$ (Fig 5) shows that isotopic variations in tap water were primarily derived from local precipitation.
- Overall the predictability is strongest for tap$_{Groundwater}$>tap$_{River}$>tap$_{Lake}$ whether by annual/seasonal precipitation$_{\delta}$ reflecting surface water being subject to post-precipitaion processes (e.g., evaporation).

3).Relationship between tap water isotopes and local surface water isotopes:

- Positive and significant correlation between tap water$_{\delta}$ and local surface water$_{\delta}$ (Fig 6) further confirms that tap water inherits its isotopic composition primarily from precipitation accumulated over the catchment
- Overall local surfcae water$_{\delta}$ does not improve predictability of isotopic variation in tap$_{Groundwater}$ but strongly improves predictability of isotopic variation in tap$_{River}$ and tap$_{Lake}$.
- So, we conclude, isotope values of tap water sourced from surface water reflect the accumulation and evaporation of precipitation in catchments (integrated into water balance models). However, tap$_{Lake}$ still remains the most isotopically variable source.

4) Residuals map: isotopic values (tap water – local surface water):

- The large positive residuals in the western Rockies and west-central Canada regions (Fig 7) shows that snow and glacier melt from the Rockies contribute to a large part of tap water sources making them vulnerable to water balance changes with ongoing climate warming.
- In the Prairies and the Great lakes regions, tap$_{Rivers}$ and tap$_{Lakes}$ mostly show large negative residuals (Fig 7) indicating substantial evaporative water loss which coincides with low d-excess values (Fig 4C) implying vulnerability to ongoing climate warming.
- The large negative residuals in the eastern coastal regions reflect evaporative water loss both naturally and due to widespraed surface reservoirs and small pounds uses by municipalities.

CONCLUSION

- Local precipitation is the primary source of isotopic composition for environmental water sources (groundwater, rivers and lakes) that are used for tap water supply in a given watershed
- Regionally snow melt and glacier melt from the Rockies is a secondary and important source that contribute to a large part of tap water sources in the western and central Canada regions making them vulnerable to water balance changes with ongoing climate warming.
- Natural and water management processes appeared to create some significant evaporative water losses in the Prairies, the Great lakes regions and eastern coastal regions implying vulnerability to ongoing climate warming as well as water management lacking (e.g., surface reservoirs).
- Climate warming has already caused significant glacier mass loss in Canada. These predicted climate warming changes in temperature, rainfall patterns and reduction in snow cover will impact the water resources (quantity and quality), environment and ecosystems.

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ABSTRACT

There is a growing need to address water security issues in Canada in relation to global warming effects and water management issues. Stable water isotopes (δ^2H and δ^{18}O) have become a popular tool to investigate regional and country level public water distribution systems to identify regional water resource issues and their underlying causes. In this study, we built the first national level maps of isotopic values in tap water across Canada using 576 tap water samples that were collected during the summer season. Observed isotopic values in tap water follow similar patterns as precipitation with highest isotopic values in the coastal and Great Lakes regions and a progressive decrease as continentality increases with lowest values found in the Rocky Mountains. We classified the tap water samples based on their supply sources including groundwater, river and lake. The isotopic values of tap water sourced from groundwater and river are well-predicted by those of local annual precipitation whereas those sourced from lakes are poorly predicted. To explain this difference, we constructed a series of water balance models to predict the δ^2H and δ^{18}O variability of surface water across Canada. We used a digital elevation model to accumulate the isotopic composition of local precipitation weighed by precipitation (total or effective) either monthly, seasonally or annually. These water balance models strongly improved the predictability of isotopic values of tap waters sourced from rivers and lakes (particularly the annual average and monthly weighted summer models, with or without accounting for evapotranspiration). Conversely, these models did not improve predictability of the isotopic values in tap water sourced from groundwater. We argue that isotope values of tap water sourced from surface water reflect the accumulation and evapotranspiration of precipitation in catchments whereas groundwater represents an annual average of the isotopic composition of local precipitation. Regionally, we find that winter precipitation and snow melt and glaciers melt from the Rockies contribute to a large part of tap water sources around the Rockies making them vulnerable to water balance changes with ongoing climate warming. In eastern Canada water management processes appear to create some significant evaporative water losses whereas in central Canada dry continental climate causes significant evaporative water loss. Our study highlights the cycling of water from precipitation to tap water across Canada for different tap water supply with implications for water managements, contamination risks and vulnerability to climate change. Our models and databases also provide an isotopic baseline for regionally important water resources monitoring as well as for human forensic cases.