EGU26 GENERAL ASSEMBLY

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Pollution dynamics in the lower Bengal Delta of Bangladesh

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Introduction

- The Bengal Delta, formed by the Ganges-Brahmaputra-Meghna river system, is located in the southwest coastal region of Bangladesh.
- It represents one of the most dynamic and ecologically sensitive deltaic environments in the world.
- Within this delta, tidal fluctuations under high and low tide conditions play a key role in altering river water chemistry, particularly through the mobilization of major ions such as Na^+, Cl^-, and SO_4^{2-}.
- Compounding these natural processes, the delta is inhabited by approximately 170 million people who directly or indirectly depend on river and groundwater resources, making anthropogenic activities a significant driver of ion composition changes in coastal water.
- Furthermore, climate shifts observed over recent decades, including rising temperatures and increasingly erratic rainfall patterns, have further intensified ion compositional changes in coastal water chemistry.
- As a consequence of these interacting natural and anthropogenic pressures, the rivers and groundwater of the Bengal Delta face severe seawater intrusion and pollution arising from the complex interplay of terrestrial, mangrove, and marine processes.

Study Area

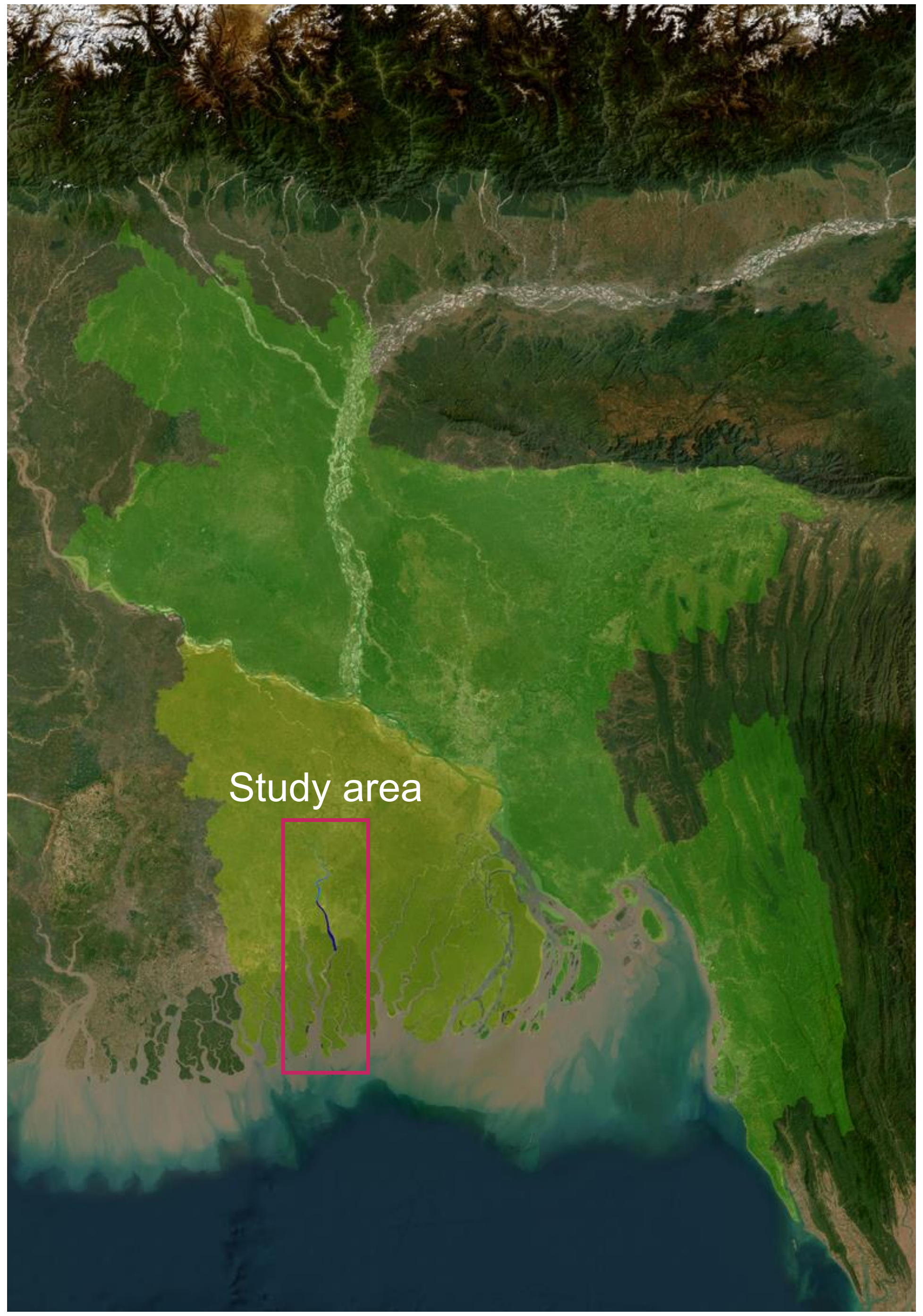

Fig.1 Study area

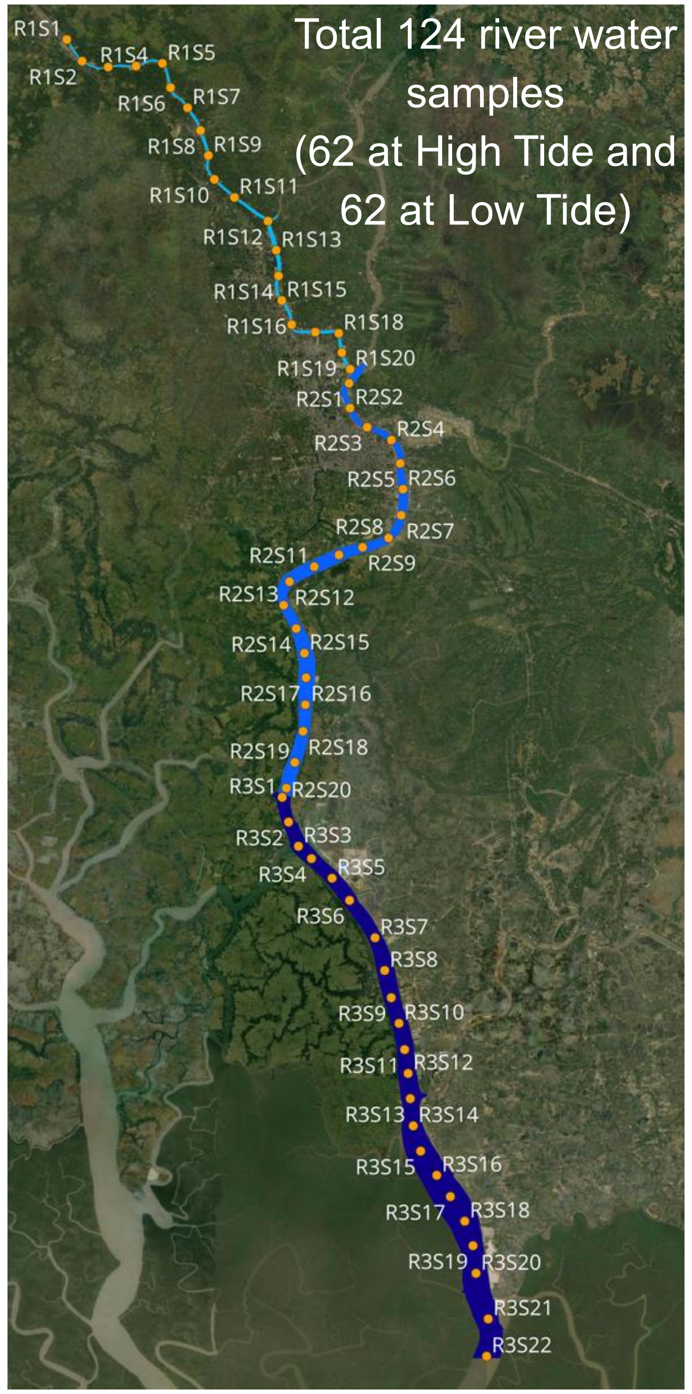

Fig. 1a river water (R1S1, R2S1, R3S1) sample locations

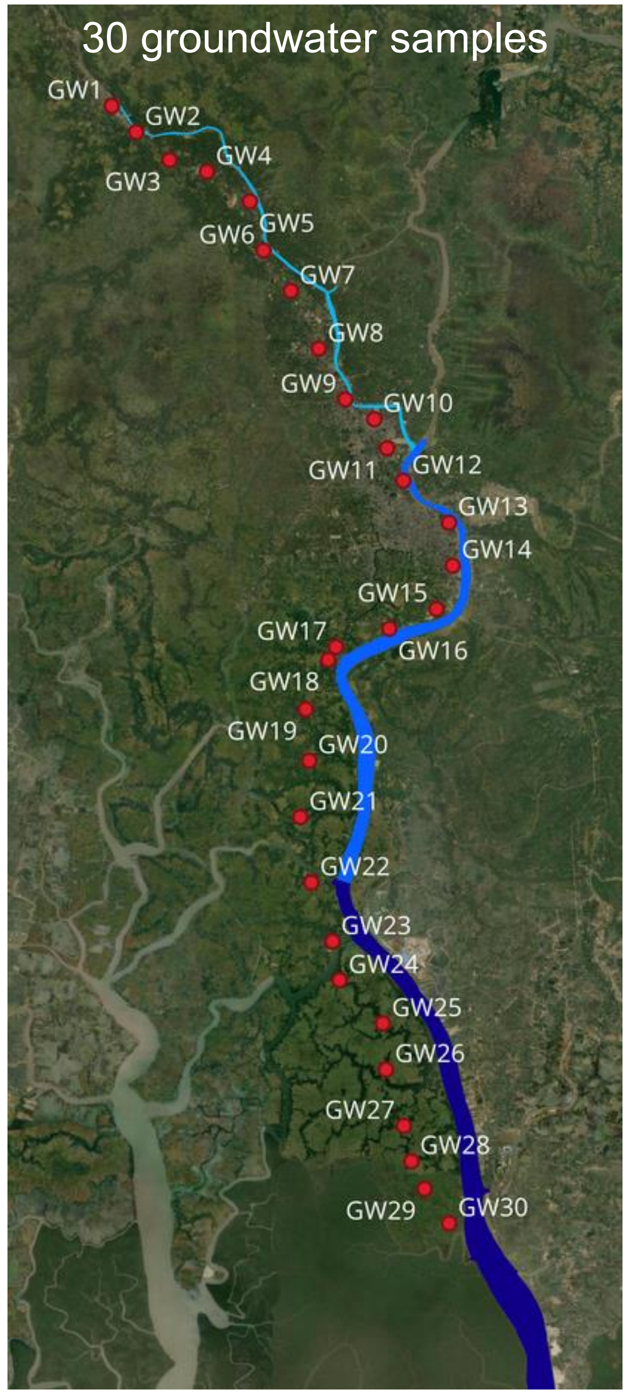

Fig. 1b groundwater (GW) sample locations

Fig. 1c rain and seawater sample locations

Materials and Methods | Field Sampling

Fig.2a Sample collection and analysis in coastal rivers

Fig.2b River and river-bank industry

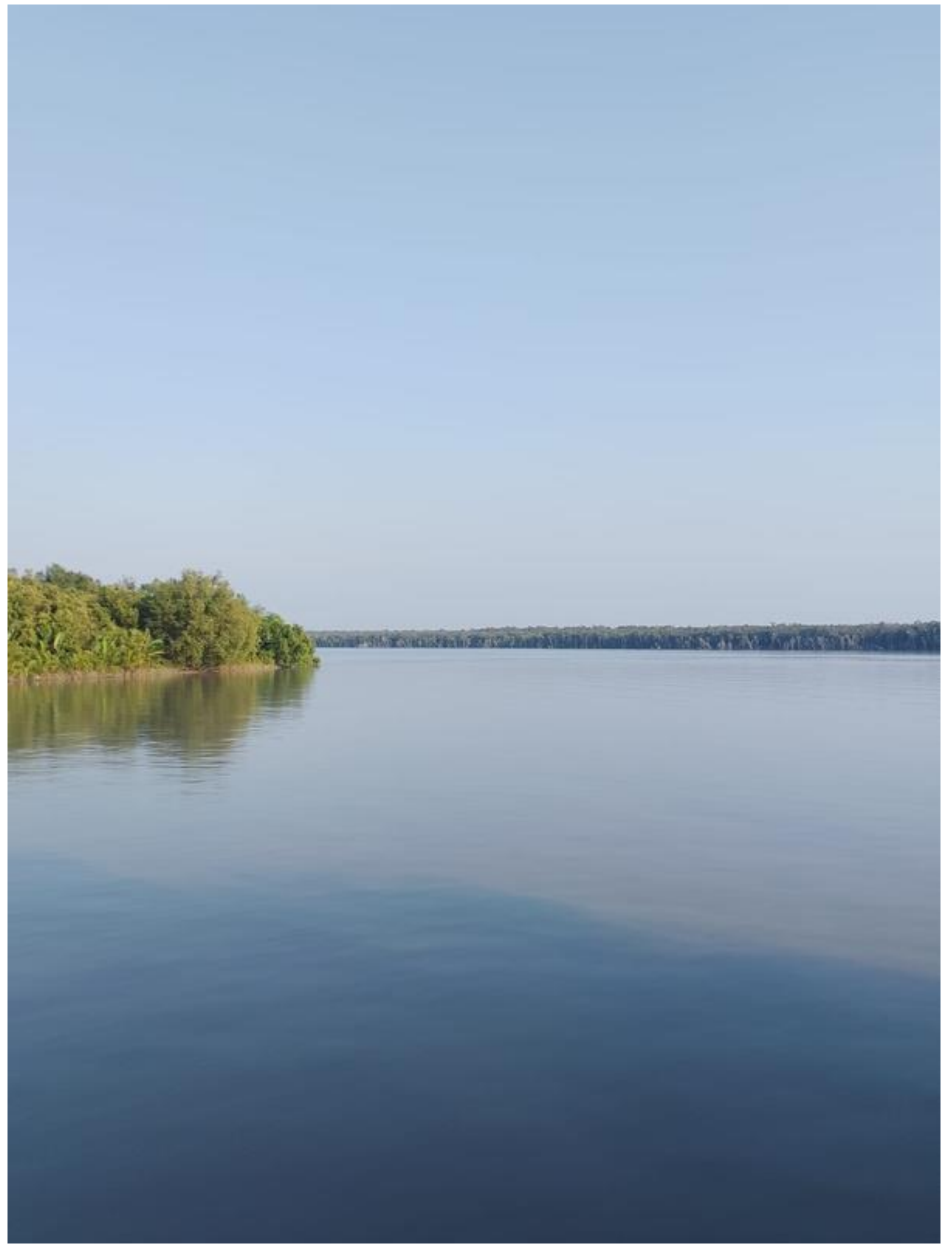

Fig.2c River and Sundarbans mangrove forest

Analyzed parameters: Water temperature, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, and Dissolved Oxygen (DO)

Materials and Methods | Sampling Procedure

Sampling technique
Composite Sampling

Sampling period
Dry season, April to May 2025

Sample collection
Total 158 water samples from (see location Fig.1)-

- Rivers
  - 3 coastal rivers
    - 62 water samples at high tide
    - 62 water samples at low tide
- Groundwater
  - 30 groundwater samples
- Sea
  - 3 seawater samples
- Rain
  - 1 rainwater sample

In-situ (field) based water chemical analysis

- pH, water temperature, EC, TDS, Salinity, and DO

Ex-situ (laboratory) based water chemical analysis

- BOD_5, COD, and $CaCO_3$
- major cations - Na^+, K^+, Ca^{2+}, and Mg^{2+}
- major anions - HCO_3^-, Cl^-, and SO_4^{2-}
- selected nutrients parameters – o-PO_4^{3-}, NO_2^--N, NO_3^--N , TP, and NH_4-N
- selected heavy metals - Cr, Cu, Cd, Mn, Pb, Zn, and Fe and
- stable water isotopes - δ^2H and $\delta^{18}O$

Hydrochemical analysis

- Box-Whisker plot
- Scatter plot
- Piper and HFE-D diagram

Isotopic analysis

- Stable water isotope analysis

Geospatial analysis

- Land use/land cover map

Materials and Methods | Pollution Status Assessment

Two equations were applied to assess the pollution status of three river catchments and groundwater quality status :

$$(\%)\text{ of pollution index} = \frac{Cl^{-} + SO_4^{2-} + NO_3^{-}\text{-}N}{Cl^{-} + SO_4^{2-} + NO_3^{-}\text{-}N + HCO_3^{-}} \times 100$$

Source: *Pacheco and Van der Weijden, 1996*

$$\text{Water quality index (WQI)} = \sum_{i=1}^{n} \frac{W_i Q_i}{\sum_{i=1}^{n} W_i}$$

Source: *Horton, 1965; Brown et al., 1970; Cude, 2001, Tripaty and Sahu, 2005; Chowdhury et al., 2012*

Classification of water quality status:

0-25 = Excellent

26-50 = Good

51-75 = Poor

76-100 = Very poor

>100 = Unsuitable

Source: *Shweta et al., 2013; Chaterjee and Raziuddin, 2002.*

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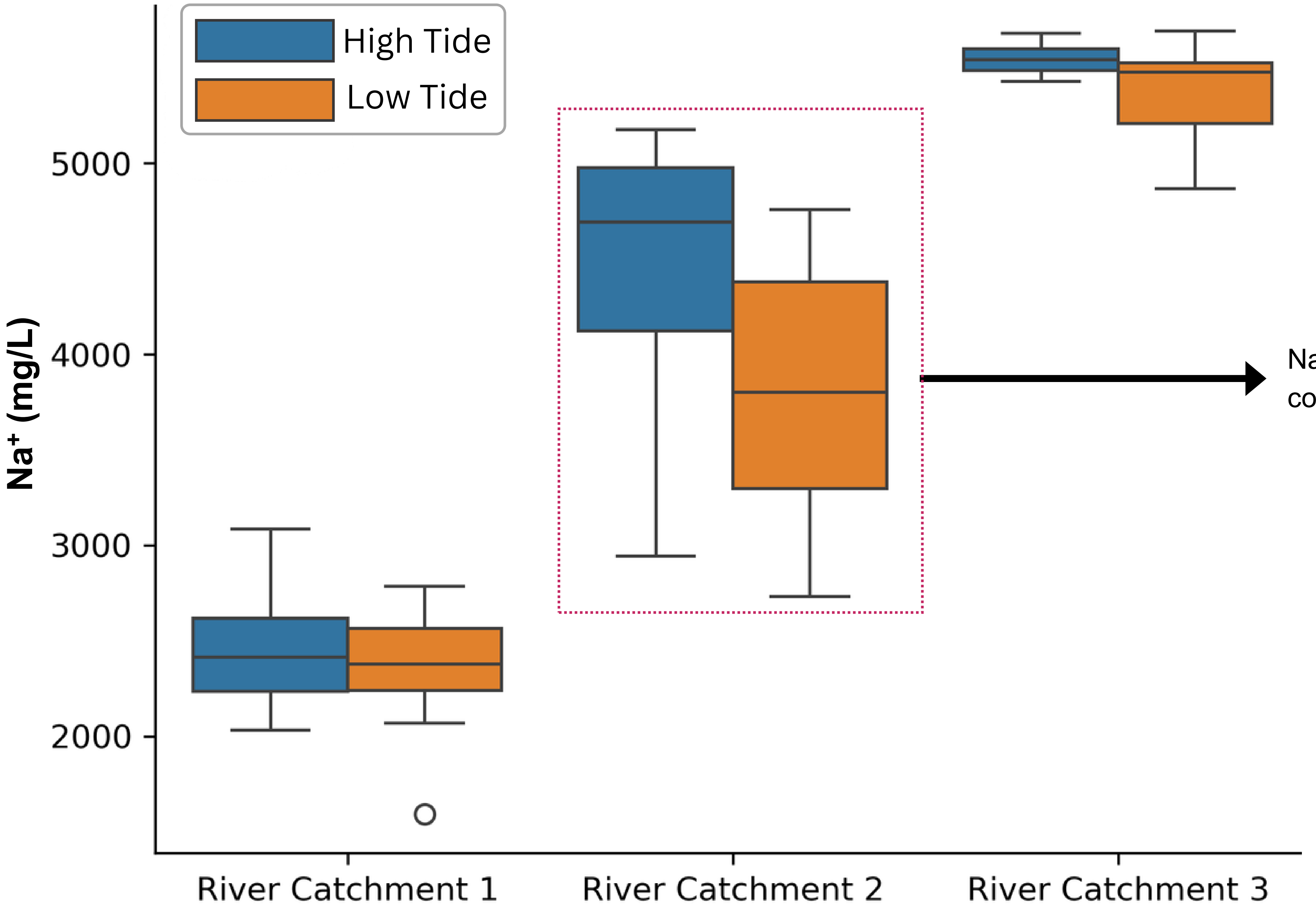
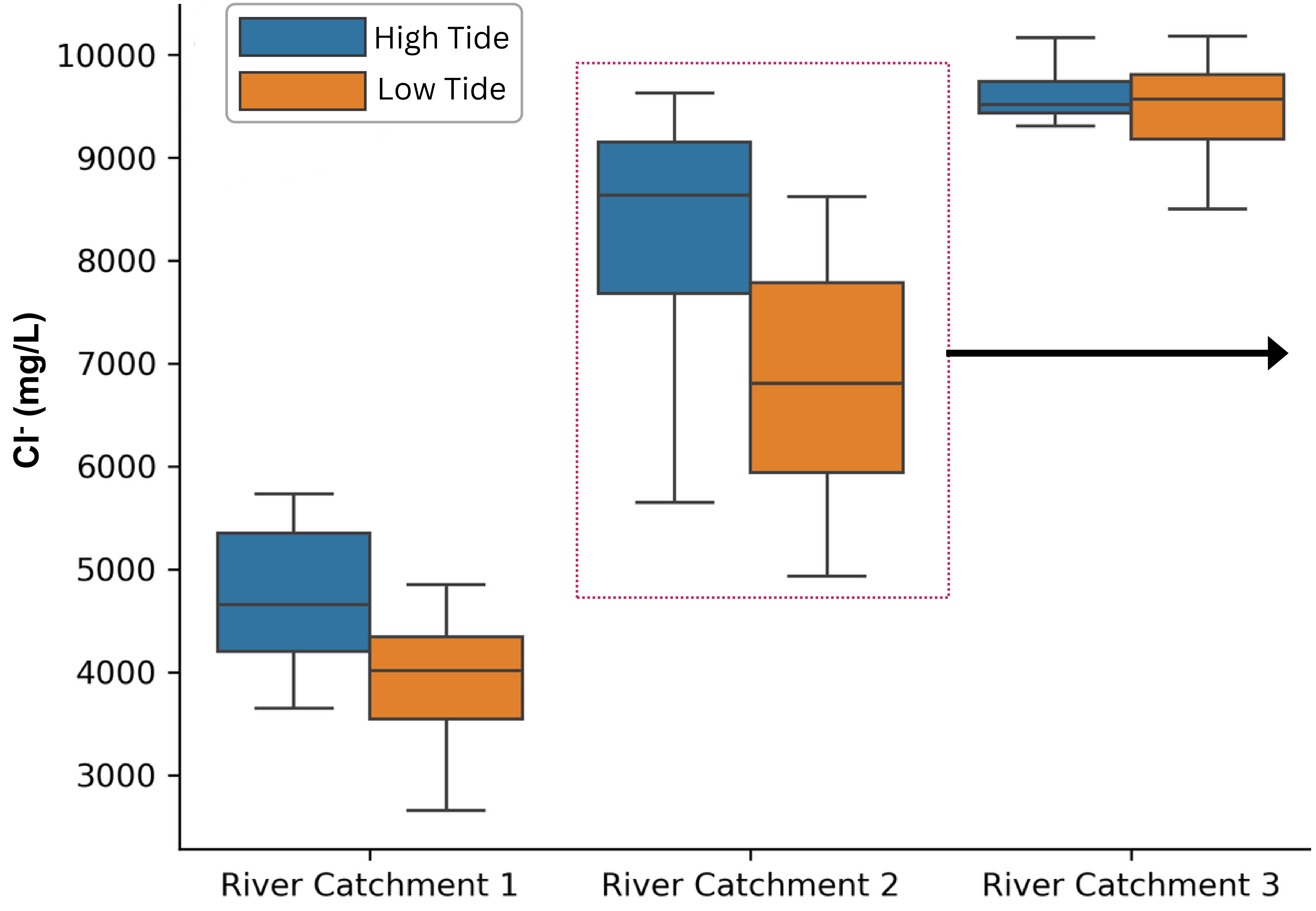
Results | Data Analysis | River Water



Na^+ variation is higher in river catchment 2 compared to river catchments 1 and 3

Fig. 3 Na^+(mg/L) vs. three river catchments

Results | Data Analysis | River Water



Cl^- variation is higher in river catchment 2 compared to river catchments 1 and 3

Fig. 4 Cl^- (mg/L) vs. three river catchments

Results | Data Analysis | River Water

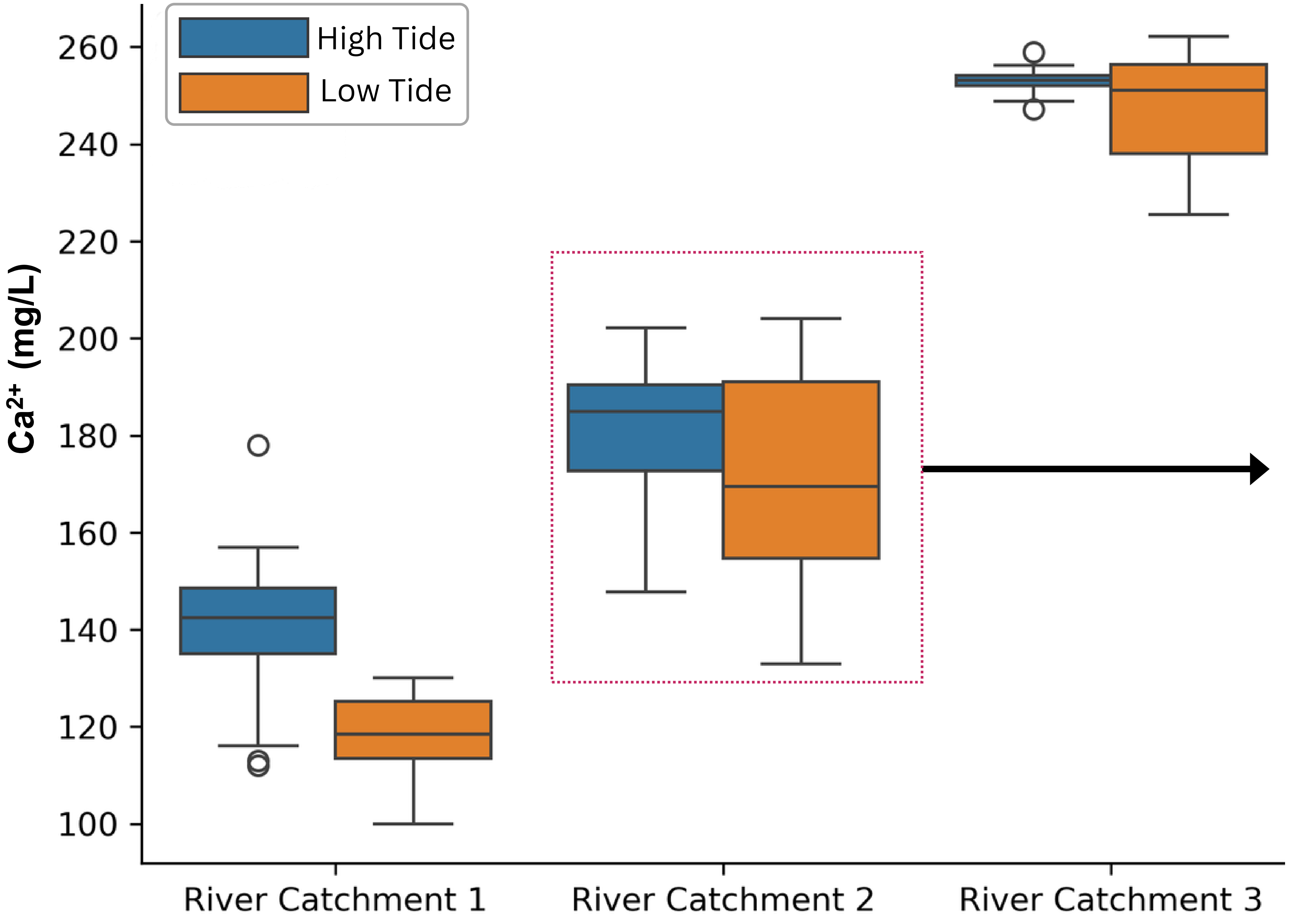
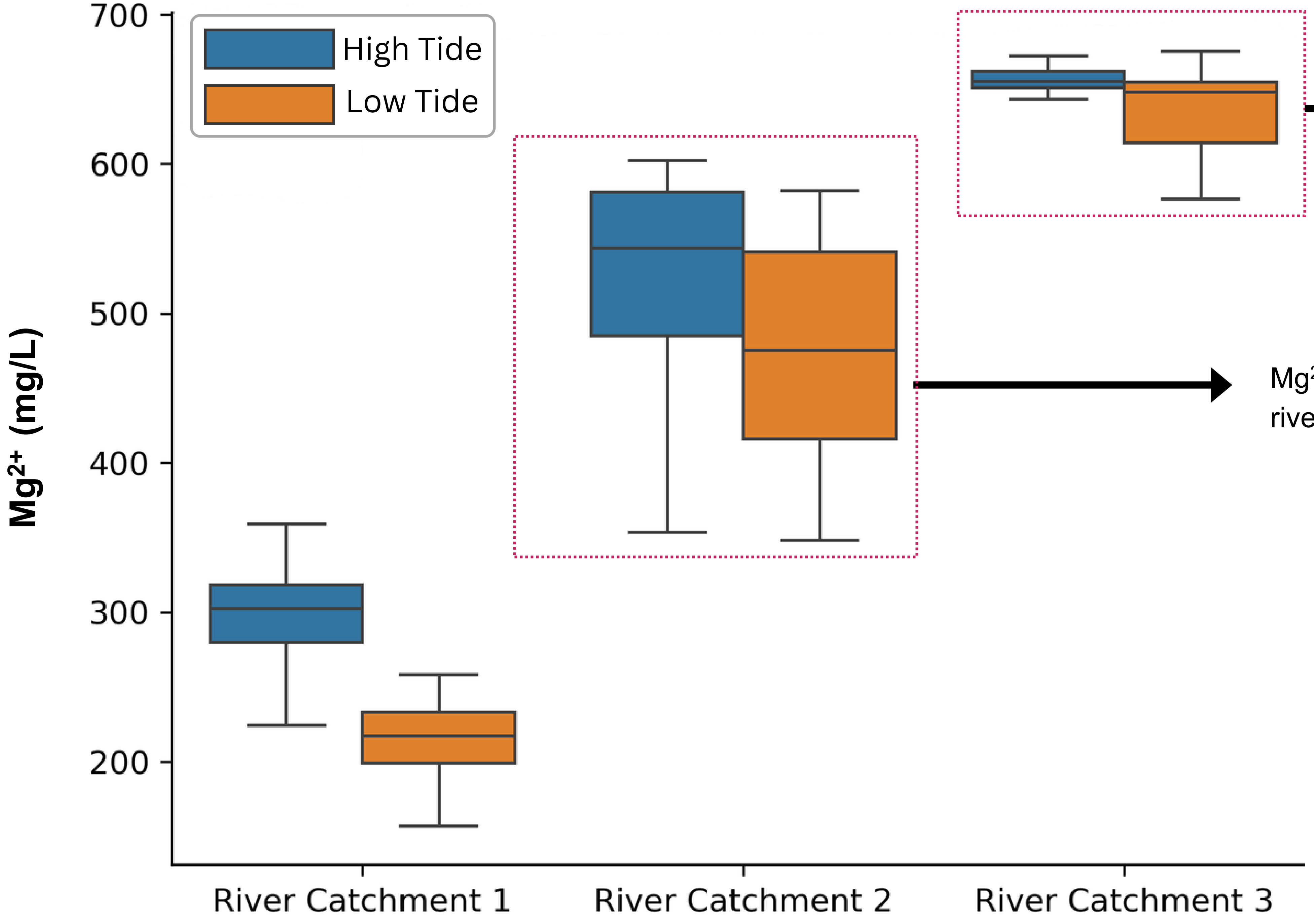


Fig. 5 Ca^{2+} (mg/L) vs. three river catchments

Ca^{2+} variation is higher in river catchment 2
Ca^{2+} concentrations are approximately equal in high tide and low tide in river catchment 2

Results | Data Analysis | River Water

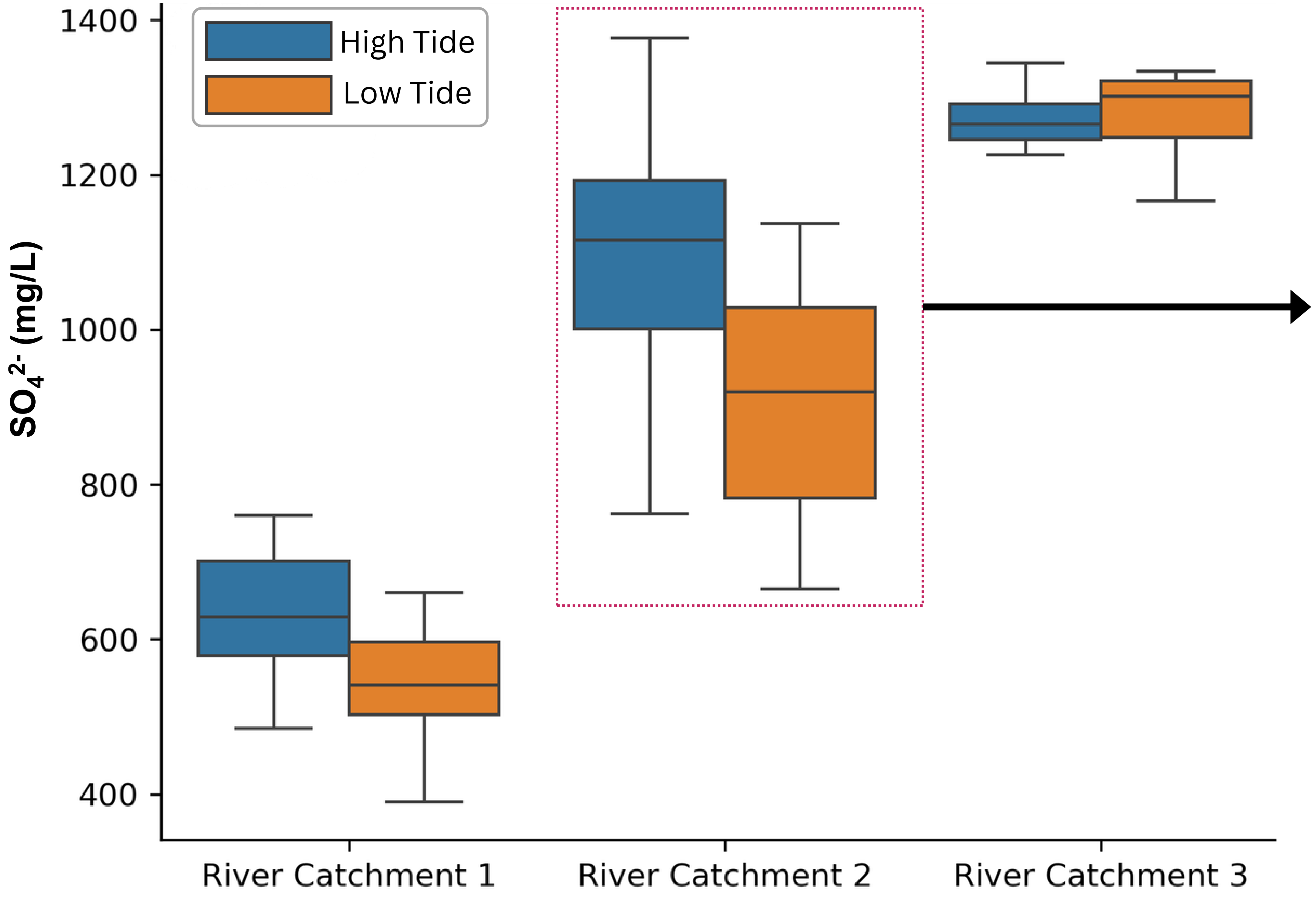


Mg^{2+} concentration is higher in river catchment 3

Mg^{2+} variation is higher in river catchment 2 compared to river catchments 1 and 3

Fig. 6 Mg^{2+} (mg/L) vs. three river catchments

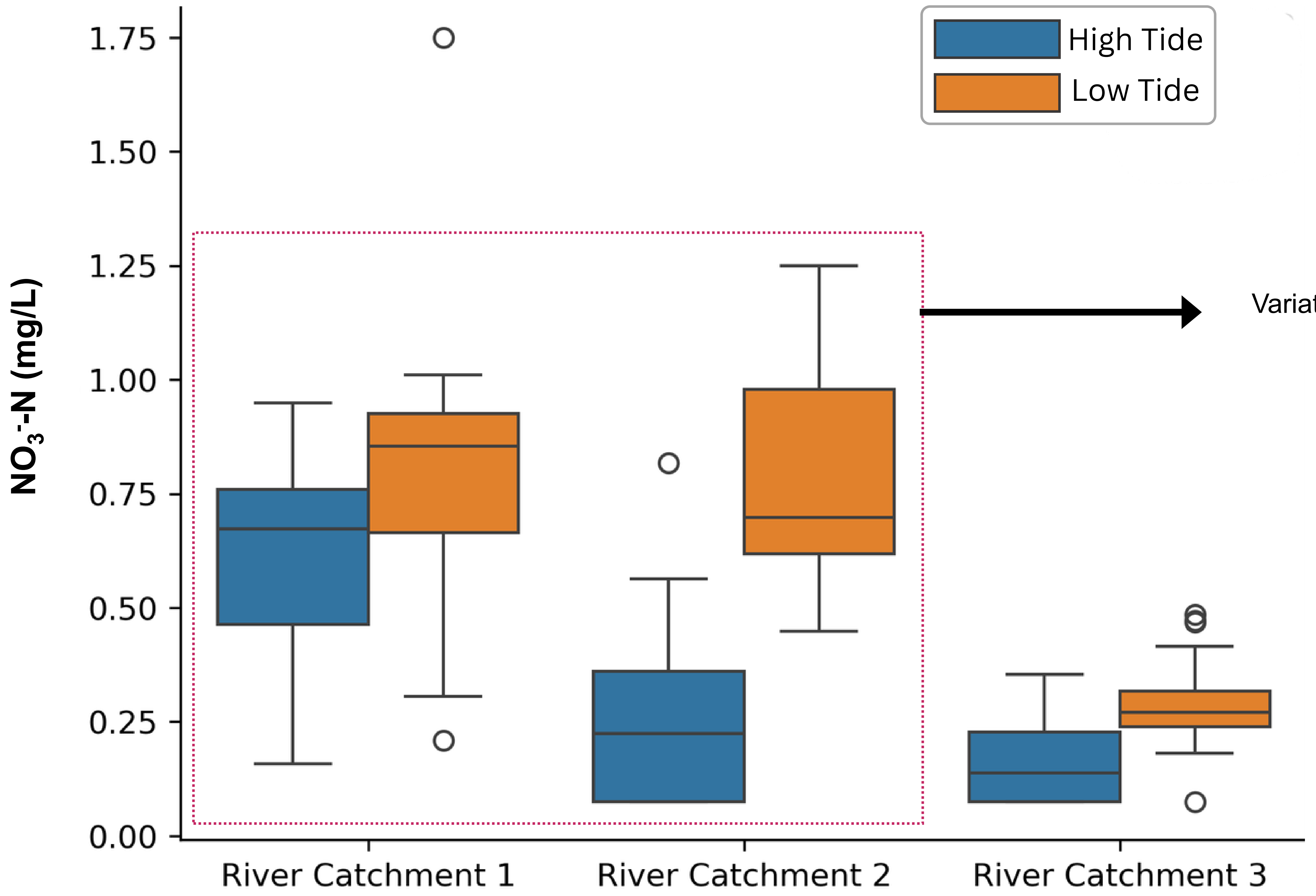
Results | Data Analysis | River Water



SO_4^{2-} variation is higher in river catchment 2
SO_4^{2-} concentrations are higher in low tide in river catchment 3 rather than river catchment 2 and 3

Fig. 7 SO_4^{2-} (mg/L) vs. three river catchments

Results | Data Analysis | River Water



Variation of NO_3^--N is higher in river catchment 1 and 2 compared to river catchment 3

Fig. 8 NO_3^--N (mg/L) vs. three river catchments

Results | Data Analysis | River Water

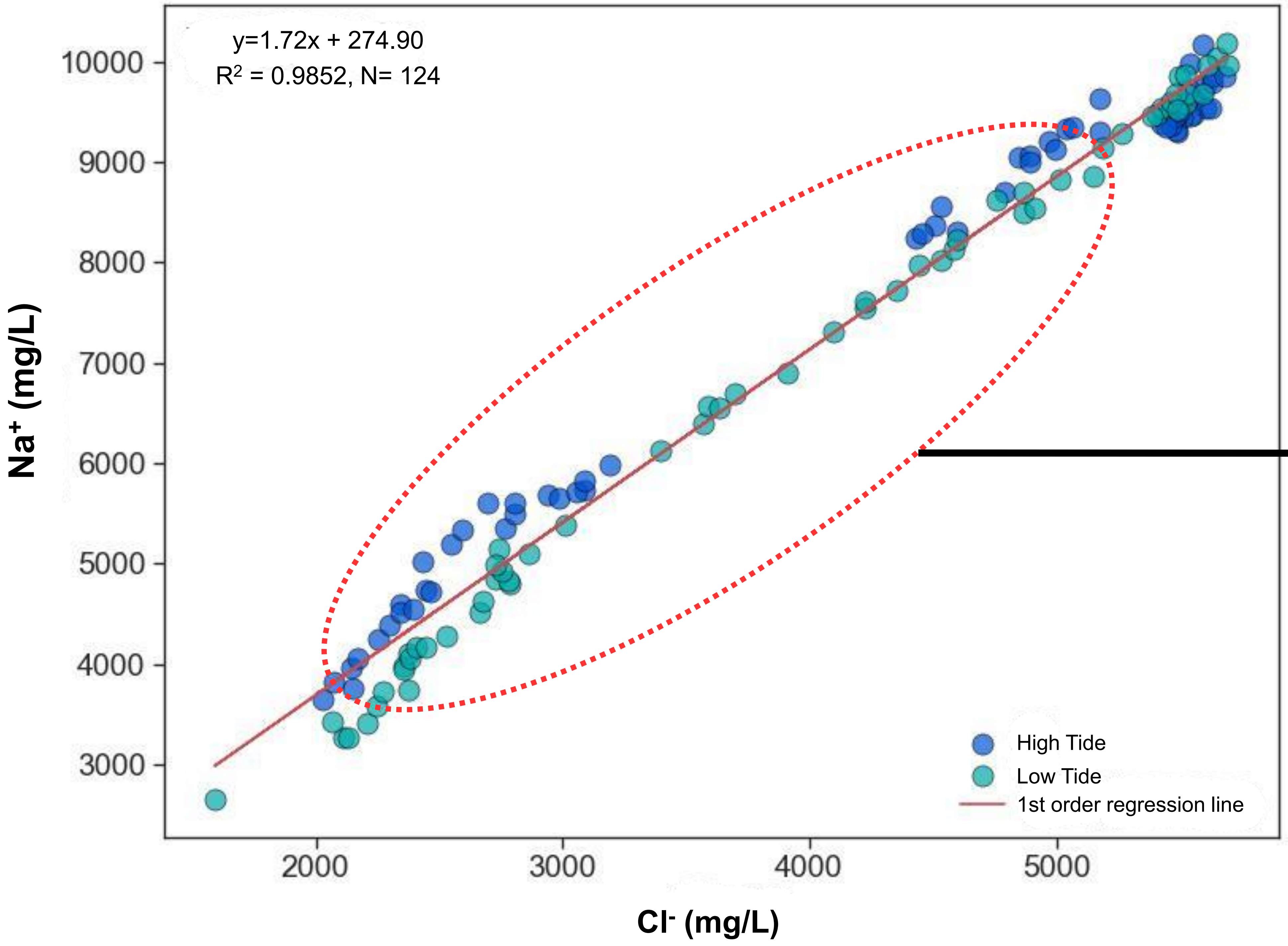


Fig. 9 Na^+(mg/L) vs. Cl^- (mg/L)

Na^+ and Cl^- dominance in coastal river water

Results | Data Analysis | Groundwater

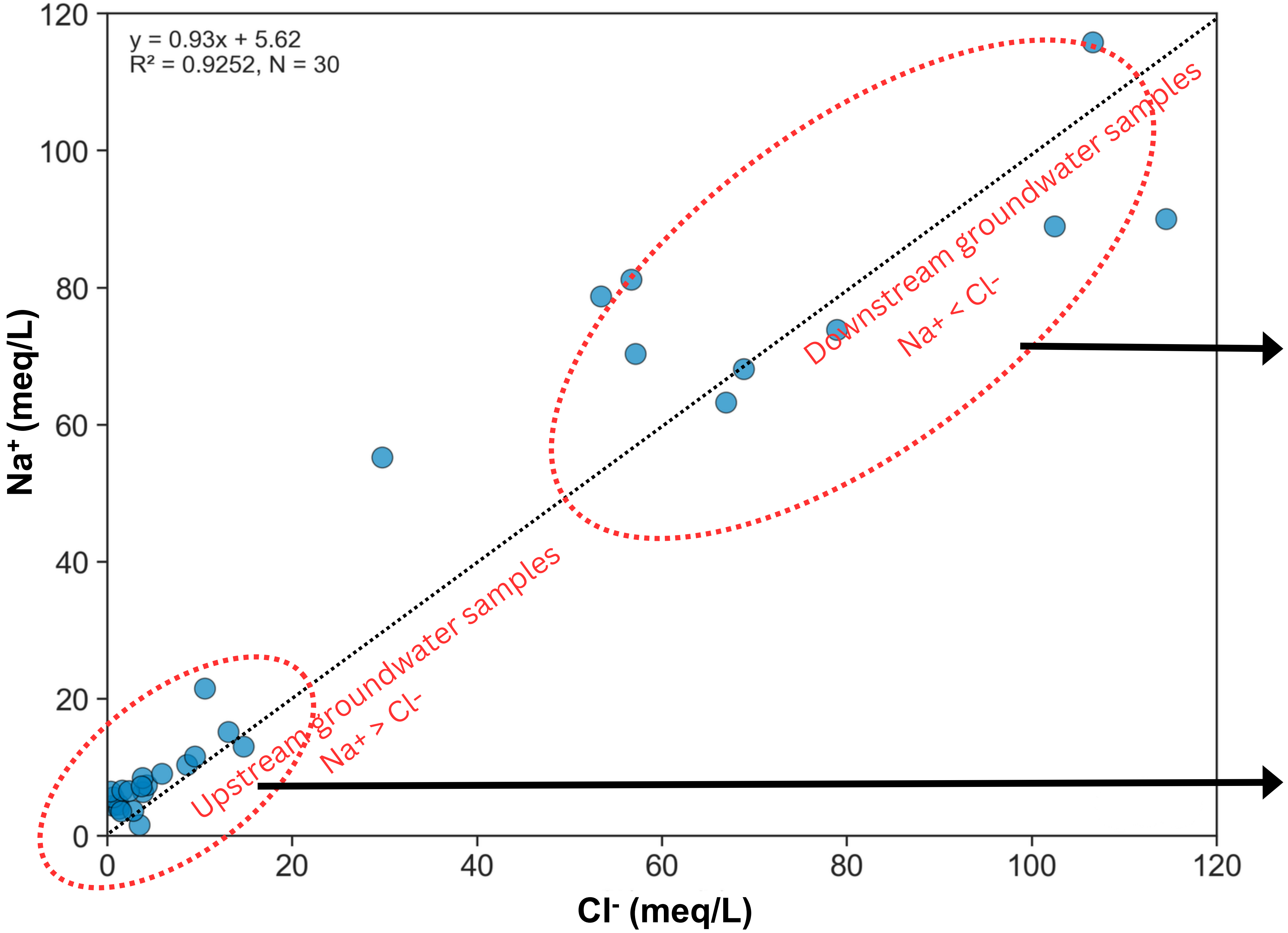


Fig. 10 Na^+ (meq/L) vs. Cl^- (meq/L)

$Na^+ < Cl^-$ indicates reverse softening, seawater influence in downstream groundwater

$Na^+ > Cl^-$ indicates natural softening, dissolution of albite-plagioclase and ion exchange signature in upstream groundwater

Results | Data Analysis | Groundwater

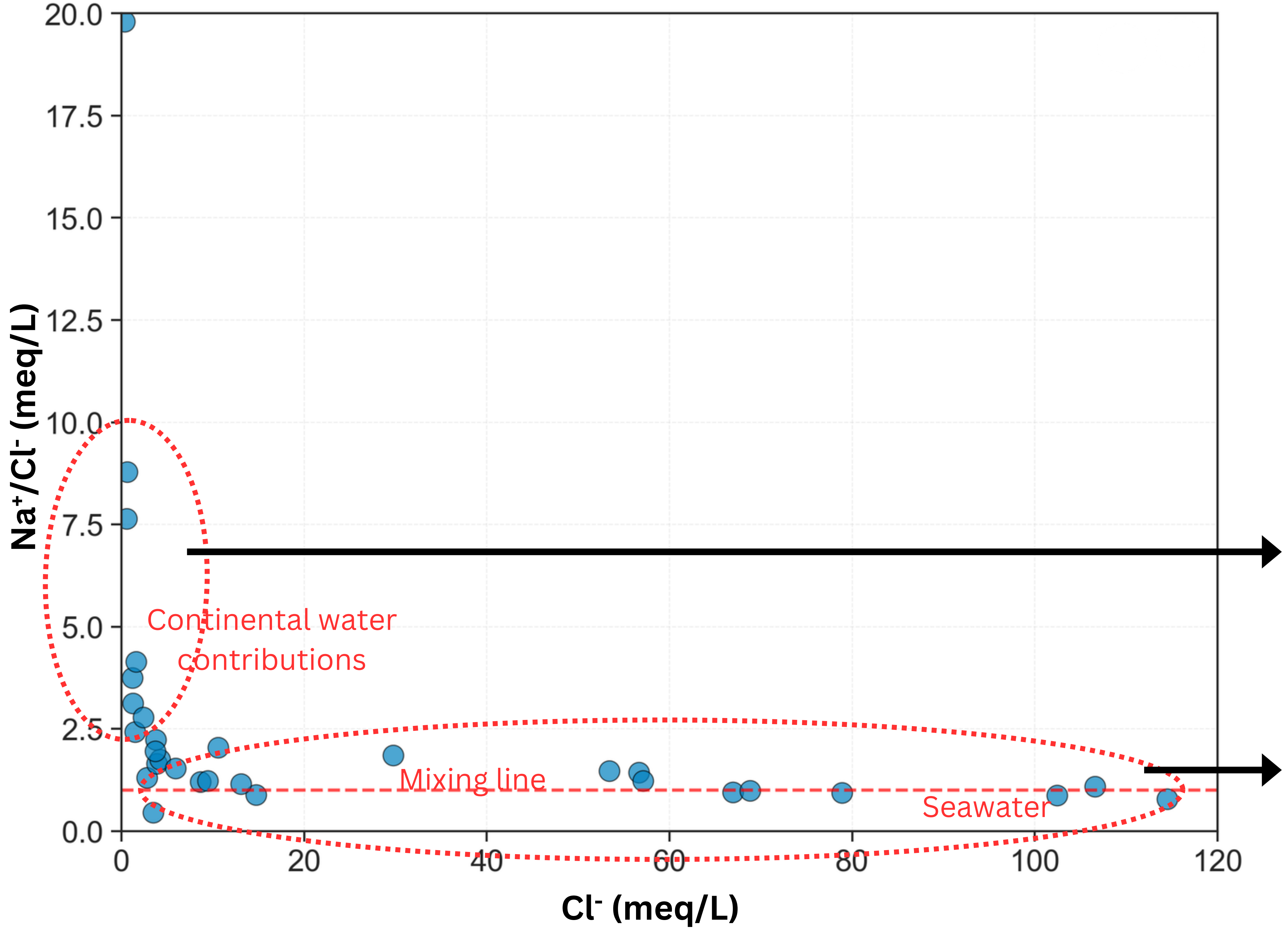


Fig. 11 Na⁺/Cl⁻ (meq/L) vs. Cl⁻ (meq/L)

Continental water contribution is higher in upstream groundwater samples

Downstream groundwater samples are influenced by seawater due to high Cl⁻ concentration

Results | Data Analysis | River and Groundwater

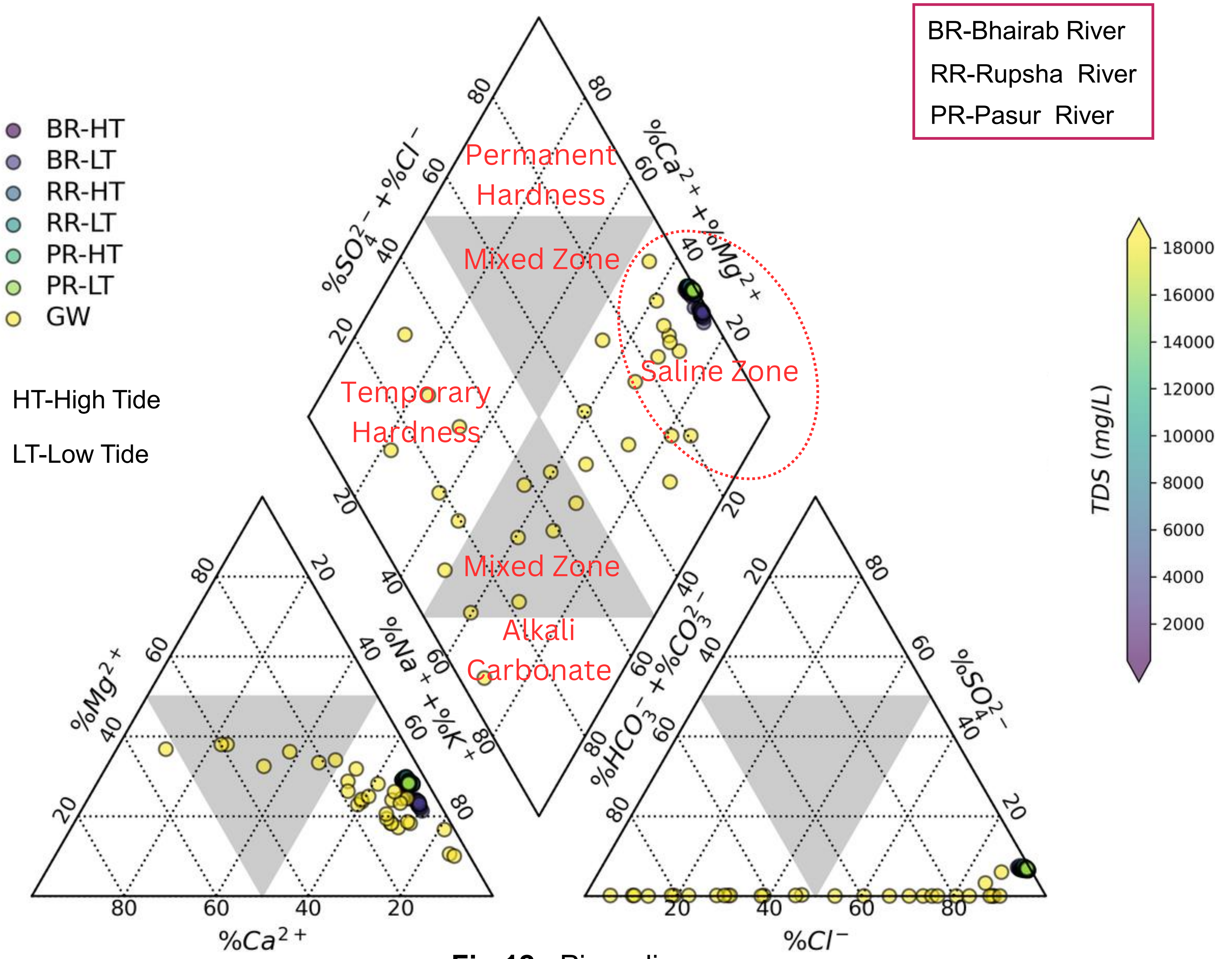


Fig.12a Piper diagram

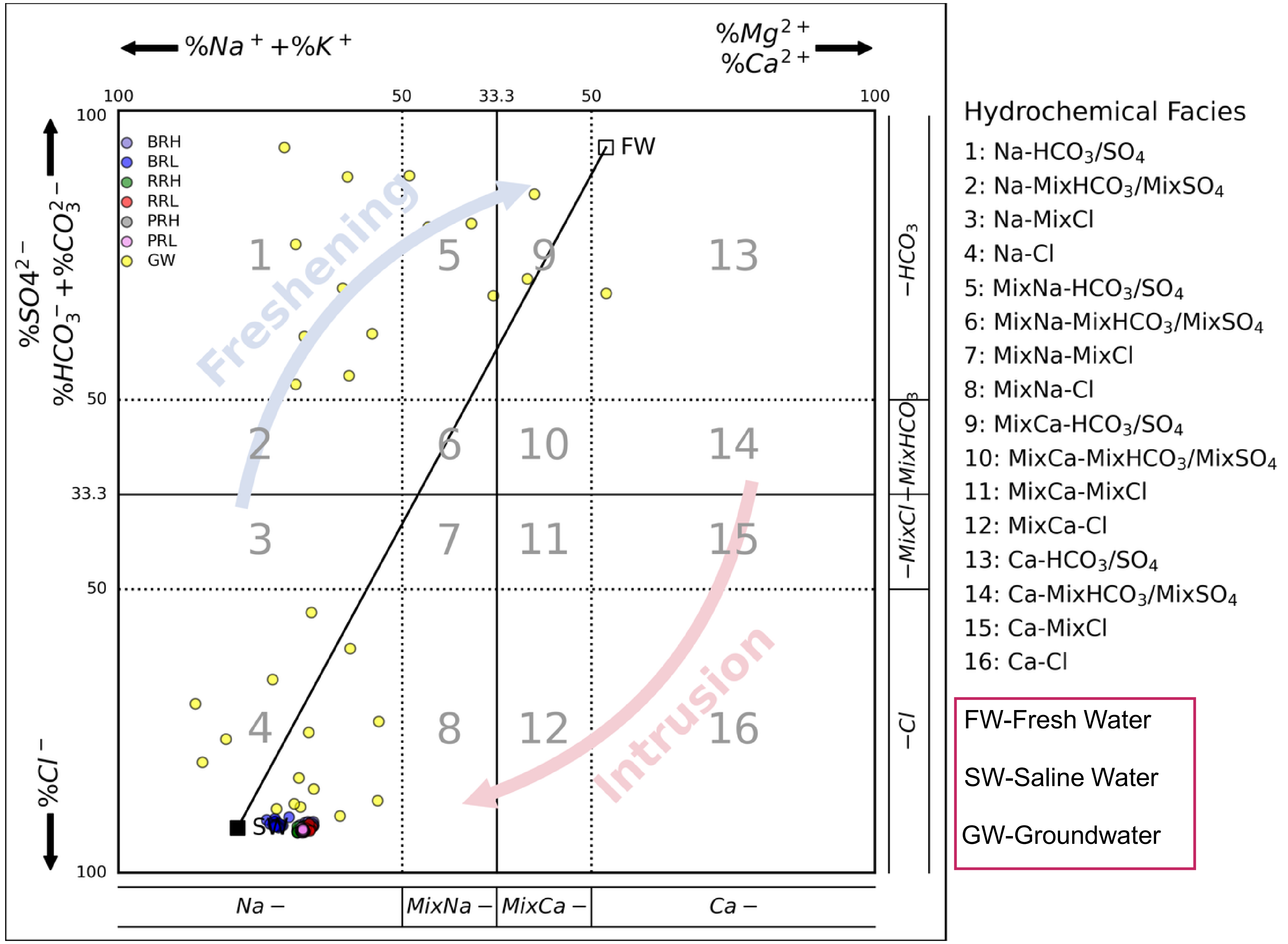


Fig.12b HFE-D diagram

Results | Data Analysis | River and Groundwater

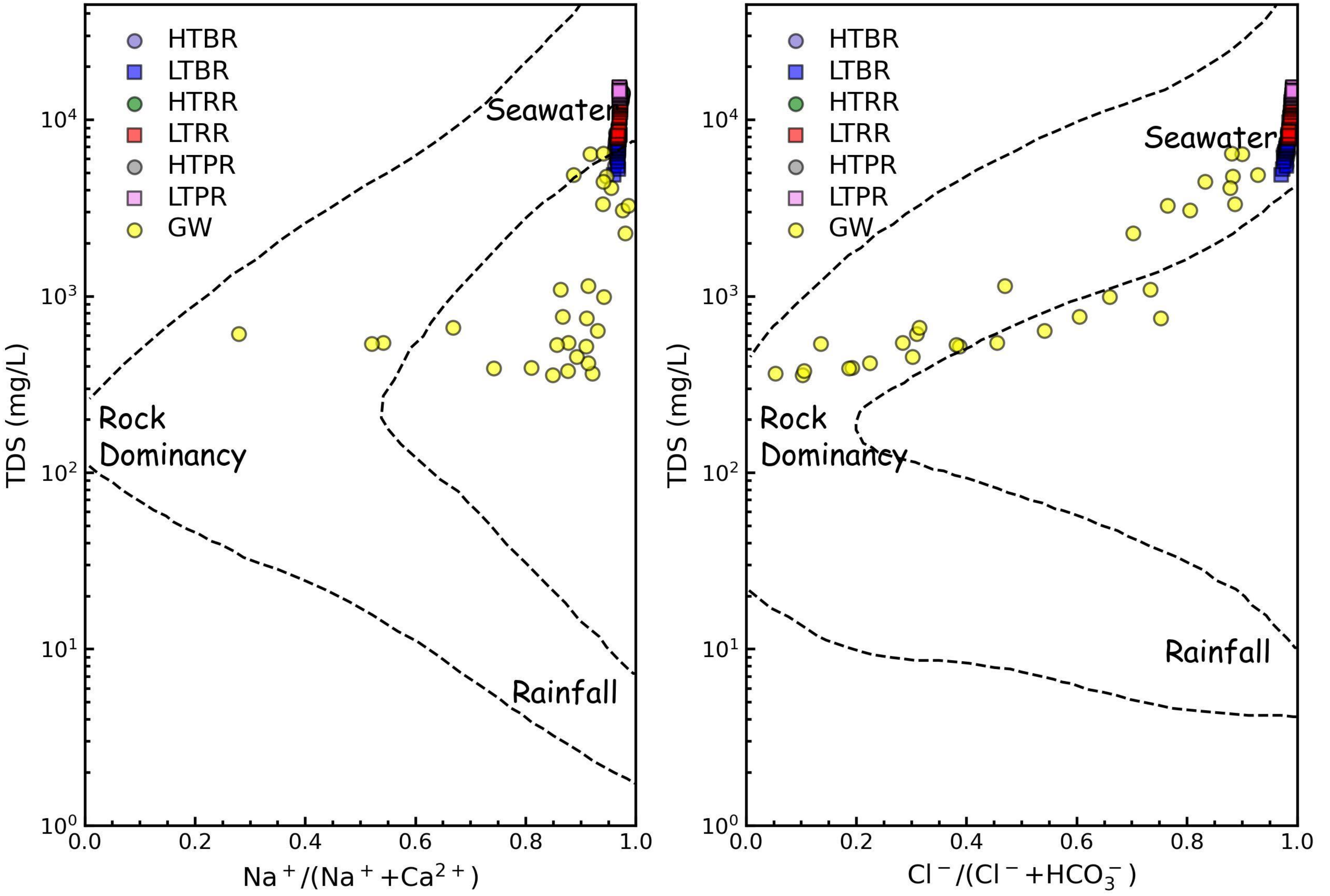
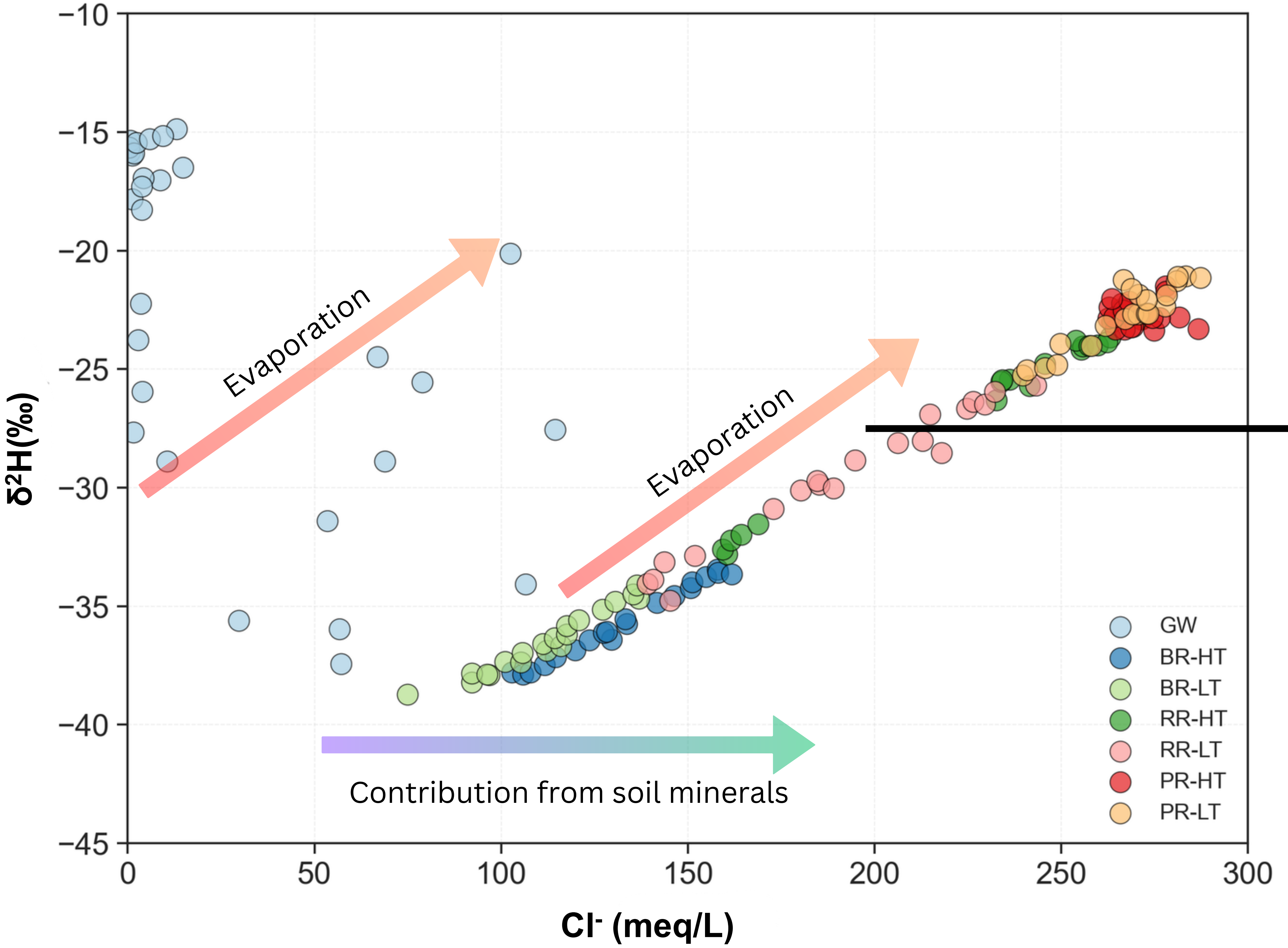


Fig.13 Gibbs diagram

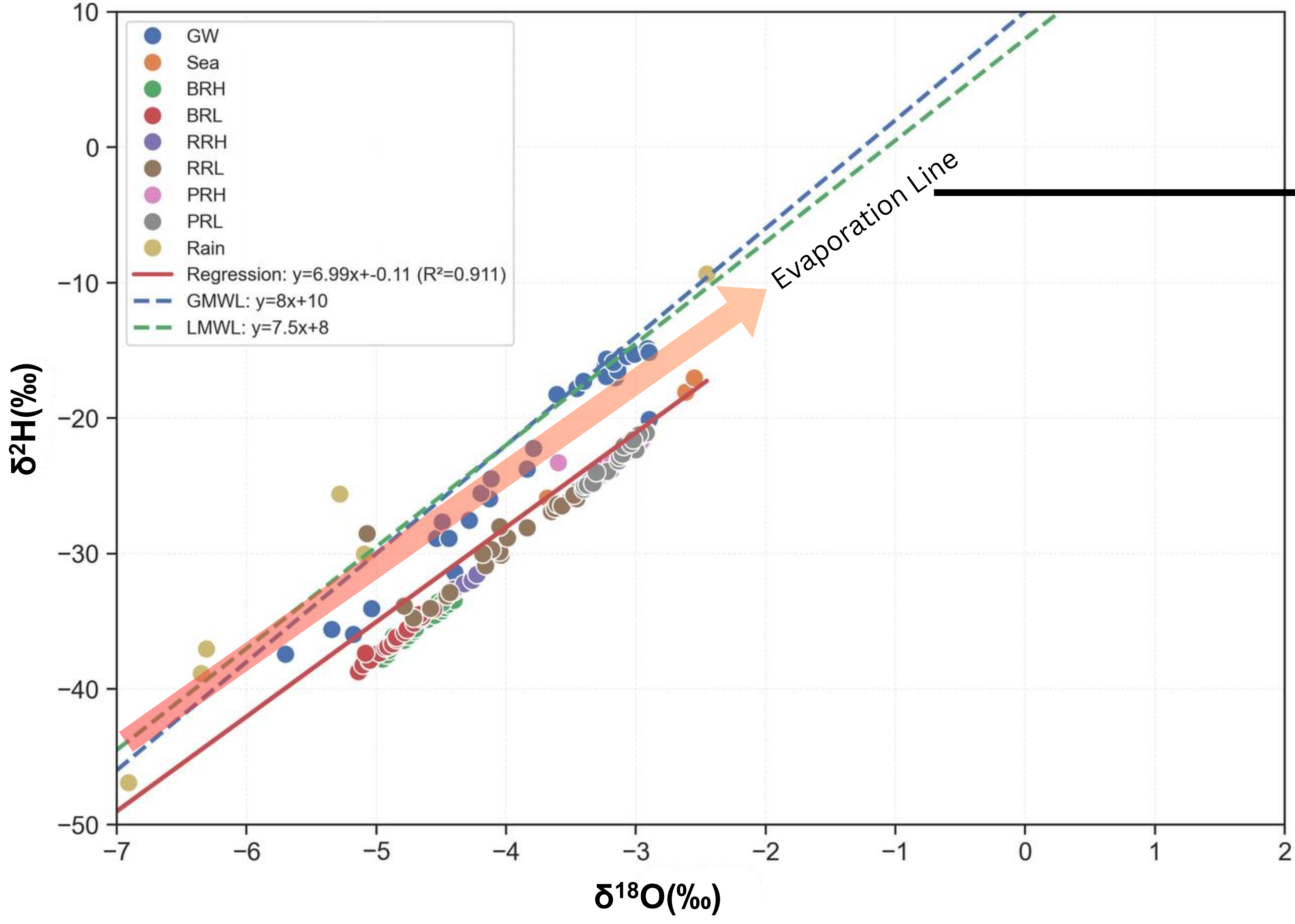
Results | Data Analysis | River and Groundwater



Increasing water salinity in hydrogeological processes indicates evaporation influence in water

Fig. 14 Hydrogeological processes of water salinity

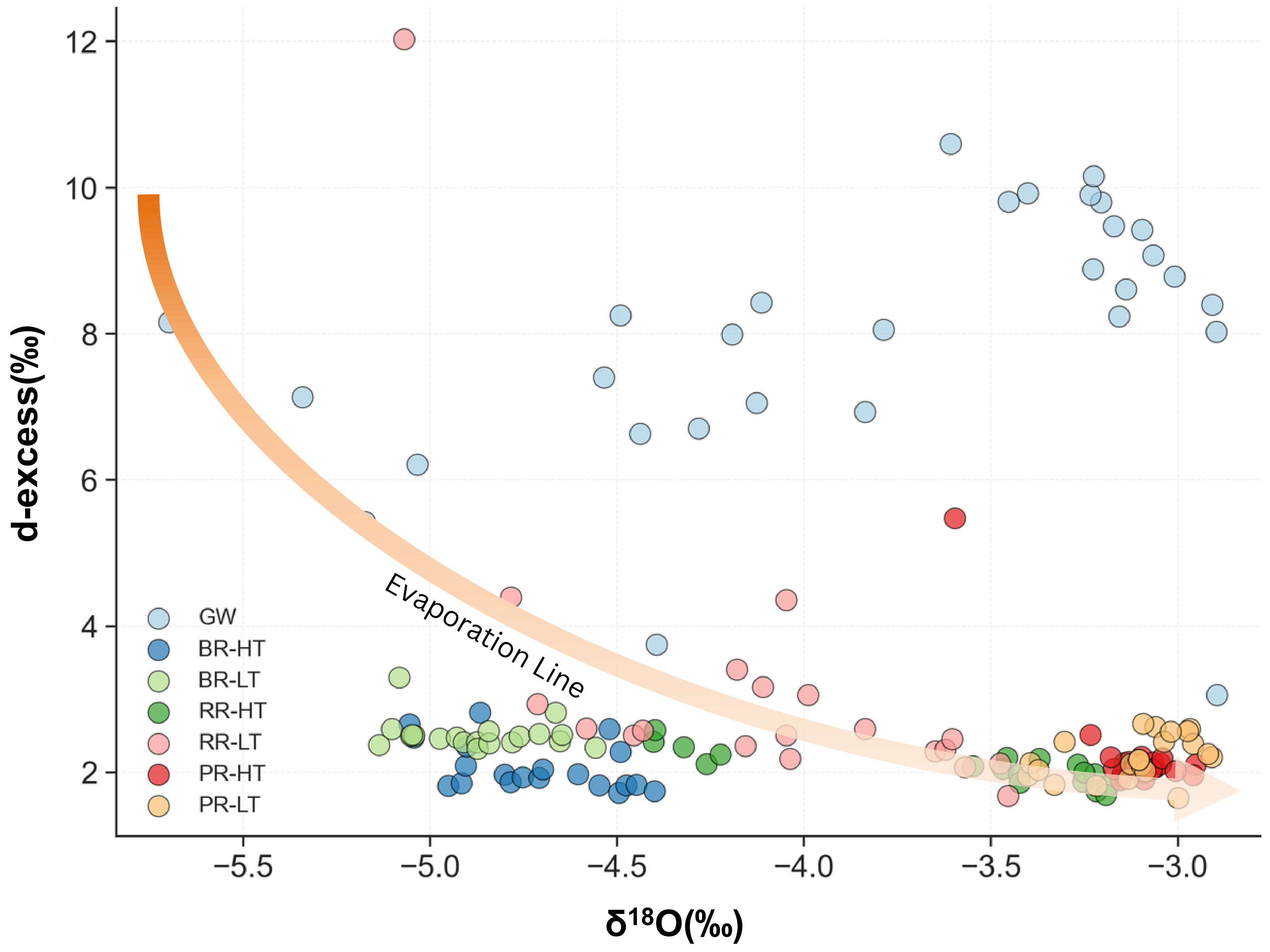
Results | Data Analysis | River and Groundwater



Evaporation influence in river and groundwater

Fig. 15 Evaporation trends of water salinity

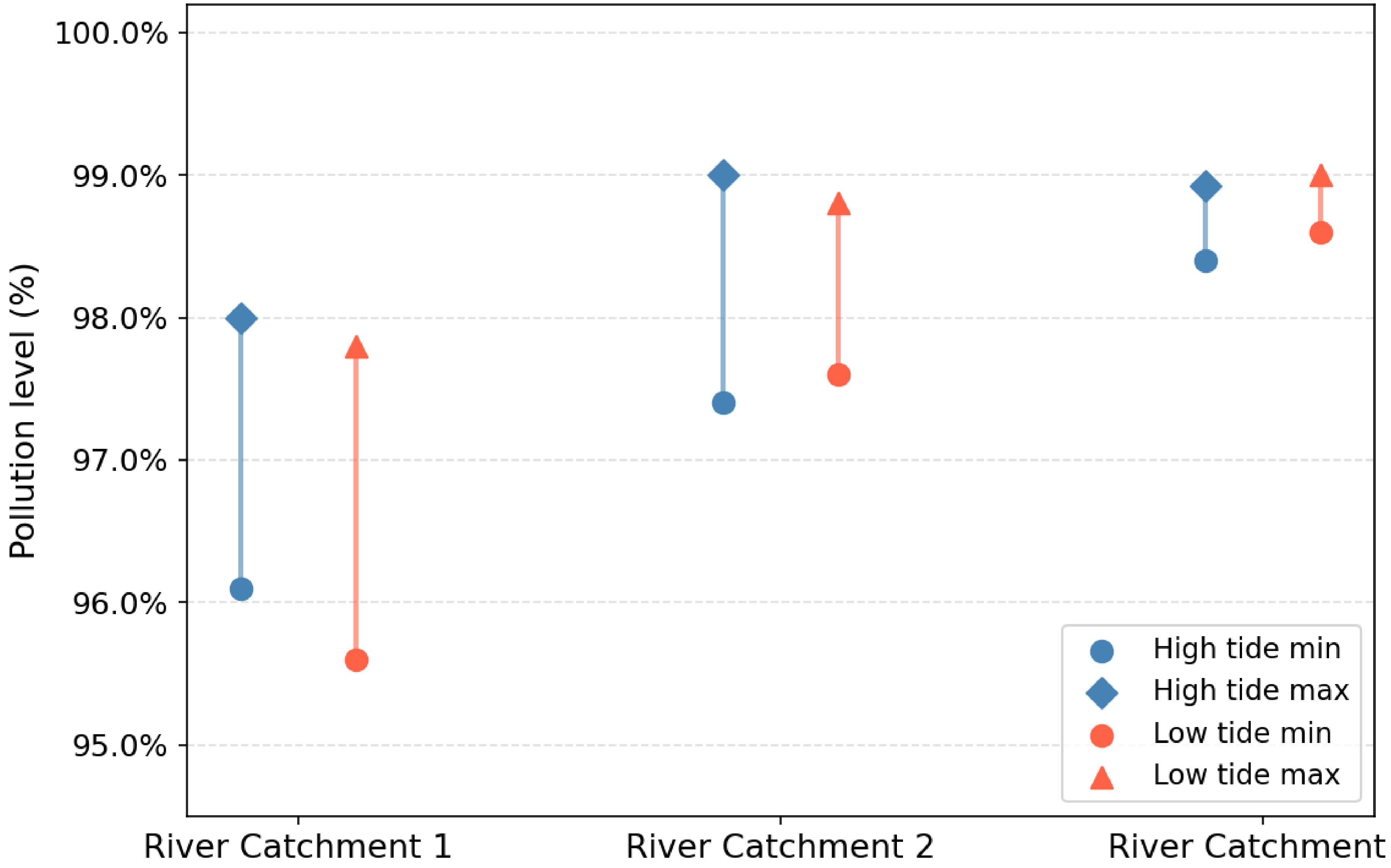
Results | Data Analysis | River and Groundwater



Lower deuterium (d) excess values indicate higher oxygen and evaporation influence in water

Fig. 16 Evaporation trends of water salinity

Results | Data Analysis | Pollution Status | All River Catchments



River Catchment 1	River Catchment 2	River Catchment 3
High Tide: 96.1 – 98.0%	High Tide: 97.4 – 99.0%	High Tide: 98.4 – 98.9%
Low Tide: 95.6 – 97.8%	Low Tide: 97.6 – 98.8%	Low Tide: 98.6 – 99.0%

Fig. 17 Pollution status of three river catchments

Results | Data Analysis | Water Quality Status | Groundwater

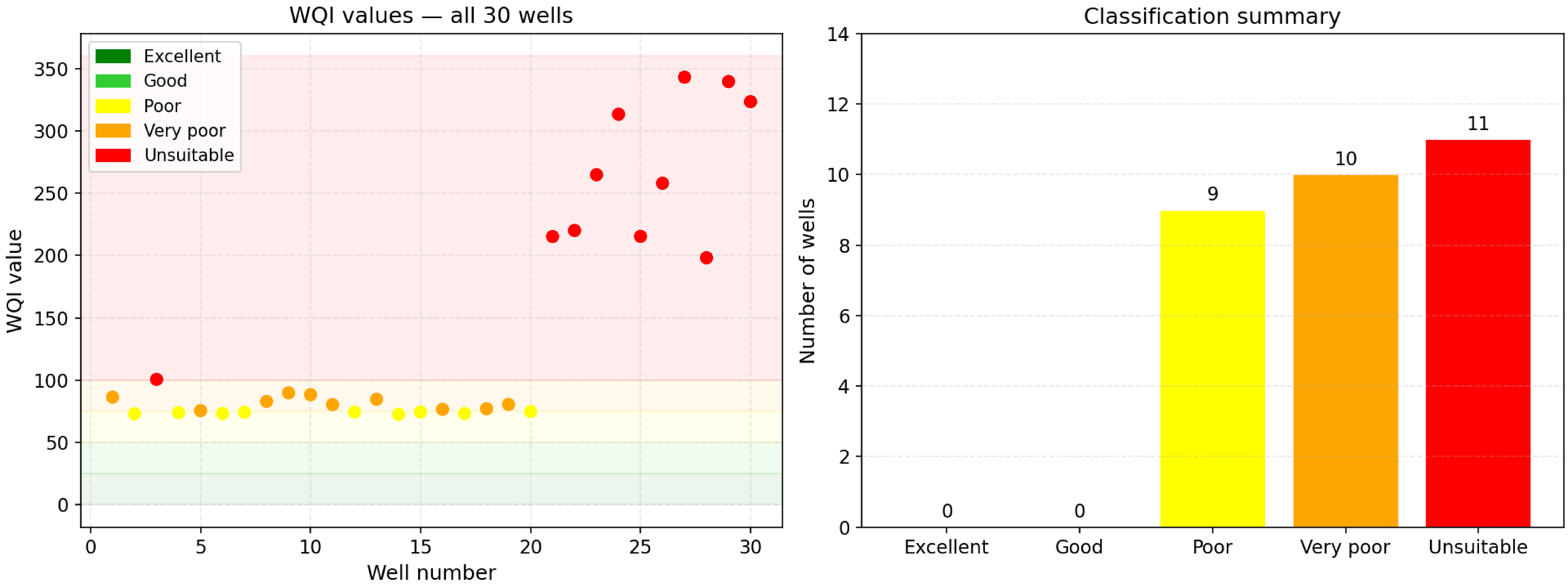


Fig. 18 Water quality status of coastal groundwater

Results | Data Analysis | Land Use/Land Cover Maps

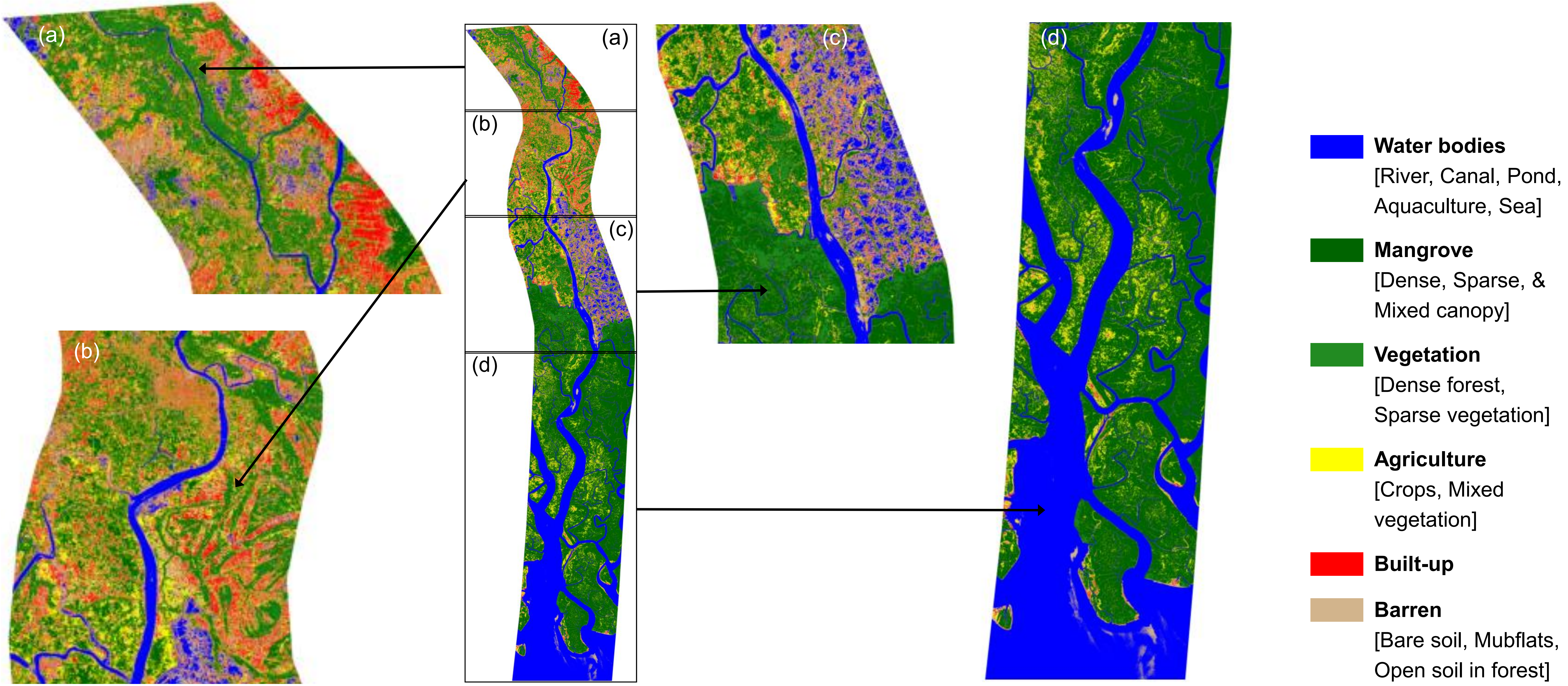


Fig. 19 Land use/Land cover maps (a) River catchment 1, (b) River catchment 2, (c) River catchment 3, and (d) Mangrove forest areas.

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Results | Data Analysis | Climate | River Catchment 1

Source: *Bangladesh Meteorological Department (BMD)*

Fig. 20 Annual rainfall (mm) and annual average temperature (deg.C) in river catchment 1

Results | Data Analysis | Climate | River Catchment 2

Source: *Bangladesh Meteorological Department (BMD)*

Fig. 21 Annual rainfall (mm) and annual average temperature (deg.C) in river catchment 2

Results | Data Analysis | Climate | River Catchment 3

Source: *Bangladesh Meteorological Department (BMD)*

Fig. 22 Annual rainfall (mm) and annual average temperature (deg.C) in river catchment 3

Conclusion

- Variation of selected ion concentrations is higher in river catchment 2, whereas NO_3^--N variation is higher in river catchments 1 and 2.
- River water in both high and low tide, and groundwater chemistry is dominated by Na^+ and Cl^-.
- Regression analysis illustrated significant positive relationship (r^2) between Na^+ and Cl^- in river ($r^2 = 0.99$) and groundwater ($r^2 = 0.93$).
- Groundwater salinity in the downstream is higher, a number of samples have a Na^+/Cl^- ratio lower than or close to 1, indicating mixing and seawater intrusion.
- A number of groundwater samples in the upstream area have a Na^+/Cl^- ratio greater than 1, indicating lesser influence of halite dissolution with lower Cl^- concentrations, and freshwater conditions.
- Increasing river and groundwater salinity in hydrogeological processes is mostly influenced by evaporation.
- Pollution levels are significantly increased across all river catchments, ranging from 96% to 99%.
- Groundwater quality status is predominantly classified as poor, very poor, and unsuitable for drinking and domestic purposes.