Hydrogeochemical evidence of seawater intrusion: a case study in Venice farmland Venice farmland

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Introduction

Seawater intrusion in the southern Venice Lagoon, Italy

- Land subsidence
  - ✓ Natural geological subsidence
  - ✓ Groundwater and gas withdrawal
  - ✓ Land sinking driven by peat oxidation
  - ✓ Sea level rise
- Seawater encroachment into the river mouth
- Sandy paleochannels ⟶ Hydraulic connection with seawater
- Presence of brine waters

Objectives

1. Identify the salinization sources of an agricultural field located right south the Venice Lagoon

2. Identify the interaction between salt-water and soil

HOW?

- Analyzing soil and groundwater chemical characteristics using statistical tools

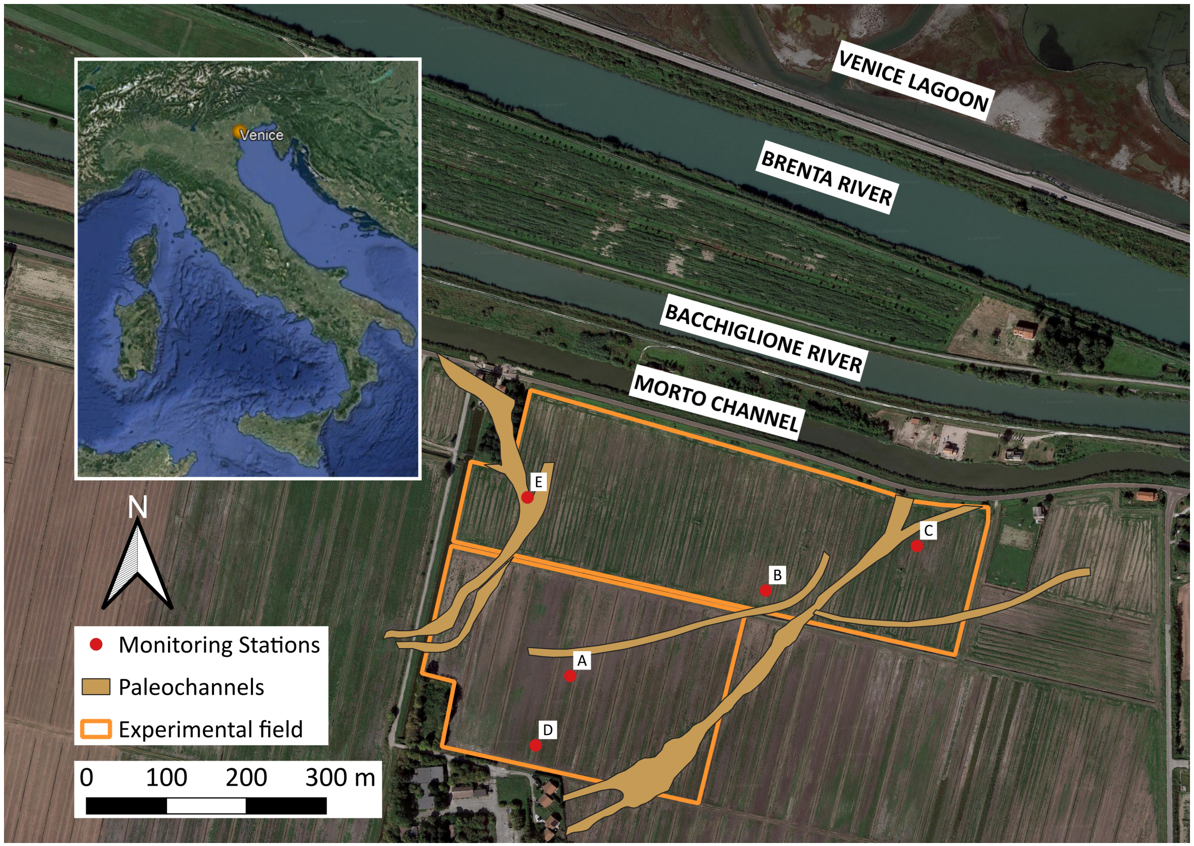
- Using ionic ratios to identify the origin of salinization

  ✓ Applicability on groundwater
  ✓ Applicability on soil water

- Analyzing soil water movement direction in relation with ion concentrations

Experimental Site

21 ha field located in Chioggia, Venice, Italy



- **Altitude**: -1.5 to -3.3 m below the mean sea level
- **Soil**: mainly silt-clay with the presence of acidic peat and sandy paleochannels
- **Saltwater contamination** down to about 20 m depth
- **Crop**: rainfed maize
- **Monitoring network**: 5 stations

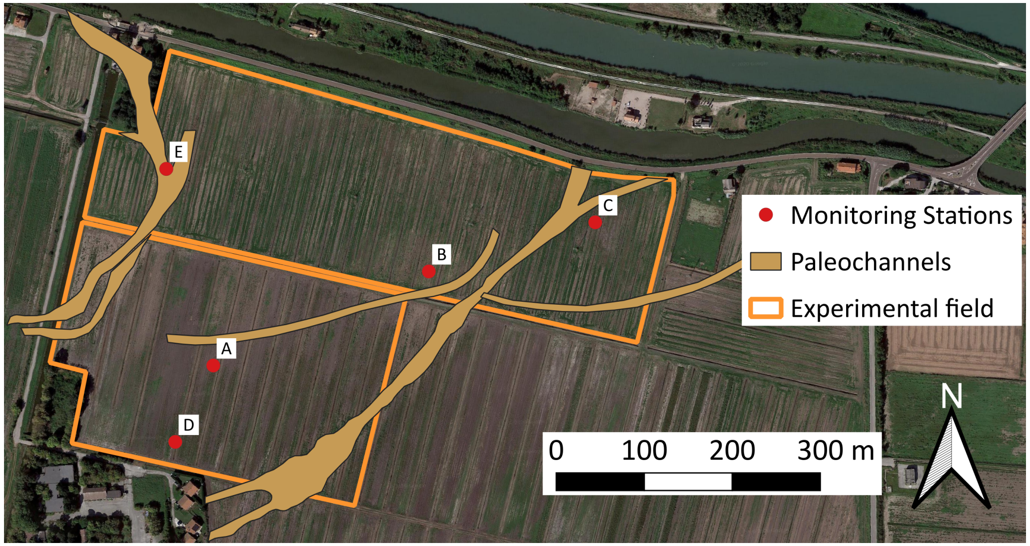
Materials and methods

Monitoring network

Study period: 2010, 2011, 2012

5 monitoring stations (A, B, C, D, E)

Each one equipped with:



- 4 5Te **soil moisture, temperature and electrical conductivity sensors** (0.1, 0.3, 0.5 and 0.7 m deep) connected to an EM50 datalogger (METER Group Inc. USA)
- 4 T8 **tensiometers** (0.1, 0.3, 0.5 and 0.7 m deep) connected to a DL6-TE datalogger (METER Group Inc. USA)
- 4 SK20 **micro-lysimeters** (0.1, 0.3, 0.5 and 0.7 m deep) (METER Group Inc. USA)
- 1 **piezometer** 2 m

Materials and methods

Soil sampling and analysis

Soil samples were collected at 4 depths per each station: 0-0.15, 0.15-0.45, 0.45-0.8 m and analyzed for

- Texture
- pH
- Electrical conductivity (EC)
- Total and organic carbon
- Total nitrogen
- Total sulfur
- Exchangeable cations (Mg^{2+}, K^+, Na^+, Ca^{2+})

Groundwater and soil water analysis

- pH
- electrical conductivity (EC)
- ionic concentrations: Cl^-, Br^-, Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}, K^+

Results

Water table depth and soil analysis

		A	B	C	D	E
Depth below the land surface	Max	0.94	1.29	0.67	1.04	1.50
	Min	0.56	0.96	0.46	0.65	1.17
	Average	0.74	1.14	0.53	0.82	1.43
Depth below the msl	Max	-3.97	-3.21	-2.73	-3.72	-3.05
	Min	-3.59	-3.54	-2.94	-4.11	-3.38
	Average	-3.77	-3.39	-2.80	-3.89	-3.31

Minimum, maximum and average value of **WATER TABLE DEPTH** [m]

Soil characteristics averaged per each monitoring station

Station	Sand	Silt	Clay	pH1:2	EC1:2	SOC	$CaCO_3^-$	Mg^{2+}	Na^+	Ca^{2+}	K^+	BD
	---------------- %	-----------------			$dS\ m^{-1}$	%	-----------------------------	meq $100g^{-1}$	-----------------------------			$g\ cm^{-3}$
A	33.21	44.52	19.96	5.53	0.57	11.45	4.33	4.55	0.27	10.87	0.24	0.93
B	64.39	27.42	8.18	7.39	0.31	4.77	10.17	2.16	0.16	9.78	0.15	1.1
C	34.75	45.54	19.71	7.22	2.08	11.02	10.64	3.19	1.64	15.87	0.29	0.65
D	40.76	43.77	15.47	5.91	1.07	20.95	1.9	5.13	4.36	12.58	0.19	0.75
E	69.42	20.87	10.72	7.76	0.22	10.68	26.75	0.62	0.09	8.23	0.07	1.47

Results

Soil water and groundwater chemical properties

	Station	n	Max	Min	Median	Mean	STDEV
EC dS m^{-1}	A	65	17.08	0.59	6.53	6.59	4.24
	B	74	11.66	0.56	2.67	3.45	2.43
	C	81	29.90	1.58	11.41	11.29	5.22
	D	43	10.65	1.54	3.38	4.59	2.32
	E	22	2.80	0.33	1.73	1.66	0.73
Cl^- mg l^{-1}	A	65	5075.54	17.09	603.3	1013.77	1074.08
	B	64	2953.01	5.94	29.57	407.34	675.24
	C	73	9227.32	132.68	2353.69	2476.03	1592.2
	D	41	2422.65	18.99	108.07	545.55	662.36
	E	22	470.00	28.89	140.87	157.24	113.19

Statistical summary of EC and Cl- concentration at the 5 monitoring stations

	EC	Cl^-	Na^+	SO_4^{2-}	Mg^{2+}	Ca^{2+}	K^+	Br^-
EC	1	0.92**	0.91**	0.24	0.57**	-0.22*	0.79**	0.54*
Cl^-	0.89**	1	0.96**	0.19	0.55**	-0.17	0.83**	0.68**
Na^+	0.91**	0.94**	1	-0.02	0.52**	-0.32*	0.91**	0.68**
SO_4^-	0.43*	0.4*	0.33*	1	0.48*	0.53*	-0.09	0
Mg^{2+}	0.72**	0.75**	0.78**	0.61**	1	0.41**	0.62**	0.37*
Ca^{2+}	0.31**	0.35**	0.28*	0.53**	0.65**	1	-0.17	-0.17
K^+	0.78**	0.85**	0.92**	0.28*	0.74**	0.23*	1	0.63**
Br^-	0.79**	0.87**	0.89**	-0.06	0.68**	0.25	0.83**	1

R^2 values from **regression analysis** between EC and ionic concentrations
** $p<0.0001$
* $0.0001<p<0.05$

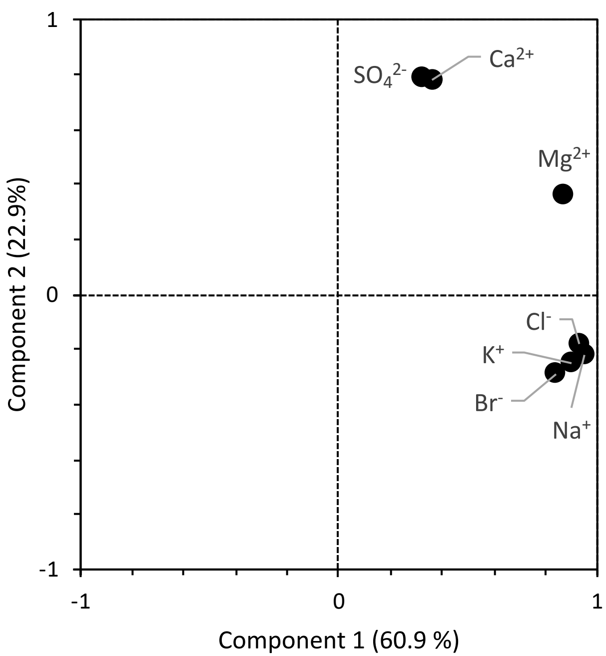
groundwater
soil water

Results

Statistical analysis

Principal component analysis PCA

84 % of the total variability was explained by 2 principal components



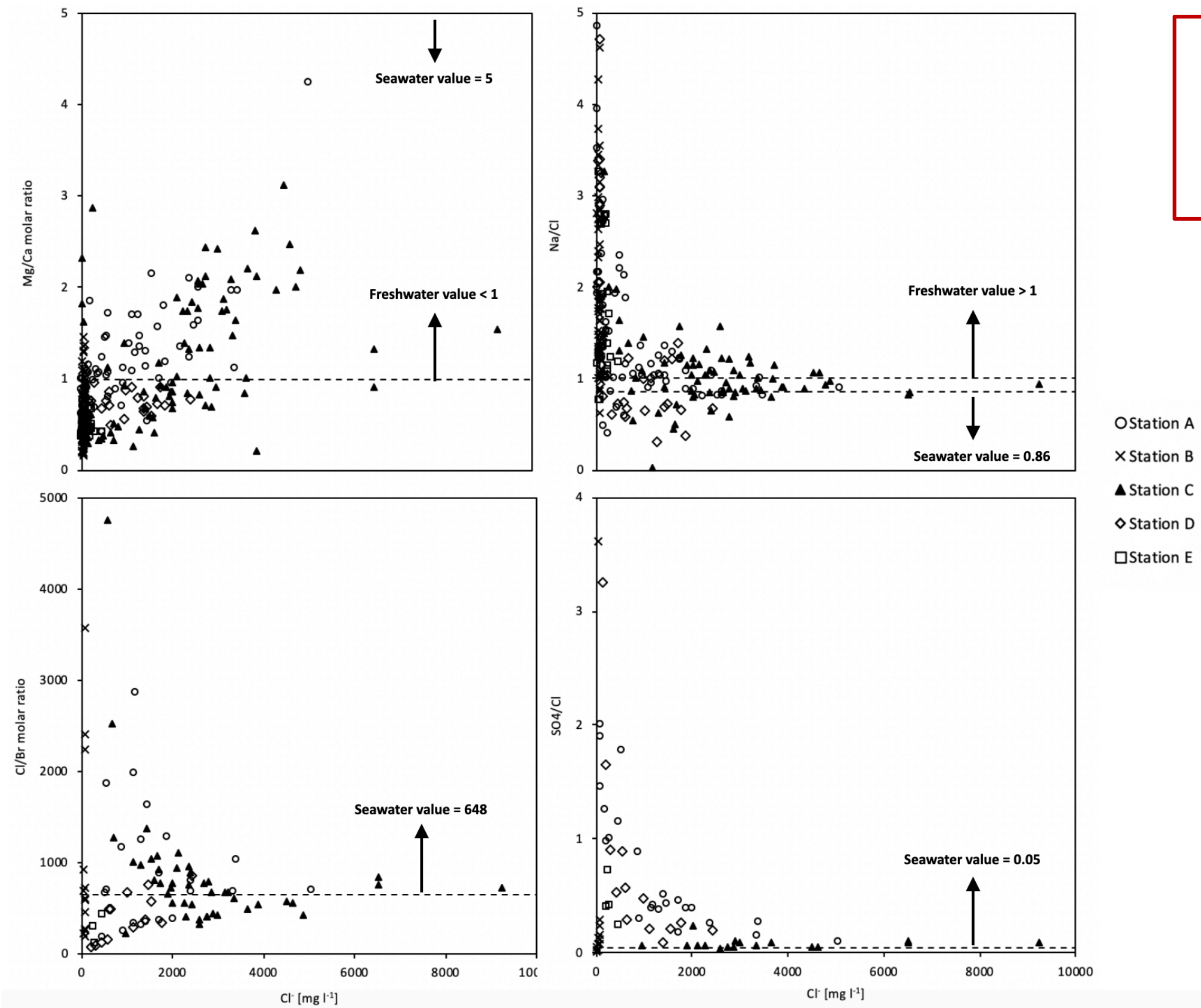
Kruskal Wallis test

Effect of the monitoring stations on water chemical properties

	p value
EC	<0.0001
Cl^-	<0.0001
Br^-	0.0269
SO_4^{2-}	0.0003
Na^+	<0.0001
K^+	<0.0001
Mg^{2+}	<0.0001
Ca^{2+}	<0.0001

$p<0.01$ indicates differences among the monitoring stations

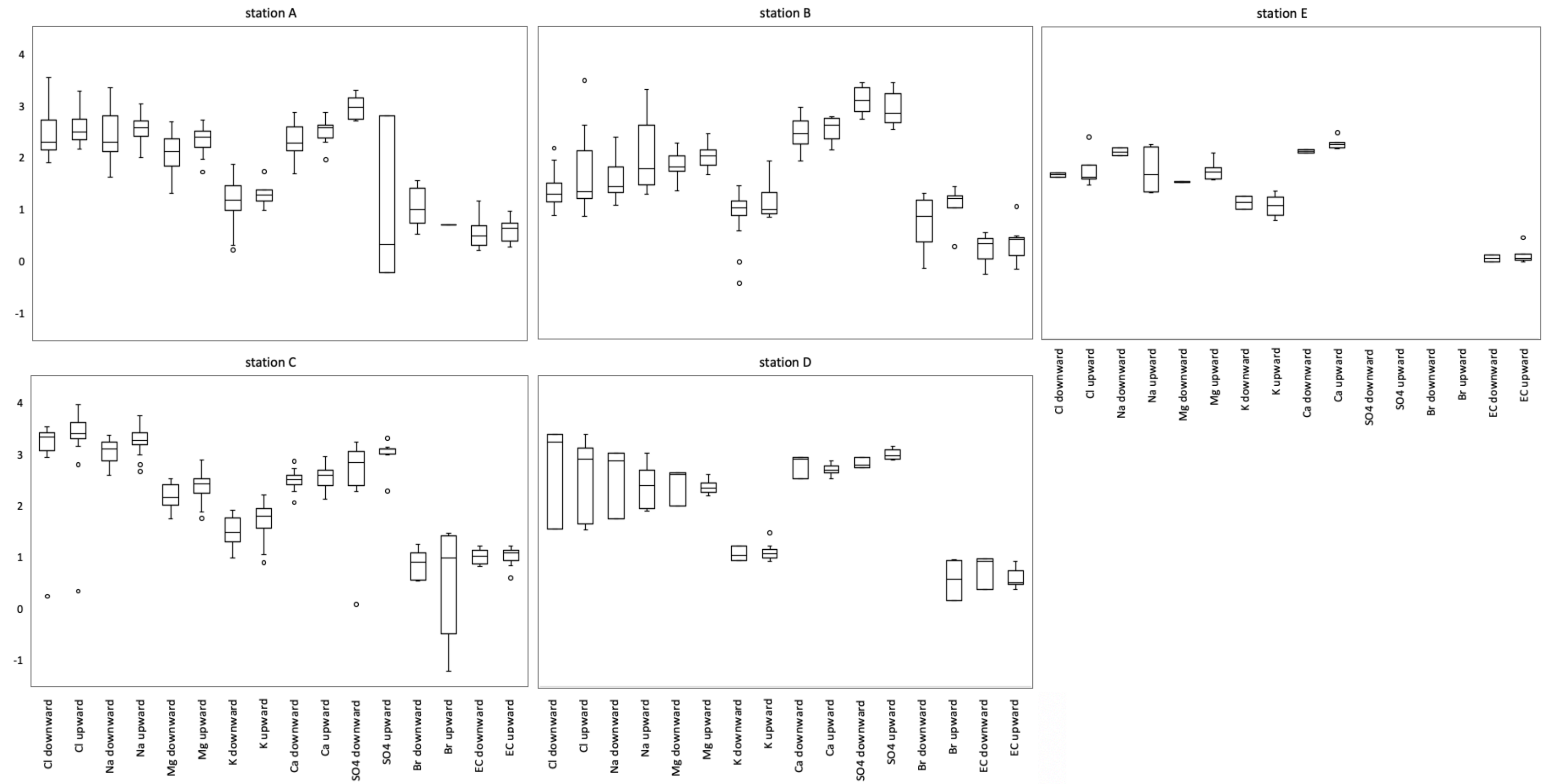
Results



Molar ratios
as function of Cl^-
concentration

Results

Ion movement along the soil profile



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