ISSUES RELATED TO SANITARY SEAWATER QUALITY MONITORING IN THE IMPACT ZONE OF COASTAL KARST SPRINGS – EXAMPLE FROM RIJEKA BAY

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Study area and problem framework

Data and methods of seawater quality analysis

Methodology of analysis/modelling of bacteriological pollution of the sea

Results and discussion

Conclusions

INTRODUCTION

Reason

The reason why seawater quality is discussed at a carstological conference is the fact that the coastal sea and its karst hinterland are in urban areas interrelated with a number of natural and anthropogenic processes

.

Sea water quality

largely depends on the dynamics of interactions of such processes (Elliott et al., 2014)

Monitoring

Based on an example of occasional loads of microbiological sea pollution on the selected beaches in the western part of the town of Rijeka, the paper discusses the monitoring-related problems and the possibilities for improvement

- Not only for status assessment
- Modelling as well→ real-time forecasting of seawater quality

For modelling purposes, the machine learning models or artificial intelligence (AI) methods were used

INTRODUCTION

TIME GAP

The main problem of the existing beach seawater quality monitoring is the fact that the information on quality becomes available only after the pollution has been detected, including a period of an analytical procedure which, according to the official reference methods, takes about two days in Croatia

- In that way, management measures including a bathing prohibition, can be taken only once the period required for the laboratory analysis of samples has passed

- This leads to a situation that a bathing prohibition is not imposed at a time when the beach water is polluted, but at a time when the pollution has most often already been eliminated

- This ***TIME GAP*** represents a potential ***HEALTH RISK*** for beach users

AIMS:

- to identify the pattern of occasional deterioration of microbiological status of seawater quality
- the impact of coastal springs on such changes
- the possibility of foreseeing such statuses

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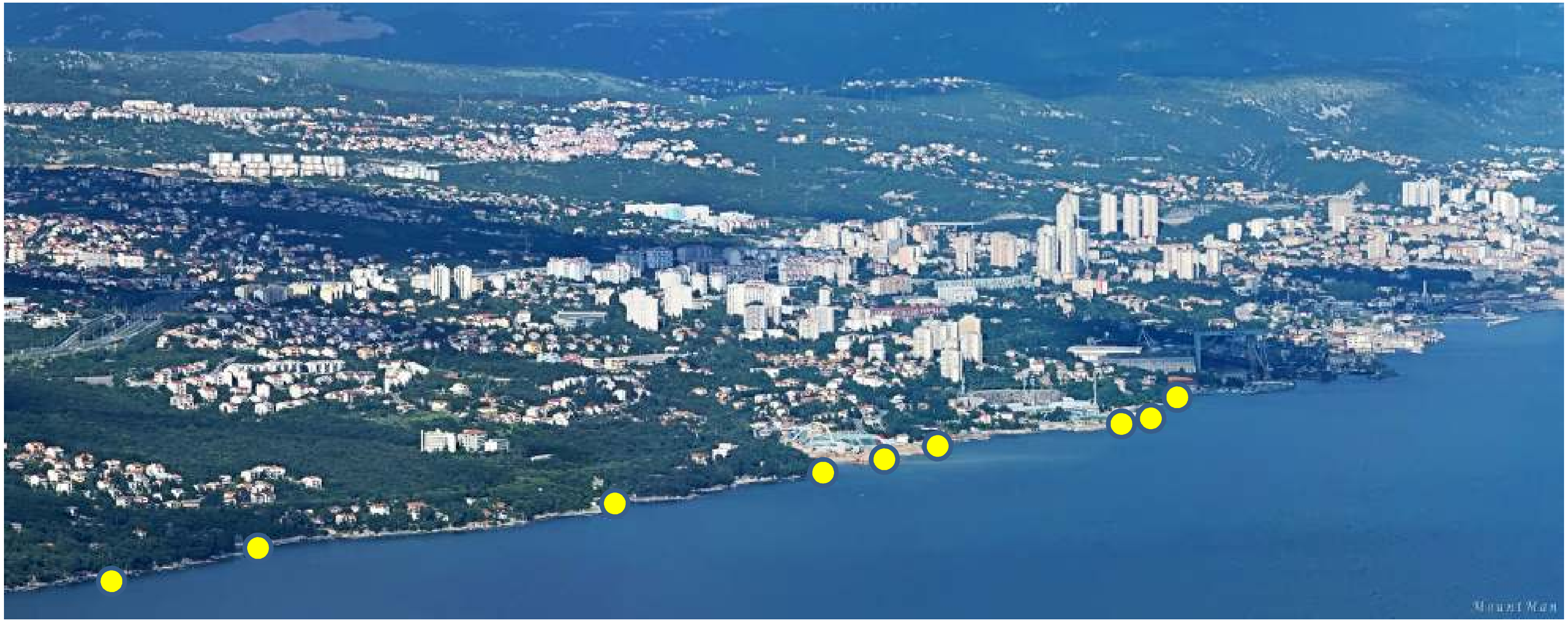
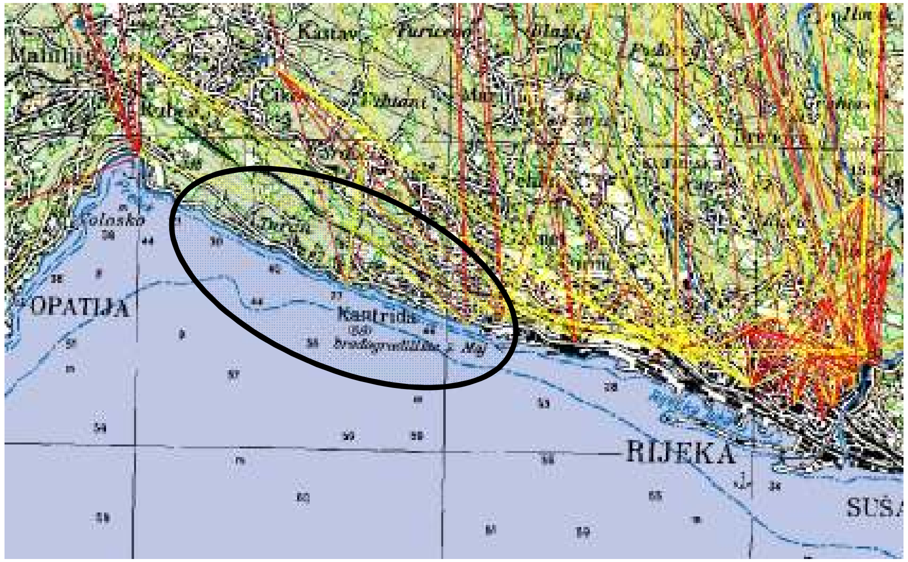
Study area and problem framework



Rijeka → industrial port & town with 150,000 inh.
Western part of Rijeka → 9 analysed seawater quality monitoring points

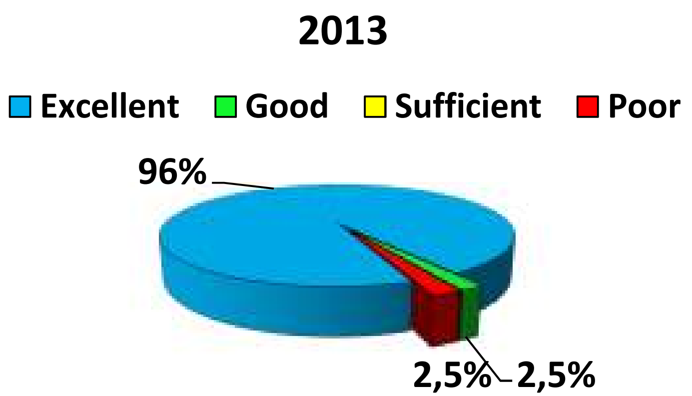
Study area and problem framework

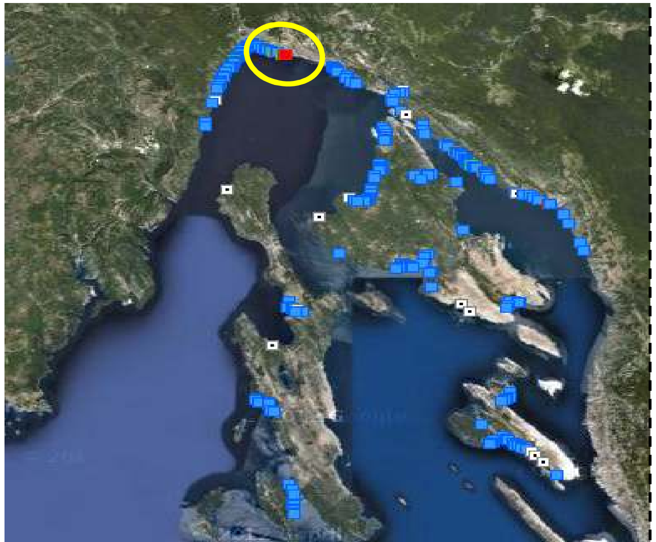


Results of groundwater tracing

Karst region with very significant rainfall in the hinterland (average annual rainfall from 1600 mm in the coastal zone to > 3000 mm)
A very large number of coastal springs and submarine springs → **7** of which lie in the analysed study area

Study area and problem framework





County map with an overview of final assessment (2010 - 2013)

- **SAMPLING FREQUENCY:**
  - twice a month
  - from mid-May to the end of September
- **PARAMETERS:**
  - includes basic physical-chemical and bacteriological characteristics of seawater
  - bacteriological parameters - the most significant indicators of pollution of the sea with sanitary wastewater
- **PERIOD OF STUDY:**
  - 2009-2013
  - during which extreme bacteriological pollution occurred twice in 2011
- **BATHING PROHIBITION**
  - by a decision of the inspection
  - measures were established on one beach, lasting for 22 days

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Data and methods of seawater quality analysis

Seawater quality on the beaches of the Croatian part of the Adriatic Sea is monitored according to the Regulation on sea bathing water quality (OG 73/08, 2008), which is harmonized with the Directive 2006/7/EC (2006)

Laboratory analyses of samples include identification of the microbiological indicators of sea pollution, intestinal enterococci (**EN**) and *Escherichia coli* (**EC**)

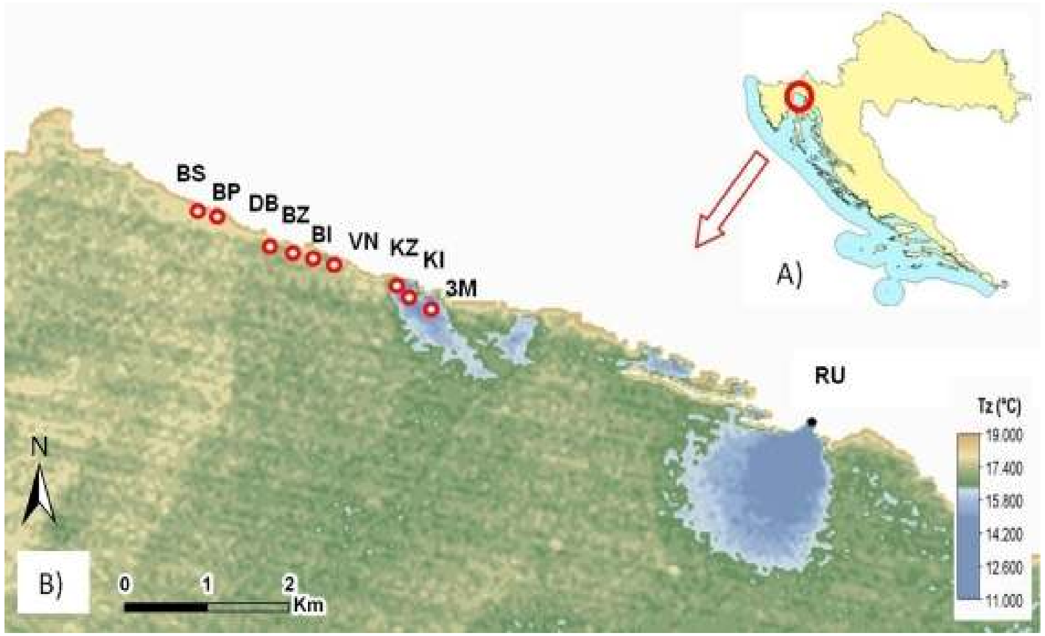
Bacteriological analyzes were performed by membrane filtration technique

Isolation and identification of EN was done using the HRN EN ISO 7899-2:2000 method (2000), and for EC, a Rapid test HRN EN ISO 9308-1:2000 (2000), was used

The results are expressed as a number of colony forming units (cfu) in 100 ml of seawater

Parameters	**Water quality**		
	Excellent	**Good**	**Sufficient**
Intestinal enterococci - EN (cfu*/100 ml)	**<60**	**61-100**	**101-200**
***Escherichia coli* - EC (cfu*/100 ml)**	**<100**	**101-200**	**201-300**

Data and methods of seawater quality analysis



Study area with remote IR satellite images of groundwater discharge locations and seawater sampling locations (3M – 3. MAJ, KI – Kantrida east, KZ - Kantrida west, VN – Vila Nora, BI – Bazen east, BZ – Bazen west, DB – Children`s hospital, BP – Bivio beach, BS – Bivio steps) and the Rječina river mouth (RU) Adapted from Landsat image dated 12.06.2002. (Rubinić et al., 2007)

- During sampling, the basic physical-chemical parameters are also monitored – salinity; seawater and air temperature; rainfall on the sampling day and on the day preceding it; the presence of clouds, visible surface seawater pollution, information about algal bloom
- There is **NO monitoring of hydrological conditions** at places of groundwater discharging into the sea, but rainfall (4 stations at a distance of 2-8 km) and wind are monitored

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Methodology of analysis/modelling of bacteriological pollution of the sea

- **STANDARD DESCRIPTIVE STATISTICAL ANALYSES**
- **REGRESSION ANALYSES** – correlation matrix
- **MODEL ANALYSES** - using methods in the field of artificial intelligence (AI), i.e. by applying the machine learning tools:
  - In classification modelling → a model based on a DECISION TREE
  - In simulation modelling - NEURAL NETWORKS (NN) –

    a multi-layer perceptron network with back error propagation

- The above modelling was done using the *WEKA* software
- It is a computer tool based on object-oriented JAVA programming language

Methodology of analysis/modelling of bacteriological pollution of the sea

DECISION TREE

- In order to separate the elements of impact on the values of two analysed parameters (EN&EC) → complete series of data observed in the 2009-2013 period were used

NEURAL NETWORKS

- When forming a model in order to predict microbiological conditions depending on potential impact factors, data from the 2009-2011 period and from the year 2013 were used to generate the model (NN learning), with the year 2012 adopted as a year for validation model

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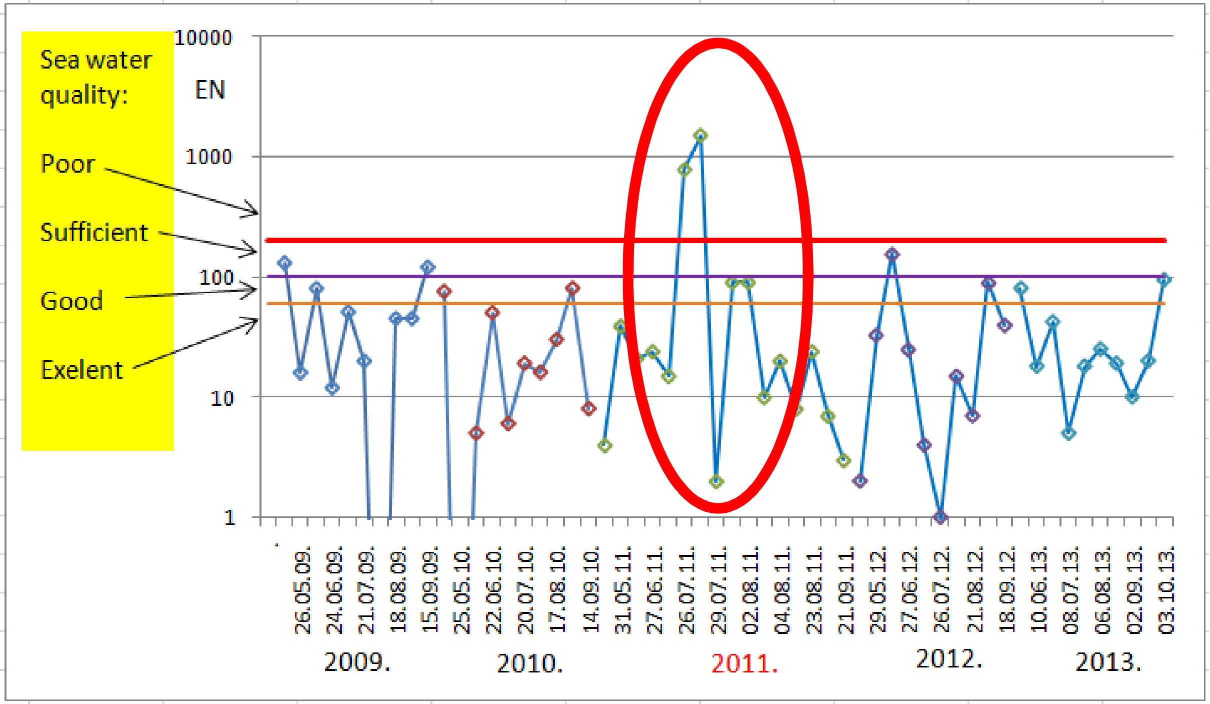


Kantrida east

- ➢Temporal series of microbiological data
- ➢EN results at KI and critical situation in 2011

CORREL.

Results and discussion

Station	Characteristic microbiological parameters observed EN/EC			Number of years with annual assessments of sea bathing water quality within a particular category of sea water quality			
	Aver	Max	Min	Excellent	Good	Sufficient	Poor
3M	79/198	1300/2500	2/3	1 (1)	0 (3)	1 (1)	3 (0)
KI	74/197	1500/2700	0/0	0 (0)	0 (2)	1 (3)	4 (0)
KZ	33/55	180/280	0/0	1 (1)	1 (4)	3 (0)	0 (0)
VN	19/25	180/130	0/0	3 (4)	2 (1)	0 (0)	0 (0)
BI	17/35	100/250	0/0	3 (3)	2 (2)	0 (0)	0 (0)
BZ*	19/22	200/180	0/0	3 (4)	1 (0)	0 (0)	0 (0)
DB	29/42	200/290	0/0	1 (3)	2 (2)	2 (0)	0 (0)
BP	11/17	130/220	0/0	5 (5)	0 (0)	0 (0)	0 (0)
BS	13/10	160/180	0/0	5 (5)	0 (0)	0 (0)	0 (0)

* Analyses started in the year 2010

Results of seawater quality analysis by individual locations (2009-2013)

		1 3. Maj	2 Kantrida istok	3 Kantrida zapad	4 Vila Nora	5 Bazen istok	6 Bazen zapad	7 Dječija bolnica	8 Bivio plaža	9 Bivio Skalete
1	3. Maj	1	0.971	0.155	0.128	0.093	0.341	0.078	-0.042	-0.015
2	Kantrida istok	0.978	1	0.152	0.199	0.151	0.341	0.020	-0.016	-0.016
3	Kantrida zapad	0.488	0.545	1	0.579	0.231	0.464	0.194	0.243	0.194
4	Vila Nora	0.333	0.381	0.502	1	0.512	0.622	0.221	0.390	0.379
5	Bazen istok	0.290	0.361	0.298	0.634	1	0.389	0.508	0.099	0.062
6	Bazen zapad	0.352	0.407	0.422	0.904	0.583	1	0.157	0.308	0.338
7	Dječija bolnica	0.149	0.164	0.253	0.721	0.707	0.717	1	0.287	0.178
8	Bivio plaža	-0.011	0.039	0.216	0.499	0.238	0.647	0.451	1	0.783
9	Bivio Skalete	0.036	0.079	0.184	0.481	0.274	0.594	0.385	0.872	1

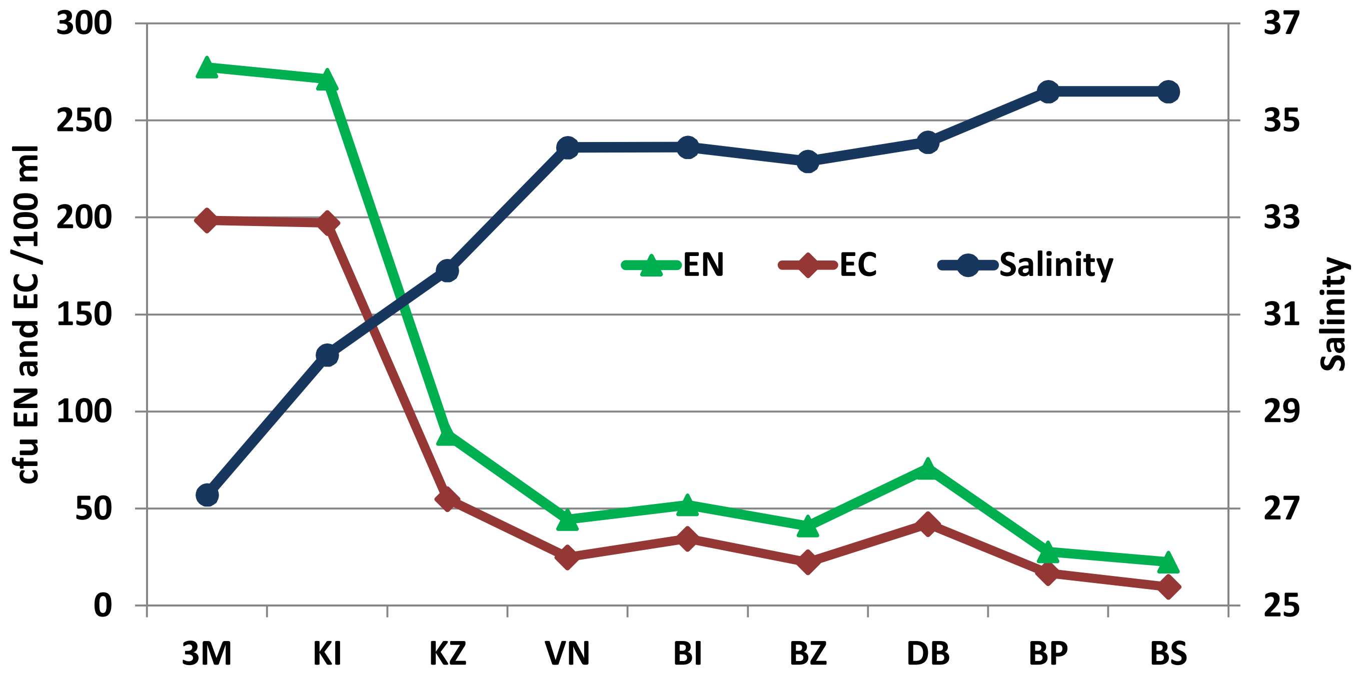
ECHERICHIA COLI (EC)

CRIJEVNI ENTEROKOKI (EN)

Correlation matrix of resulting EC&EN values

REGR. ANALY.

Results and discussion

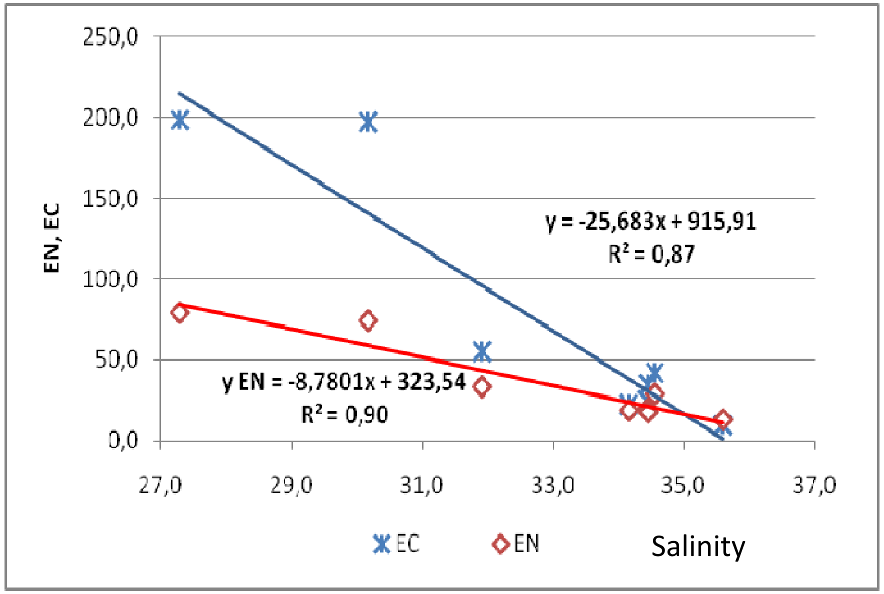


Changing average annual EC&EN values depending on salinity in particular locations

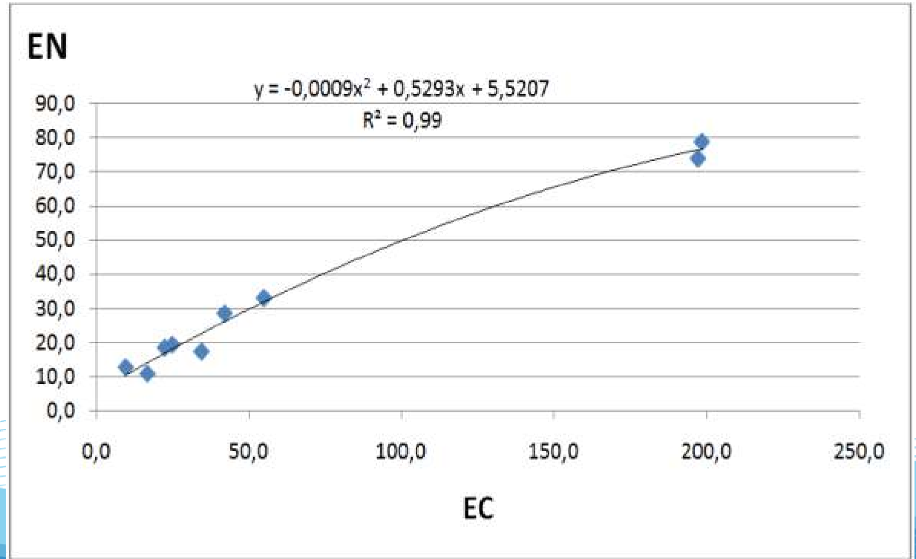
Increased microbiological pollution of the sea is inversely proportional to seawater salinity → impact of coastal springs implied

REGR. ANALY.

Results and discussion



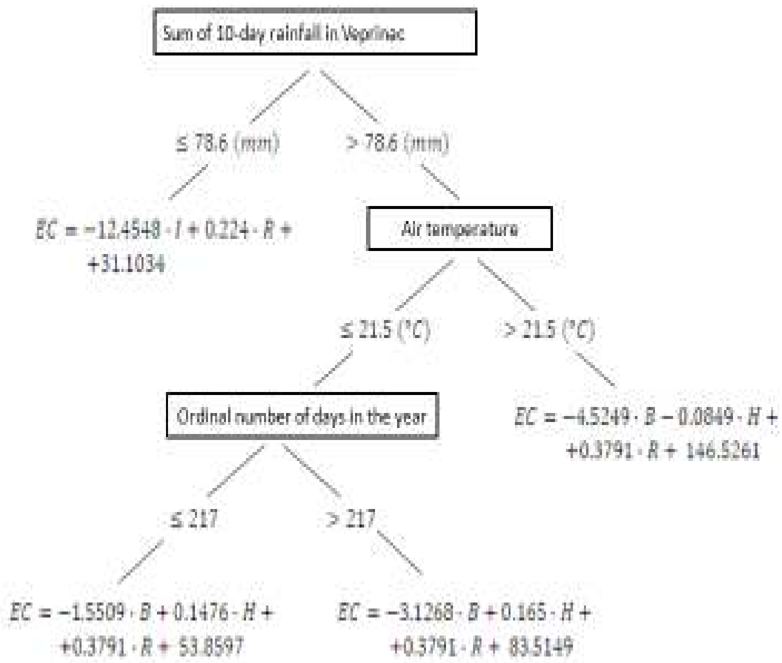
Regression analysis of correlations between sea salinity (impact of coastal springs) and EC&EN values



Regression analysis of correlations between EC&EN

DECIS. TREE

Results and discussion



Presentation of the regression tree model to assess the occurrence of EC at the location of BI

The Symbols in regression formulas:

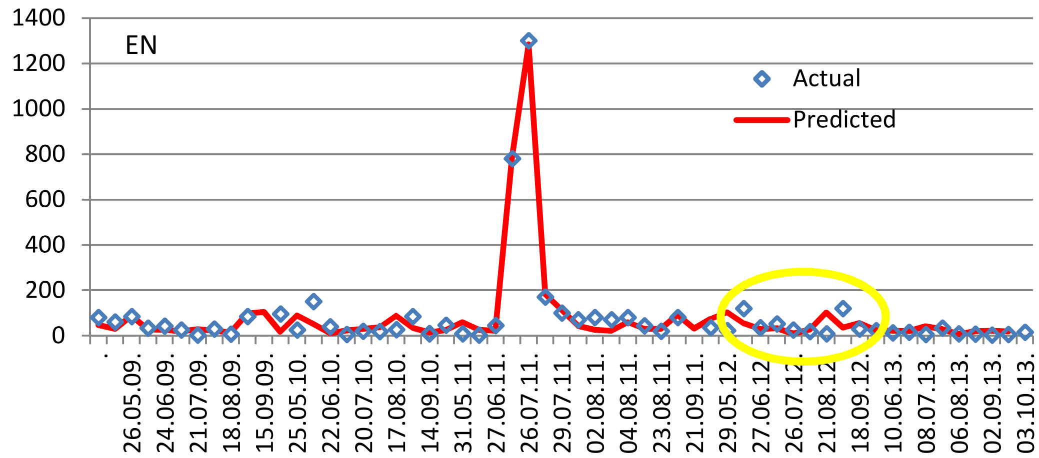
- I = average wind speed (m/s)
- R = sum of 10-day rainfall at Volosko (mm)
- B = air temperature
- H = ordinal number of the day in the year

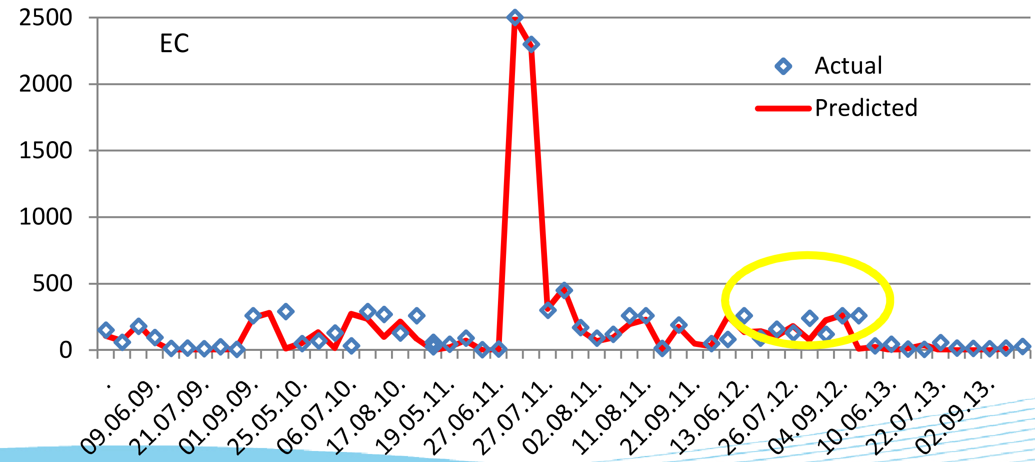
Resulting correlation coefficient 0.78

GENERAL OBSERVATION:
Results of modelling at locations under stronger impacts of groundwater discharge, gives the trees which are less extended (often with only one regression equation), and the results are more impacted by rainfall over longer past periods

NEURAL NETWORK

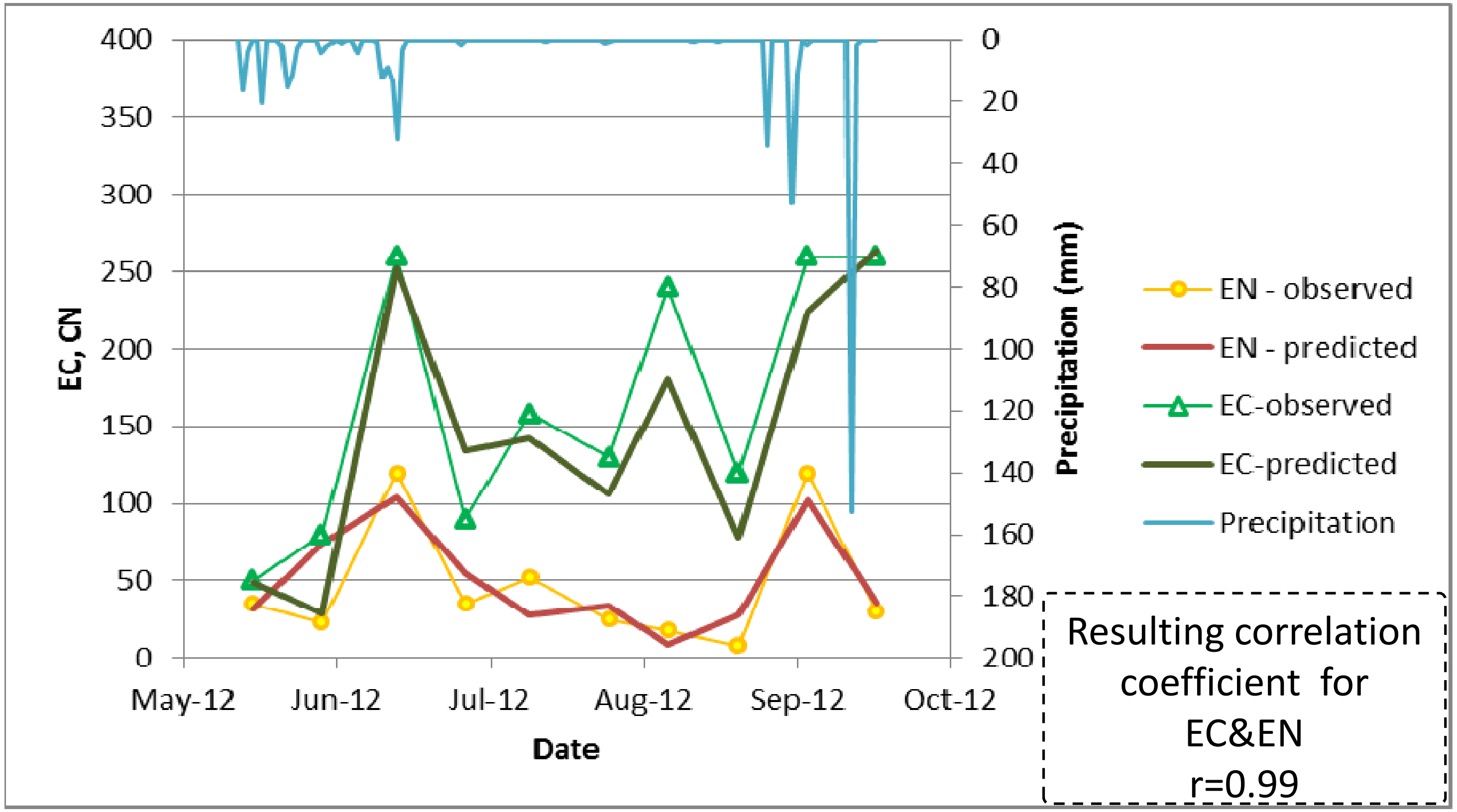
Results and discussion





- Example of results of EN&EC modelling made for 3M beach using neural networks (NN)
- The year 2012 was used as year for validation of modelling results

Results and discussion



Comparison of observed values of microbiological indicators and values predicted by a NN-model at station 3M for the year 2012

A very good match between the results of the observed and NN model-generated series is noticeable

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- **The hydrological conditions at fresh groundwater inflows in coastal karst aquifers has a dominant impact on seawater quality/microbiological indicators**

- **Increased pollution events can be modelled in a satisfactory manner – artificial intelligence/machine learning methods**

Conclusions

- On the basis of such models it is possible to generate predictions which might be used for operational purpose in the order to protect human health

•To obtain even better results of modeling, it is necessary to establish monitoring of hydrological conditions at coastal springs