INCOME Water Care

Improved Management of Contaminated Aquifers by Integration of Source Tracking, Monitoring Tools and Decision Strategies

A.3.4. The risk evaluation (Final report)

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1. Introduction

This action was following step to a previous action A.3.3. The first aim was to develop a GIS based risk map as a decision making tool to a quick reference risk assessment of eventual further pressures or accidental spills in any given point. The second aim was to produce a quick reference tool for decision makers for prioritizing and designing the local distribution of protection measures.

The activities were performed by Geological survey of Slovenia within the project INCOME (LIFE07 ENV/SLO/000725). The main objective of the project is long-term effective management of aquifers and preservation of the quality of these water resources for future generations. The project is co-financed by European Commission, Municipality of Ljubljana and Ministry of the Environment and Spatial Planning of Republic of Slovenia.

2. Probability assessment of accidental pollution with dangerous substances maintained in the most susceptible impact zones

The first step was a spatial analyze of the point, nonpoint, line and diffused sources of potential pollutions of water protected areas (VVO I) with GIS tools. Non-point sources include septic tanks, petrol stations, industrial waste water discharges, quarries, greenhouses, dry cleaners and landfills. Line sources include sewage systems, rainfall runoff from roads (urban runoff), electricity and gas network. Diffused sources include potential areas of individual tanks and dispersed buildings. Diffused sources include specially agriculture land use. The risks of spills from these sources were assessed by existing literature failure rates.

We find out that public available data on the transport of dangerous goods are not collected in one place, as well as there is no uniform, comparable data base of road accidents that have occurred in the transport of dangerous goods. There are some individual institutions collecting data, but with review and comparisons we found that this data bases often do not match and are somewhat incomplete.

In the table below are results from review and analyze of existing documents on accidents in the areas of Ljubljana and Ig Communities (sources Community of Ljubljana - Board for the protection, rescue and civil defence, Ministry of Defence - Administration of the Republic of Slovenia for Civil Protection and Disaster Relief). The goal was to define level of endangerment of water protected areas - an incidence rate of accidents with dangerous substances (Incidence rate = Number of accidents / Time [365 days]):

Table 1

Accidents with dangerous substances	2005	2006	2007	2008	2009	2010
Number of accidents with dangerous substances (excluding gas)	39	56	46	41	47	47
Incidence rate	0.11	0.15	0.13	0.11	0.13	0.13

In the period from 2005 till 2010 there were 276 accidents with dangerous substances, prevailing (55 %) in traffic and the less (1.8 %) in industry.

For final probability assessment of accidental pollution with dangerous substances we used "Decision tree« model and failure rates that are represented below.

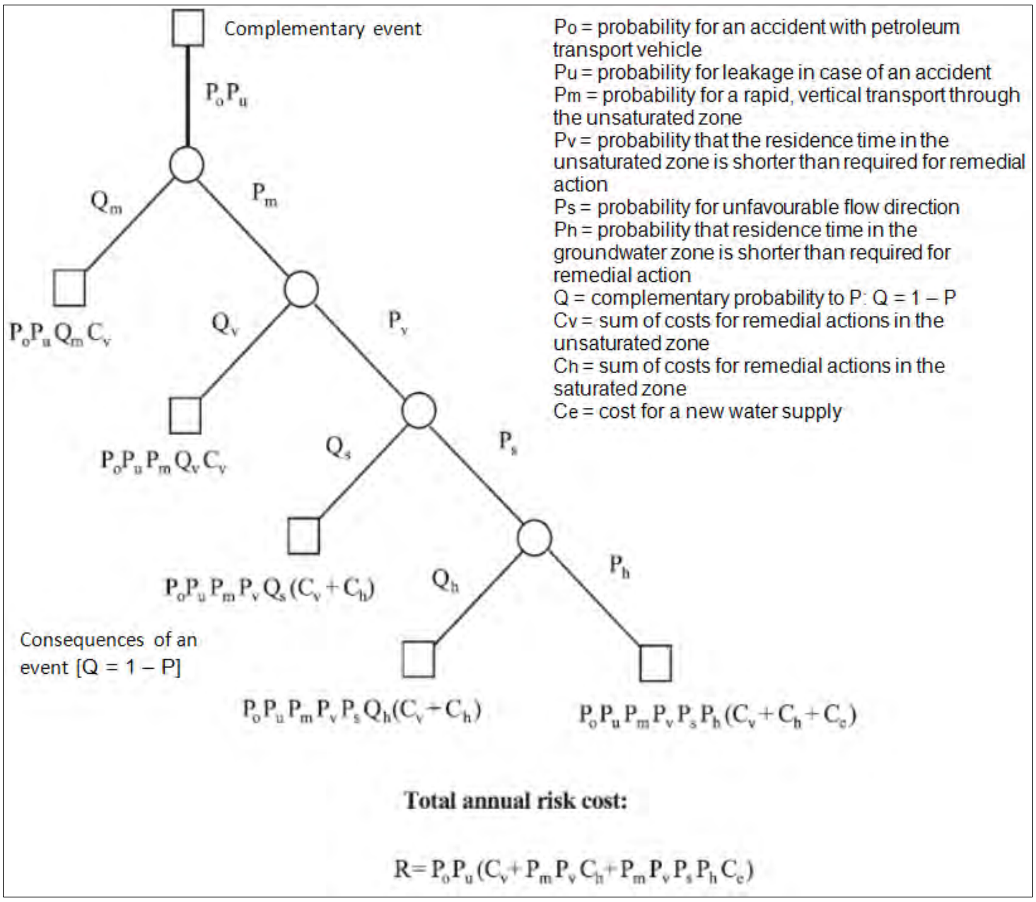

Figure 1. Decision tree for risk analysis for a road accident involving petroleum transport threatening a groundwater supply (*Source:* Swedish Nat. Road Adm. and Swedish Rescue Service Agency, 1998).

Table 2

Traffic - average probability (2005-2010)	roads length [km]	P [No. accidents / year]
MOL	1804	25
Income Life ∩ MOL vs MOL	1152	16
VVO 0, I in IIA vs MOL	176	6,8

Table 3

Industry - average probability (2005-2010)	
MOL	0.8
P (Income) [No. accidents / year]	0.8
P (vvoIIA) [No. accidents / year]	0.046

Table 4

Households - average probability (2005-2010)	
P (MOL) [No. accidents / year]	5.7
P (Income) [No. accidents / year]	6.1
P (vvoIIA) [No. accidents / year]	0.4

Table 5

Other contaminants	
P (Income) [No. accidents / year]	13.3
P (vvoIIA) [No. accidents / year]	0.74

Table 6

Tanks: No. areas: 1358	
Mean (Anyakora, S.N. et. al. 1971;Rothbart, H. 1964)	3.55*10^-6
P (Income) [No. accidents / year]	0.0048209
P (vvoIIA) [No. accidents / year]	0.0000355

For a better probability assessment of accidental pollution it is important to use a standardised form for the data collection from the very beginnings of the inventory. Two types of inventory forms may be needed:

1) a simple form for recording data from agency files, archives, literature, etc. (Figure 2) and

2) a more detailed form for the on-site description of a source and potential problems (Figure 3).

Source ID number ____________ Date of inventory ________________

Map ID number ____________ Inventory person ________________

INVENTORY FORM

Landowner/Company/Facility name ________________________________

Address ____

Contact person __________________ Phone number ____________

Type of property:	Residential ____	Commercial ____	Industrial ____
	Agricultural ____	Governmental ____	Other ____ (Specify)

Potential contamination source

Type ____

Areal extent ____

Unregulated/regulated by ________________________________

Material(s)/Waste used/stored/disposed (check one)

Type ________________________ Quantity ______________

History of any releases or contamination incidents ________________

____

Source of information: Agency file ____ Archives ____ Literature/report ____

Name ____

Address ____

Contact person __________________ Phone number ____________

Figure 2. Sample form for office inventory (Groundwater contamination inventory, UNESCO, 2002).

Source ID number ____________ Date of site visit ____________

Map ID number ____________ Inventory person ____________

Location: coordinates ____________

how determined (topo map, surveying, GPS) ____________

distance from roads and dwellings ____________

SURVEY INVENTORY FORM

Landowner/Company/Facility name ____________

Address ____________

Contact person ____________ Phone number ____________

Physical setting of the site ____________

Number and location of contamination sites ____________

____

Description of contamination source(s)

Type ____________

Characteristics/Appearance ____________

Maintenance/Operation ____________

Description of contaminant(s)

Type ____________

Amount ____________

Nature of release ____________

Protective measures/controls ____________

Apparent problems ____________

History of any discharges or contamination incidents ____________

____

Area(s) affected by contamination ____________

Remediation efforts ____________

Figure 3. Sample survey form (Groundwater contamination inventory, UNESCO, 2002)

3. Risk assessment for crucial selected points of compliance

The representatives of the existing monitoring network (Figure 4) were estimated on four selected industrial plants and existing system of groundwater level contour lines for a case of emergency (Table 7, Figure 5).

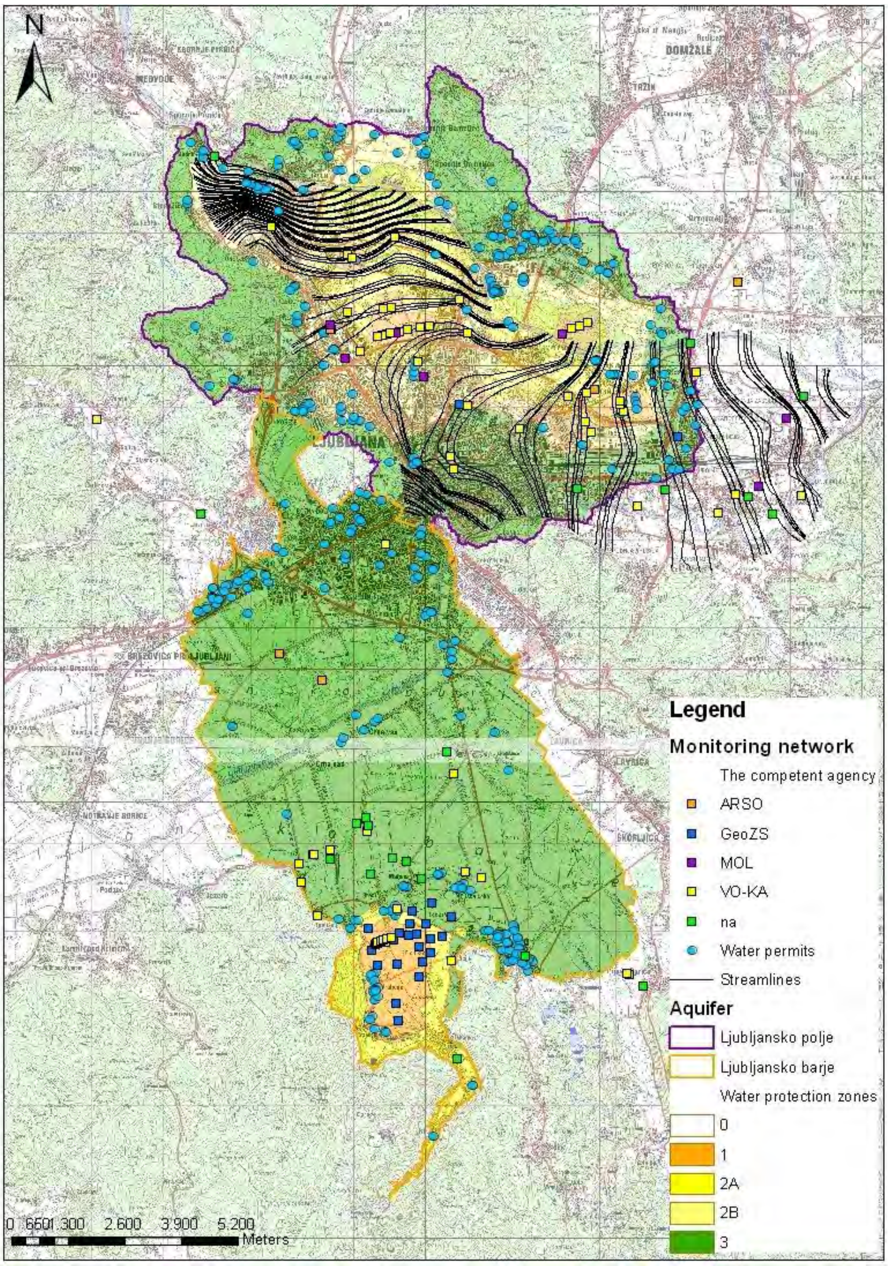

Figure 4. A representativity of the existing monitoring network.

Table 7. Primary data.

Plant with a high risk for ground water pollution	ŽLINDRA, d.o.o.	TERLEP JANEZ S.P. - TEROXAL	METALTERM, d.o.o.	GOLMAJER FRANC S.P. – GALVANIZERSTVO
M-1 VD Kleče 12	-	-	l = 1,3 km r = 0,4 km	-
M-2 Petrol	l = 0,36 km r = 60 m	-	l = 0,86 km r = 0,2 km	-
M-3 LP Vodovodna	-	-	l = 2,3 km r = 0,4 km	-
M-4 GZL	l = 3,1 km r = 0,0 km	l = 2,87 km r = 0,65 km	l = 3,7 km r = 0,0 km	-
M-5 BŠV-1/99	l = 4,4 km r = 50 m	l = 4,15 km r = 0,22 km	l = 5 km r = 50 m	l = 2,85 km r = 0,22 km
M-6 BRP-1B in M-7 BRP-1C M-8 Bauhaus	l = 5,9 km r = 0,5 km l = 6,1 km r = 0,2 km	l = 5,67 km r = 0,5 km l = 5,87 km r = 0,2 km	l = 6,5 km r = 0,5 km l = 6,7 km r = 0,2 km	l = 4,35 km r = 0,5 km l = 4,55 km r = 0,2 km
M-9 Navje	-	l = 2,55 km r = 0,64 km	-	l = 1,26 km r = 0,24 km

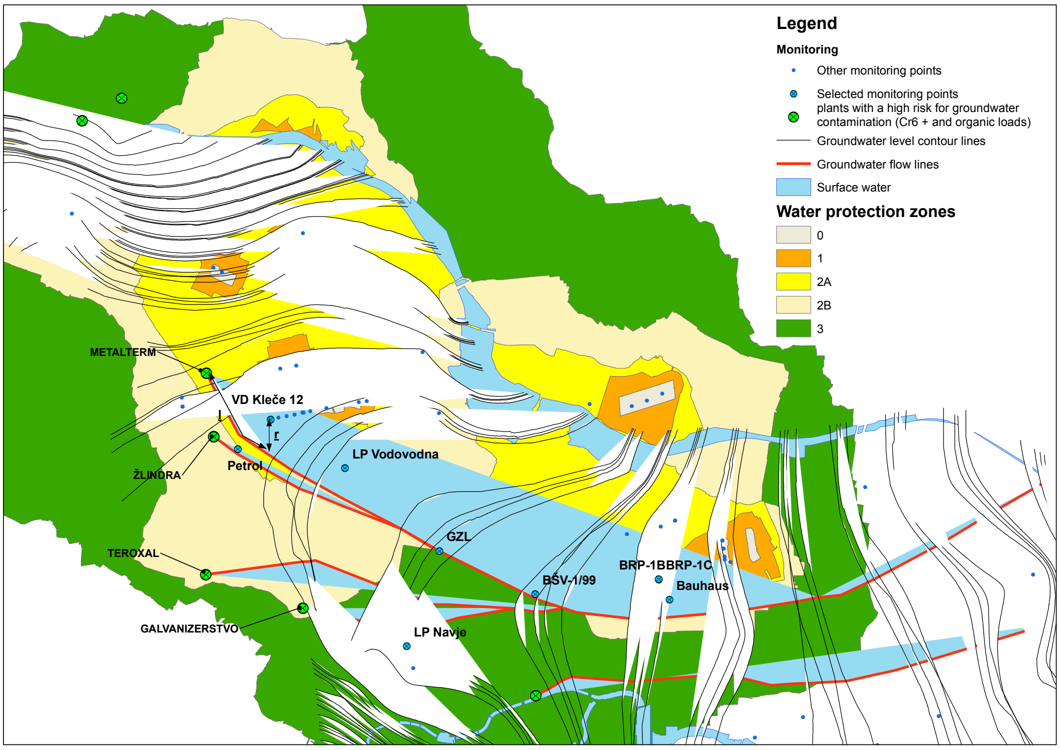

Figure 5. The fragment of study area.

The impact zones for risk assessment (pressures – impacts) were defined based on groundwater flowlines and groundwater level contour lines. The groundwater level counter lines were gained with interpolation and extrapolation of measured data by kriging method. On the figure below are represented the flow paths from existing monitoring points to the surface water body.

Further the comparison of results computed with model MIKE-SHE and manual determined results can be made.

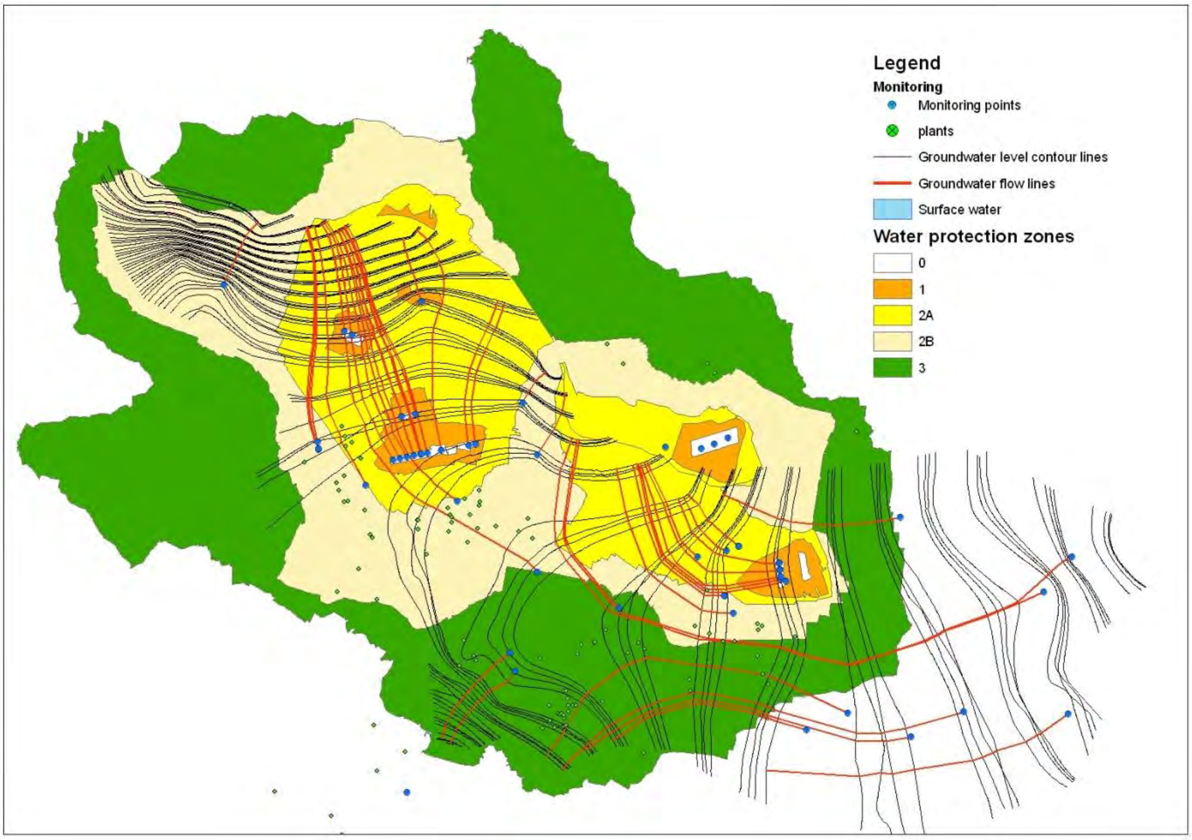

Figure 6. Flow paths from existing monitoring points to the surface water body.

As quick risk assessment tool the Beatsle model was set, based on correlation of results gained by tracer test (Brancelj at all, 2005[1]) in the water protected area of Ljubljansko polje (Figure 7). The results of preformed trace tests indicated, that the dispersion was rising with the distance. On the distance about 1 kilometer the dispersion was between 50 and 90 meters. The input data from tracer test were the amount of the substance deposited in the point source and the distance from source to observed wells.

[1] Rejec Brancelj, I. (ur.) 2005: Podtalnica Ljubljanskega polja, Geografija Slovenije 10. Ljubljana, 251 str.

The dispersion equation – Beatsle, L. H. method (Eq. 1):

$$C = \frac{M}{8(\pi t v/R)^{3/2}\sqrt{\alpha_L \alpha_T \alpha_Z}} \exp\left(-\frac{(x - vt/R)^2}{4\alpha_L vt/R} - \frac{y^2}{4\alpha_T vt/R} - \frac{z^2}{4\alpha_Z vt/R}\right), \qquad \text{Eq. 1}$$

Where:

C - The tracer concentration in well (mg/l),

M - Amount of the substance injected in the point source (kg),

x, y, z - Distance in x, y, z directions between filters of well and point source of tracer (m),

v - Velocity of the groundwater flow (m/s),

t - Time (s),

αT - Transversal dispersion coefficient (m),

αL - Longitudinal dispersion coefficient (m),

αZ - Vertical dispersion coefficient (m) ,

R - Retardation factor (-).

Later we computed and analyzed the expected transport of pollutants in the water protected area of Ljubljansko polje (Figure 7), where the tracer test was just started.

For the computations of the cloud dispersion we used equation - Beatsles, L. H. method (Eq. 1) and values of dispersion and flow velocities that were determined during this action A.3.4.

The input data from tracer test were: the amount of the substance (uranin) injected in the point source (Arharjeva 4) and the distance from source to observed wells (x and y directions) (Table 8). The groundwater flowlines (violet lines on Fig. 7) were defined on the bases of groundwater level counter lines (blue lines on Fig. 7).

The results from the computation (Table 9) show that expected concentrations of tracer in the targeted sampling points will be below 0,001 mg/l (Fig. 8 and Fig. 9). The cloud of expected concentration higher than 0.000033 mg/l is shown on the Figure 9 and Figure 10.

The final results of tracer test can be compared with the computational model. This will serve to improve the reliability of risk assessment model.

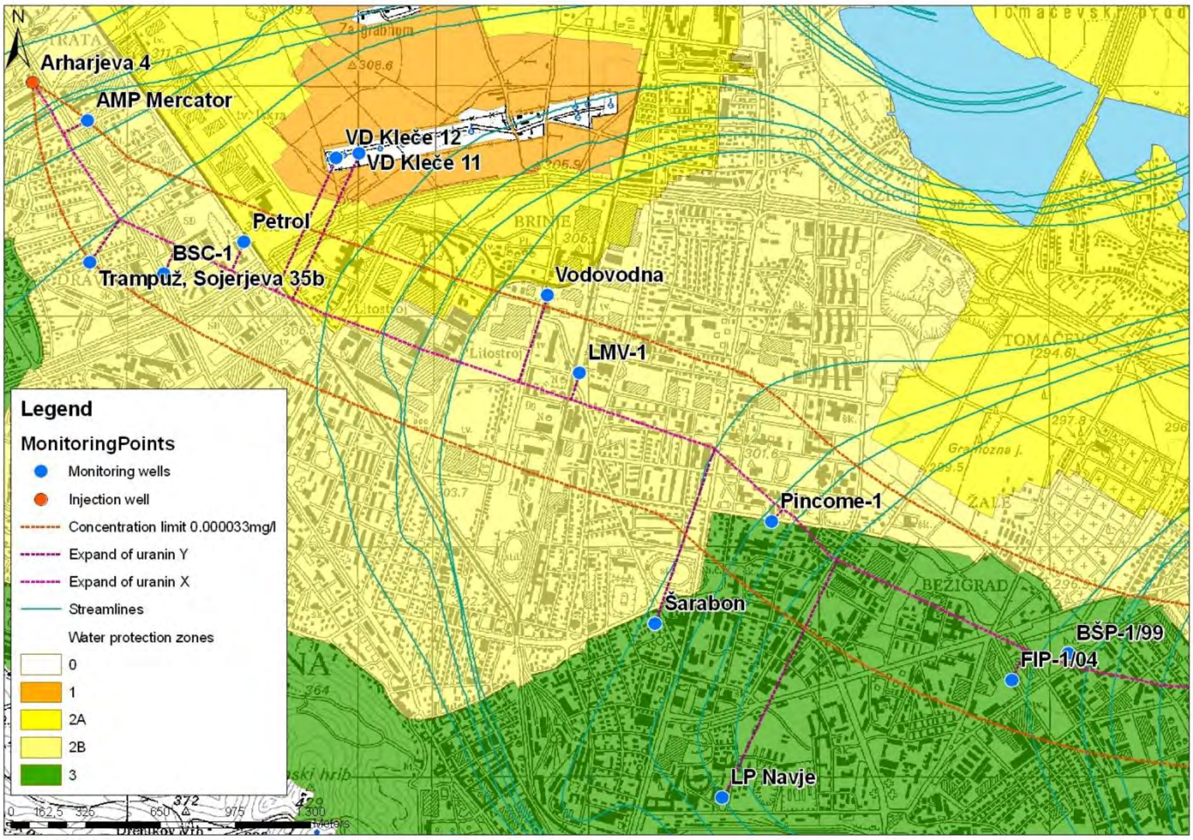

Figure 7. Study area.

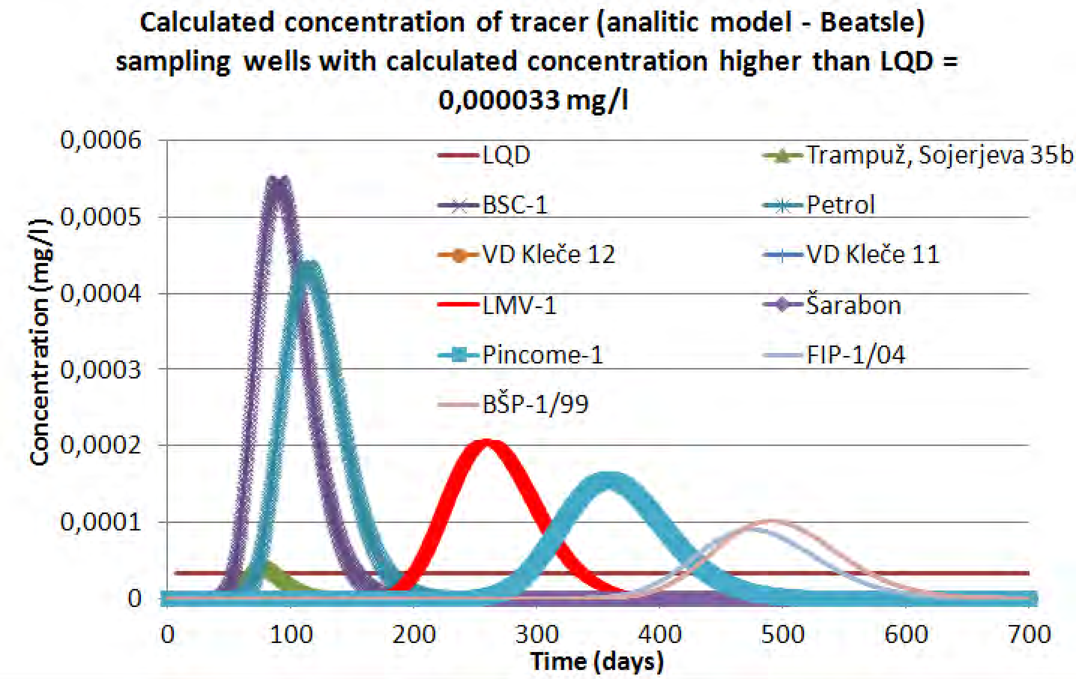

Figure 8. Results - expected concentrations of tracer above the LQD.

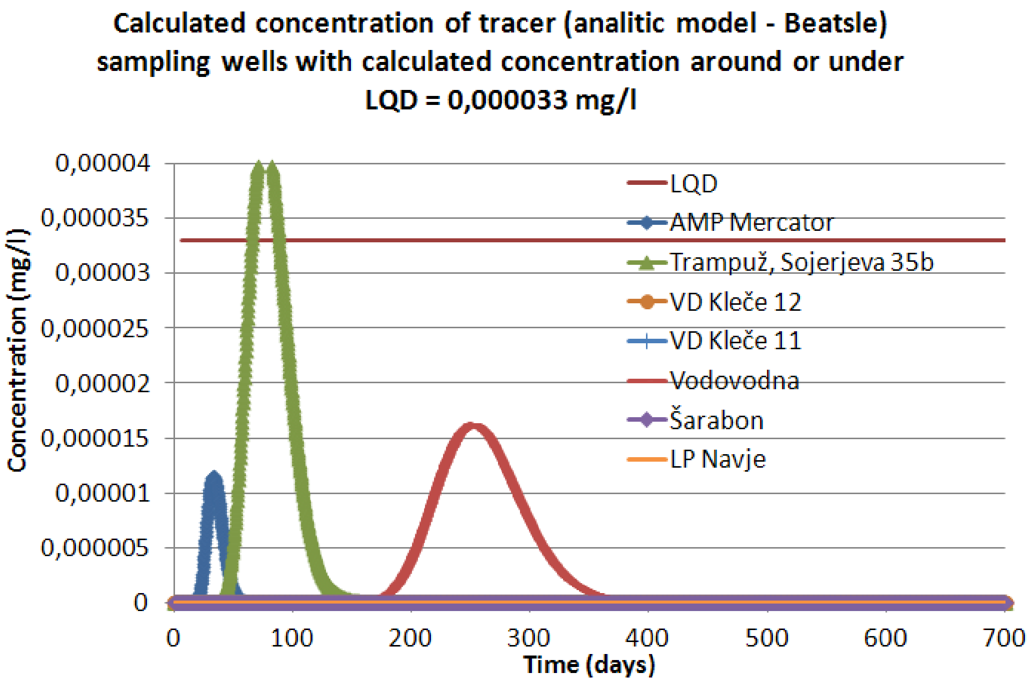

Figure 9. Results - expected concentrations of tracer below the LQD.

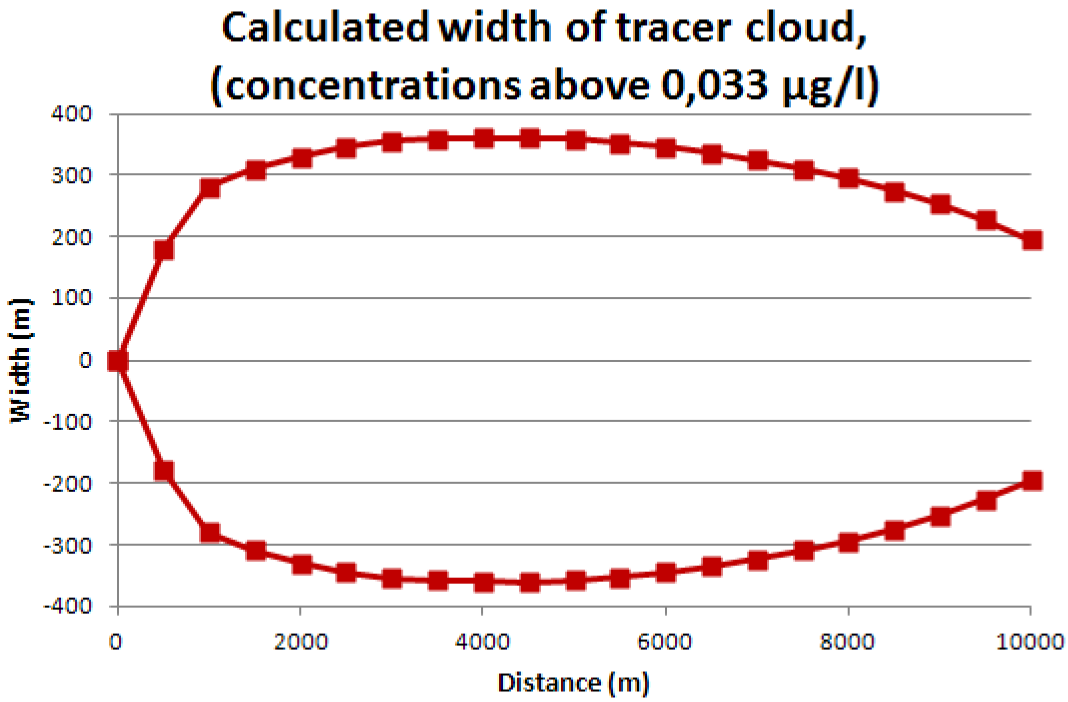

Figure 10. Concentration limits.

Table 8. Input data from tracer – Beatsle model.

Monitoring well	Amount of the substance deposited in the point source (kg)	Velocity of the groundwater flow (m/day)	Retardation factor	Transversal dispersion coefficient (m)	Longitudinal dispersion coefficient (m)	Vertical dispersion coefficient (m)	Location of filters despite the pollution (m)		
	M	v	R	αT	αL	αZ	x	y	z
AMP Mercator	10	10,6	1	1,359	6,902	0,060	258	119	0
Trampuž, Sojerjeva 35b	10	10,6	1	3,706	18,824	0,163	705	220	0
BSC-1	10	10,6	1	5,139	26,104	0,226	978	134	0
Petrol	10	10,6	1	5,256	26,700	0,232	1.235	139	0
VD Kleče 12	10	10,6	1	5,256	26,700	0,232	1.448	636	0
VD Kleče 11	10	10,6	1	5,256	26,700	0,232	1.528	695	0

Vodovodna	10	10,6	1	5,256	26,700	0,232	2.572	399	0
LMV-1	10	10,6	1	5,256	26,700	0,232	2.813	124	0
Šarabon	10	10,6	1	5,256	26,700	0,232	3.474	799	0
Pincome-1	10	10,6	1	5,256	26,700	0,232	3.870	72	0
LP Navje	10	10,6	1	5,256	26,700	0,232	4.193	1.149	0
FIP-1/04	10	10,6	1	5,256	26,700	0,232	5.100	143	0
BŠP-1/99	10	10,6	1	5,256	26,700	0,232	5.280	48	0

Table 9. Results - Beatsle model.

Results - Beatsle model			
Monitoring well	Max trace concentration in well (mg/l)	Time to peak concentration (h)	Time to peak concentration (day)
	C_{MAX}	t_{MAX}	t_{MAX}
AMP Mercator	1,14E-05	798	33
Trampuž, Sojerjeva 35b	4,29E-05	1.827	76
BSC-1	5,47E-04	2.149	90
Petrol	4,35E-04	2.667	111
VD Kleče 12	7,14E-09	4.354	181
VD Kleče 11	1,71E-09	4.683	195
Vodovodna	1,62E-05	5.719	238
LMV-1	2,06E-04	5.908	246
Šarabon	4,39E-08	8.253	344
Pincome-1	1,56E-04	8.589	358
LP Navje	1,21E-10	10.976	457
FIP-1/04	9,02E-05	11.389	475
BŠP-1/99	1,02E-04	11.774	491

4. GIS based map for the use at the intervention procedures

- GIS based map for the use at the intervention procedures (restricted access) in scale 1: 5.000.

Appropriate, standardised forms for recording data should be prepared to be used by experts involved in the inventory. Examples of inventory forms are shown on Figure 2 and Figure 3. The selection of a uniform base map, on which the information obtained during the inventory, should have unique identification (ID) number.

A suggested layout of GIS map for intervention procedures based on standard topographic maps in scale 1:5.000:

- Flow paths from existing monitoring points to the surface water body;
- Groundwater travel (residence) time (10 days 20 days 30 days 40 days 50 days 60 days 70 days 80 days 90 days 100 days 200 days 300 days 400 days 2 years 3 years) between the perimeter of the zone to the well;
- Speed and direction of groundwater flows;
- Monitoring points, boreholes and wells, water permit;
- Sewage system categorized by age of construction and material used;
- Depth to groundwater;
- Thickness of the aquifer;
- Points of compliance.

5. GIS based map of the "impact zones"

Impact zones are defined in accordance with the Regulation (Rules on construction in water protection zones that may be carried out only pursuant to the water consent and on the required documentation for obtaining water consent – Ur.L.RS 62/2004) (restricted access).

The groundwater contamination risk map can be used as it is for many purposes, including education and informing the public and decision-makers about dangers to the water supply sources. This action will need to be taken in order to solve, reduce, or prevent contamination that threatens the groundwater resource. In order to do this, a GIS based maps needs to be provided in scale 1: 25.000.

A suggested layout of GIS map for the educational and designing purposes:

- Direction of groundwater flows;
- Depth to groundwater;
- Thickness of the aquifer;

- Water protected areas including layer with protective measures for the interventions and activities in environment;
- Extreme low and extreme high groundwater levels (return periods 5, 10, 20, 50 and 100 years);
- The persistence of perched groundwater.

5.1. The most probable "sewage risk impact zone" – pollution from sewage system

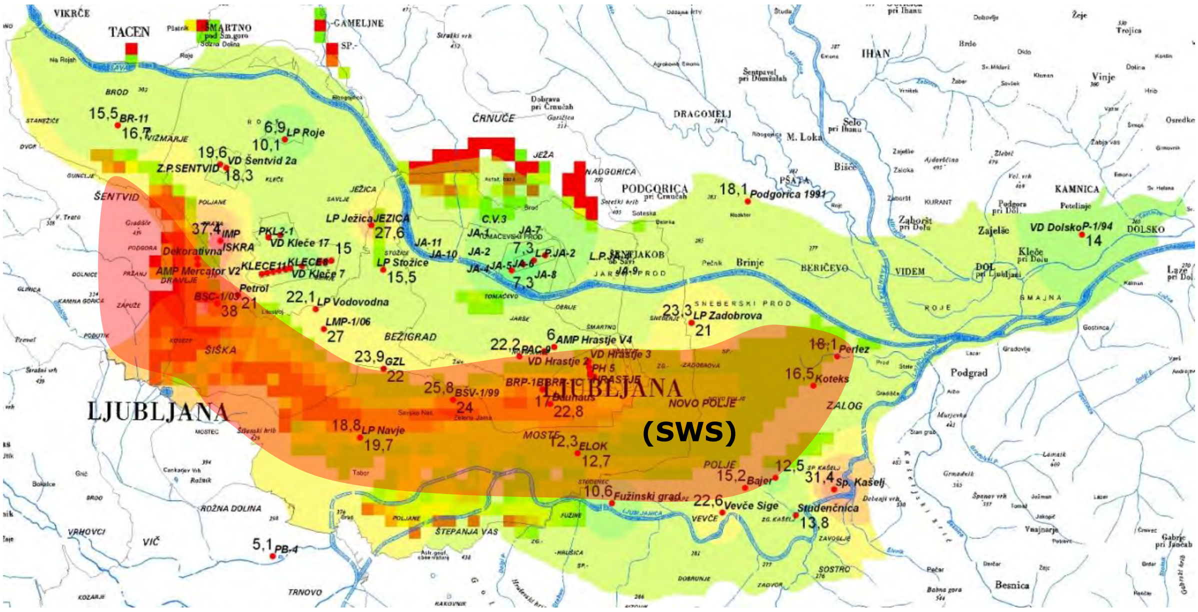

Figure 11. The area (SWS) with the highest risk for contaminant spreading from eventual pollution in sewage system.

5.2. The most probable "plant protection product risk impact zone" – pollution from agriculture

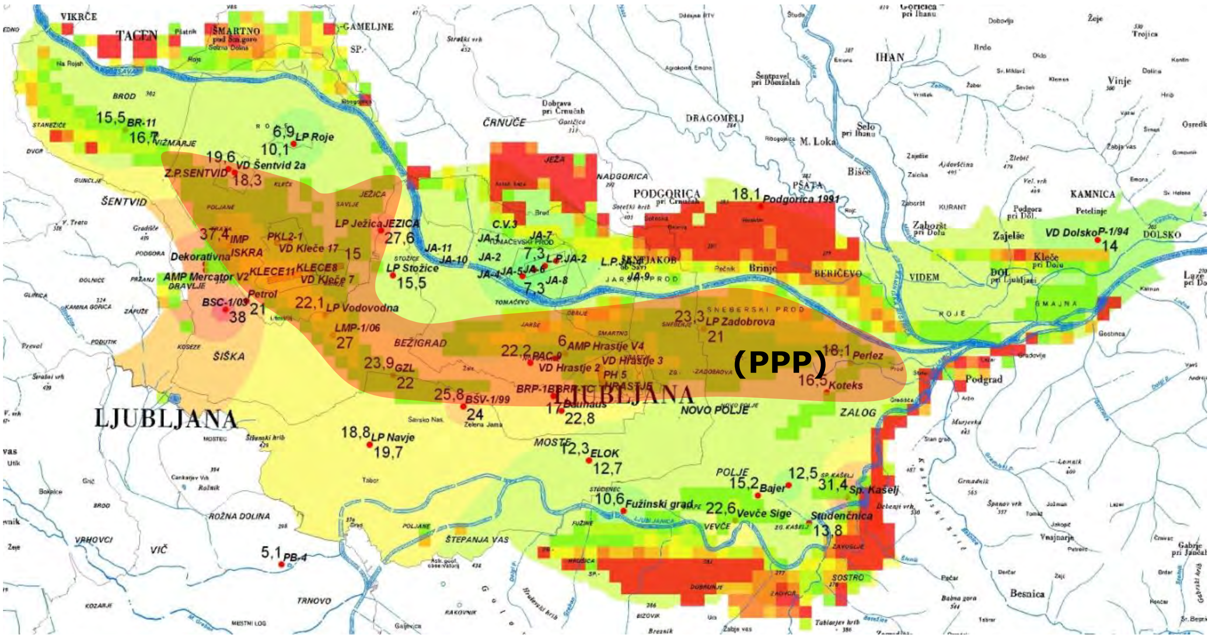

Figure 12. The area (PPP) with the highest risk for contaminant spreading from eventual plant protection product pollution in agriculture.

Main references

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APPENDIX 1

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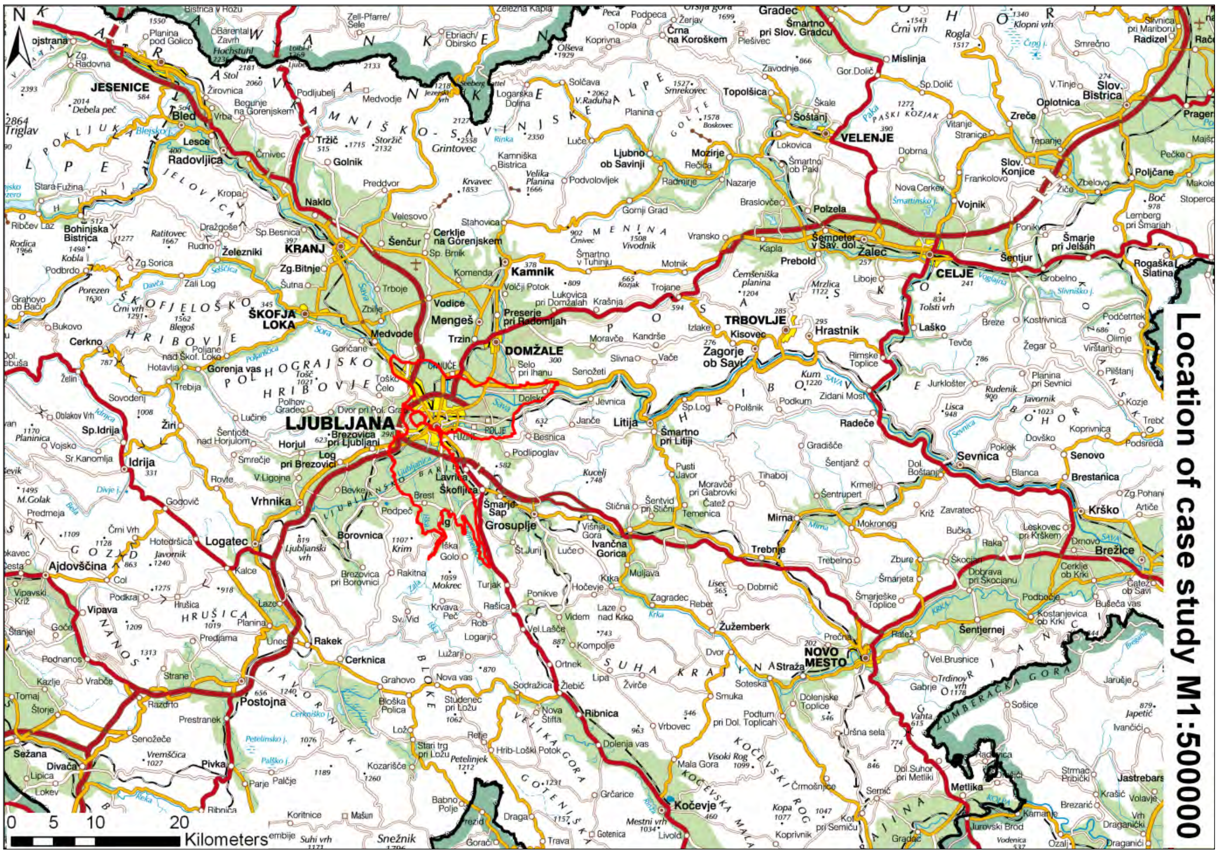
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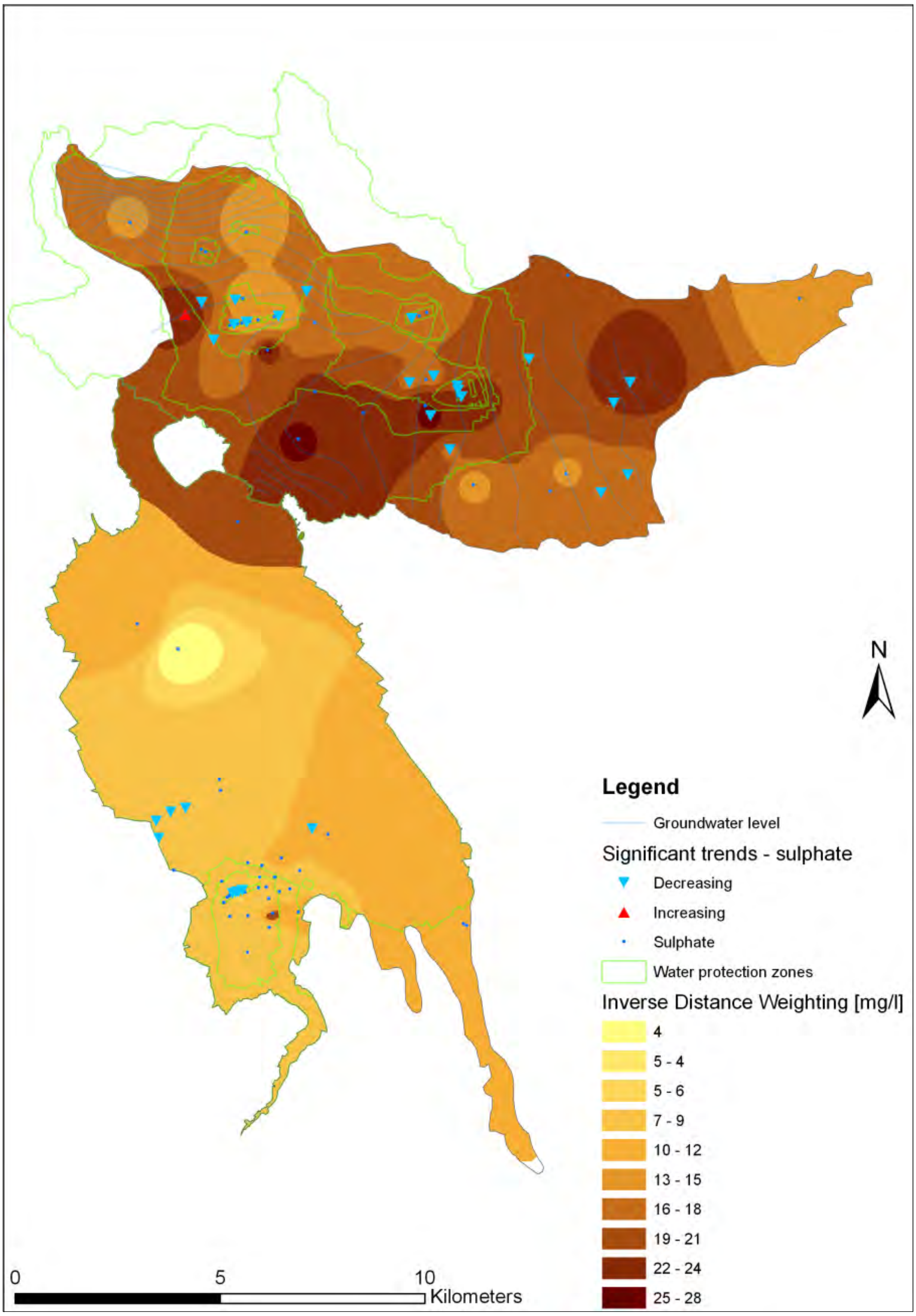
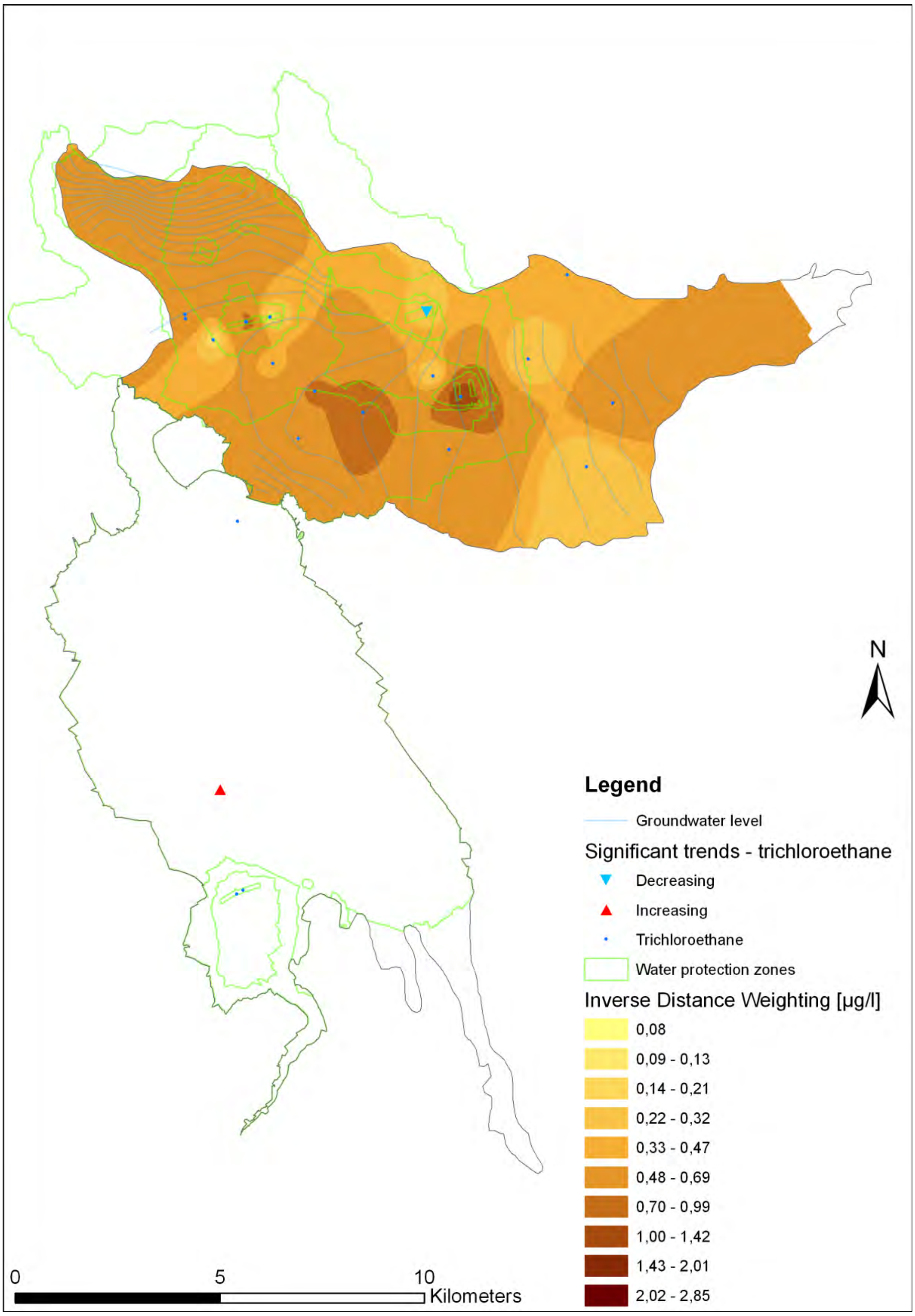
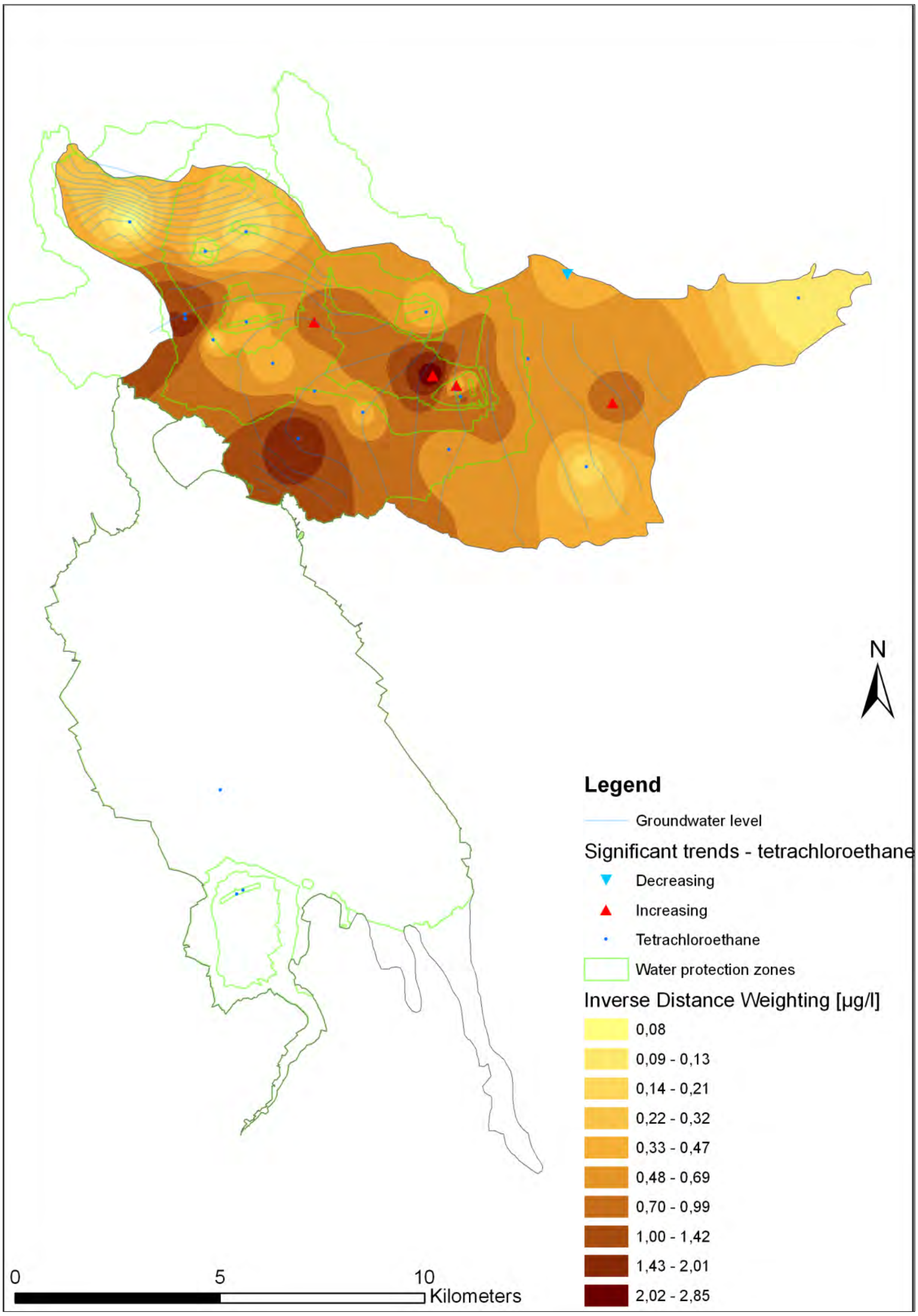
Kilometers
LJUBLJANA


N
Legend
Groundwater level
Significant trends - sulphate
Decreasing
Increasing
Sulphate
Water protection zones
Inverse Distance Weighting [mg/l]
4
5 - 4
5 - 6
7 - 9
10 - 12
13 - 15
16 - 18
19 - 21
22 - 24
25 - 28
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - trichloroethane
Decreasing
Increasing
Trichloroethane
Water protection zones
Inverse Distance Weighting [µg/l]
0,08
0,09 - 0,13
0,14 - 0,21
0,22 - 0,32
0,33 - 0,47
0,48 - 0,69
0,70 - 0,99
1,00 - 1,42
1,43 - 2,01
2,02 - 2,85
0
5
10
Kilometers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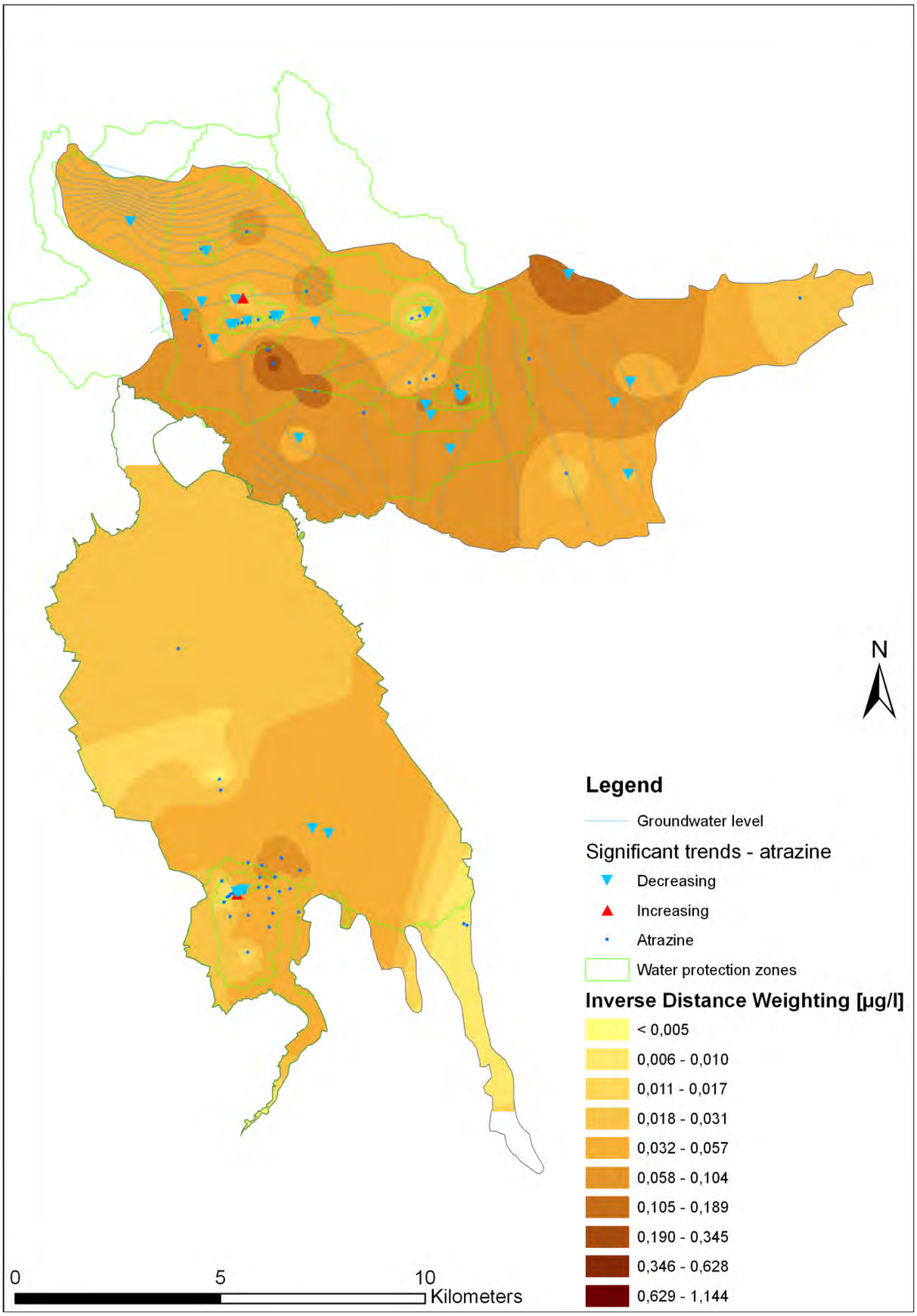
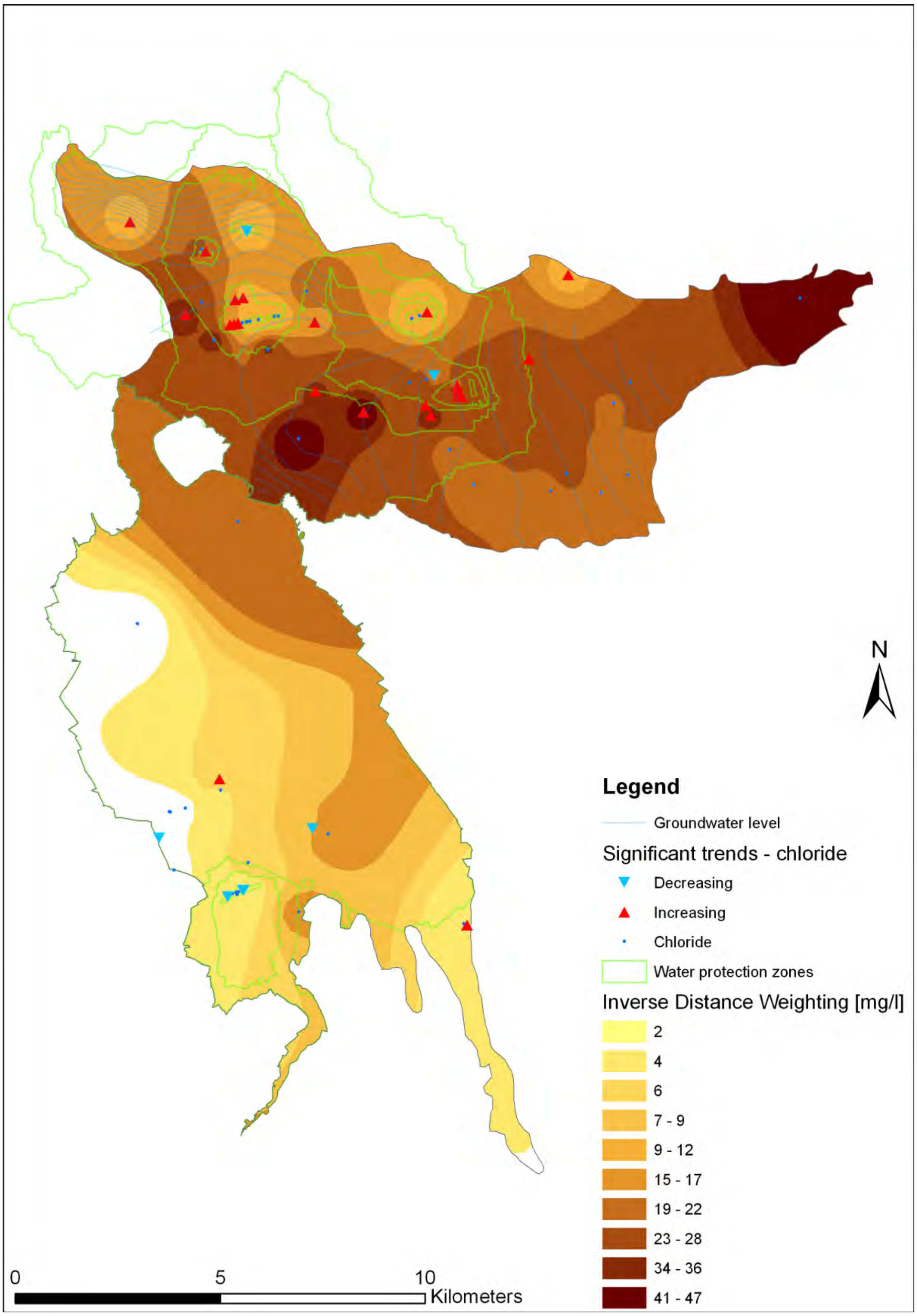
Legend
Groundwater level
Significant trends - tetrachloroethane
Decreasing
Increasing
Tetrachloroethane
Water protection zones
Inverse Distance Weighting [µg/l]
0,08
0,09 - 0,13
0,14 - 0,21
0,22 - 0,32
0,33 - 0,47
0,48 - 0,69
0,70 - 0,99
1,00 - 1,42
1,43 - 2,01
2,02 - 2,85
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - atrazine
Decreasing
Increasing
Atrazine
Water protection zones
Inverse Distance Weighting [µg/l]
< 0,005
0,006 - 0,010
0,011 - 0,017
0,018 - 0,031
0,032 - 0,057
0,058 - 0,104
0,105 - 0,189
0,190 - 0,345
0,346 - 0,628
0,629 - 1,144
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - chloride
Decreasing
Increasing
Chloride
Water protection zones
Inverse Distance Weighting [mg/l]
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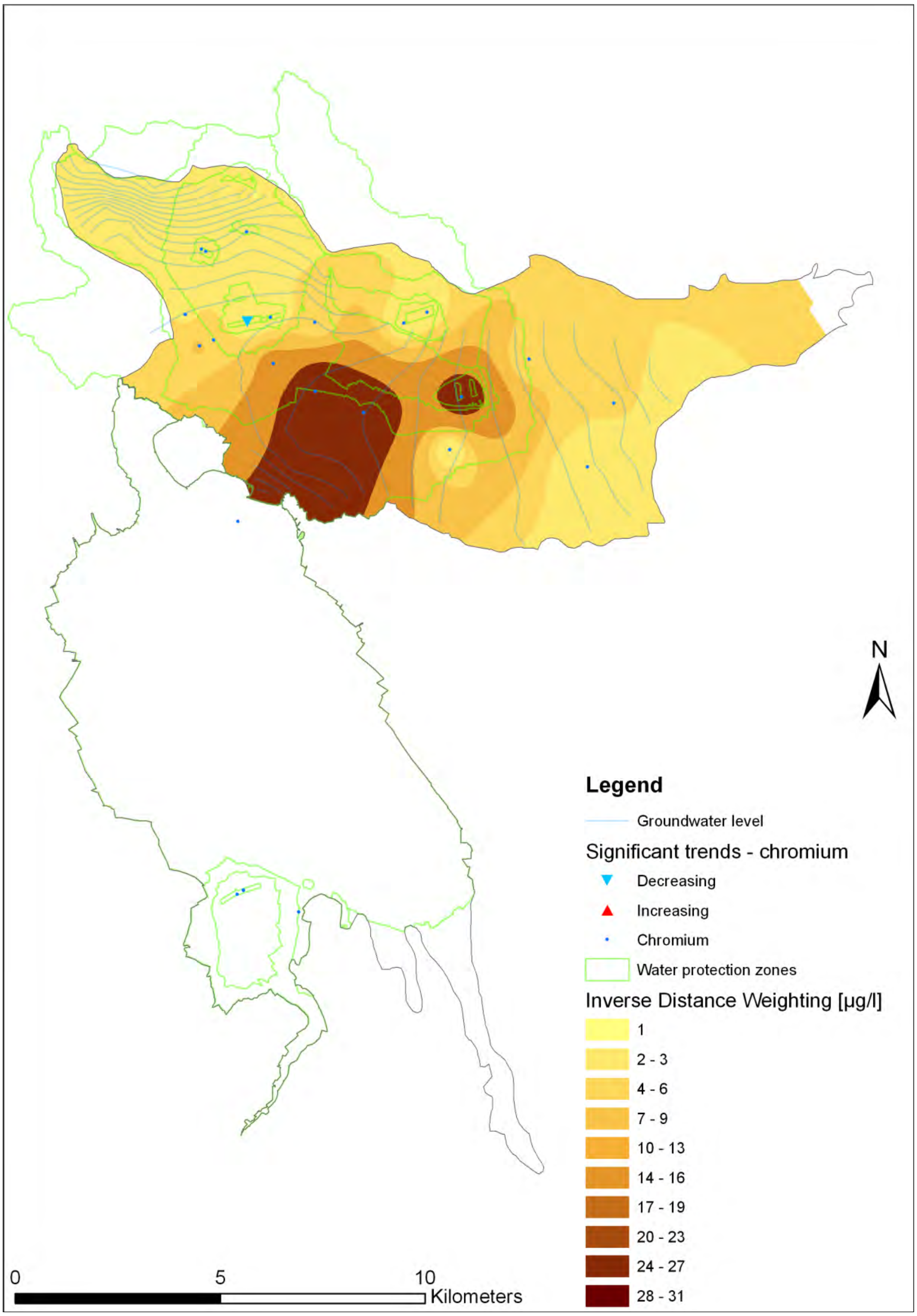
4
6
7 - 9
9 - 12
15 - 17
19 - 22
23 - 28
34 - 36
41 - 47
0
5
10
Kilometers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Legend
Groundwater level
Significant trends - chromium
Decreasing
Increasing
Chromium
Water protection zones
Inverse Distance Weighting [µg/l]
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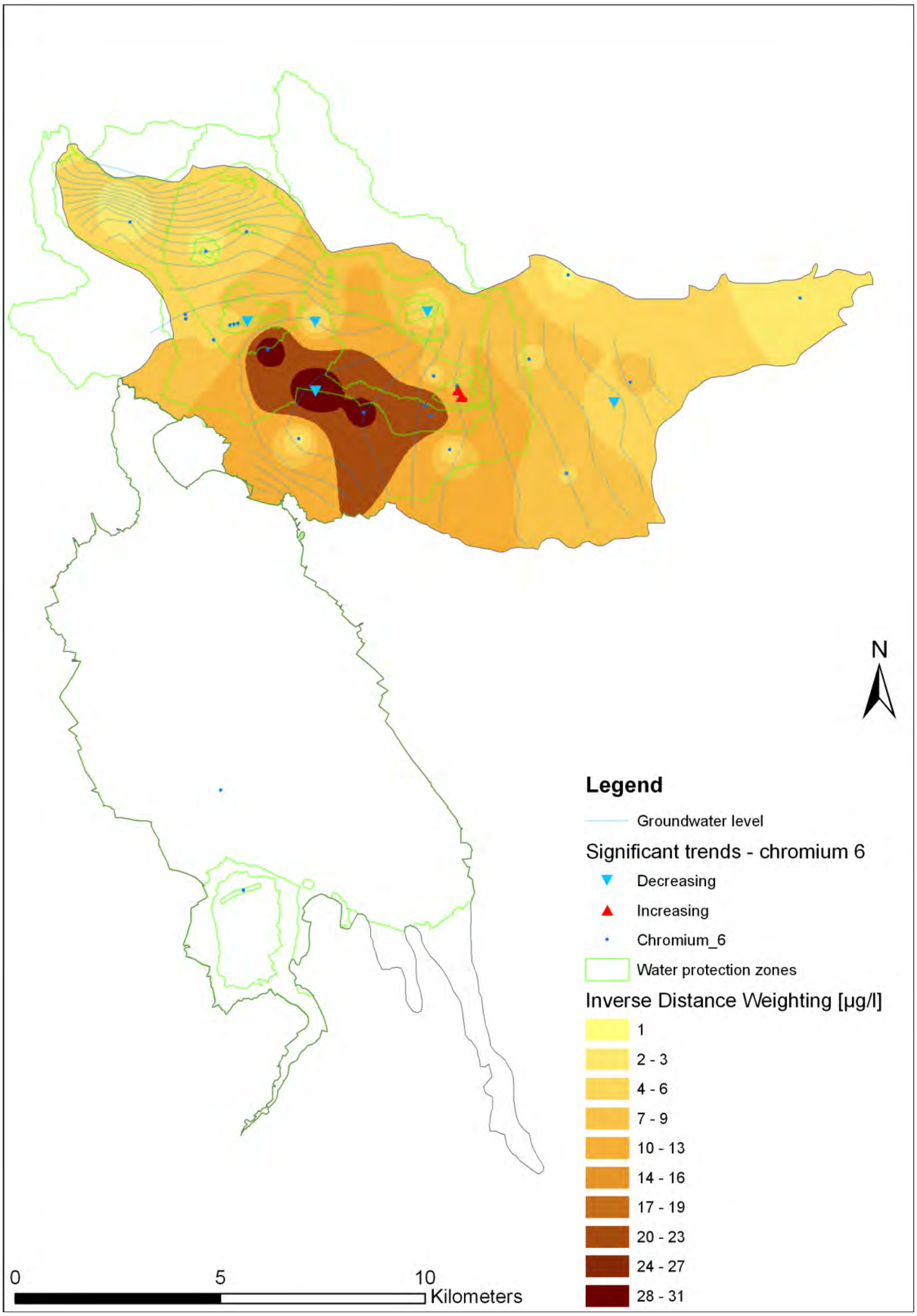
2 - 3
4 - 6
7 - 9
10 - 13
14 - 16
17 - 19
20 - 23
24 - 27
28 - 31
0
5
10
Kilometers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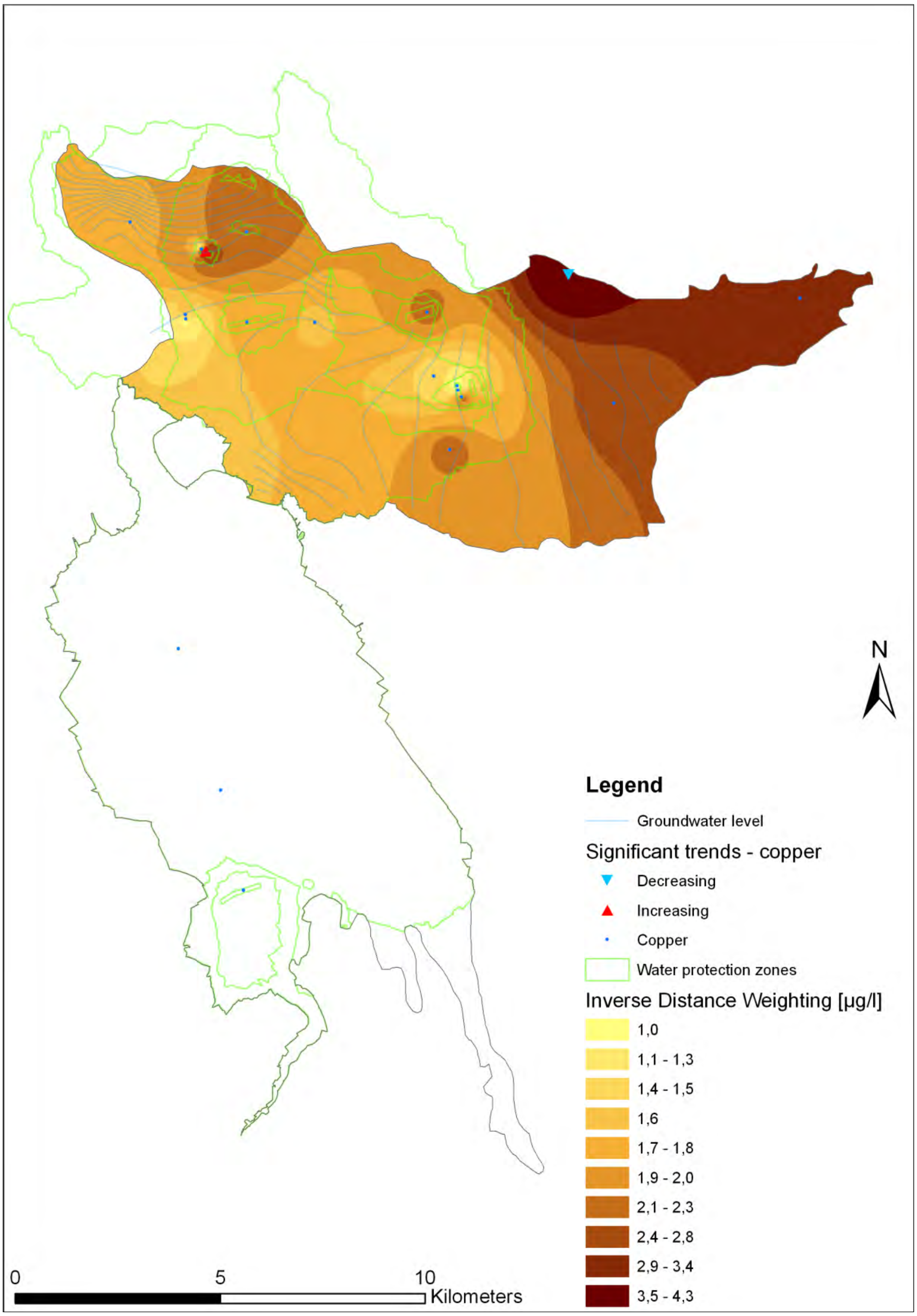
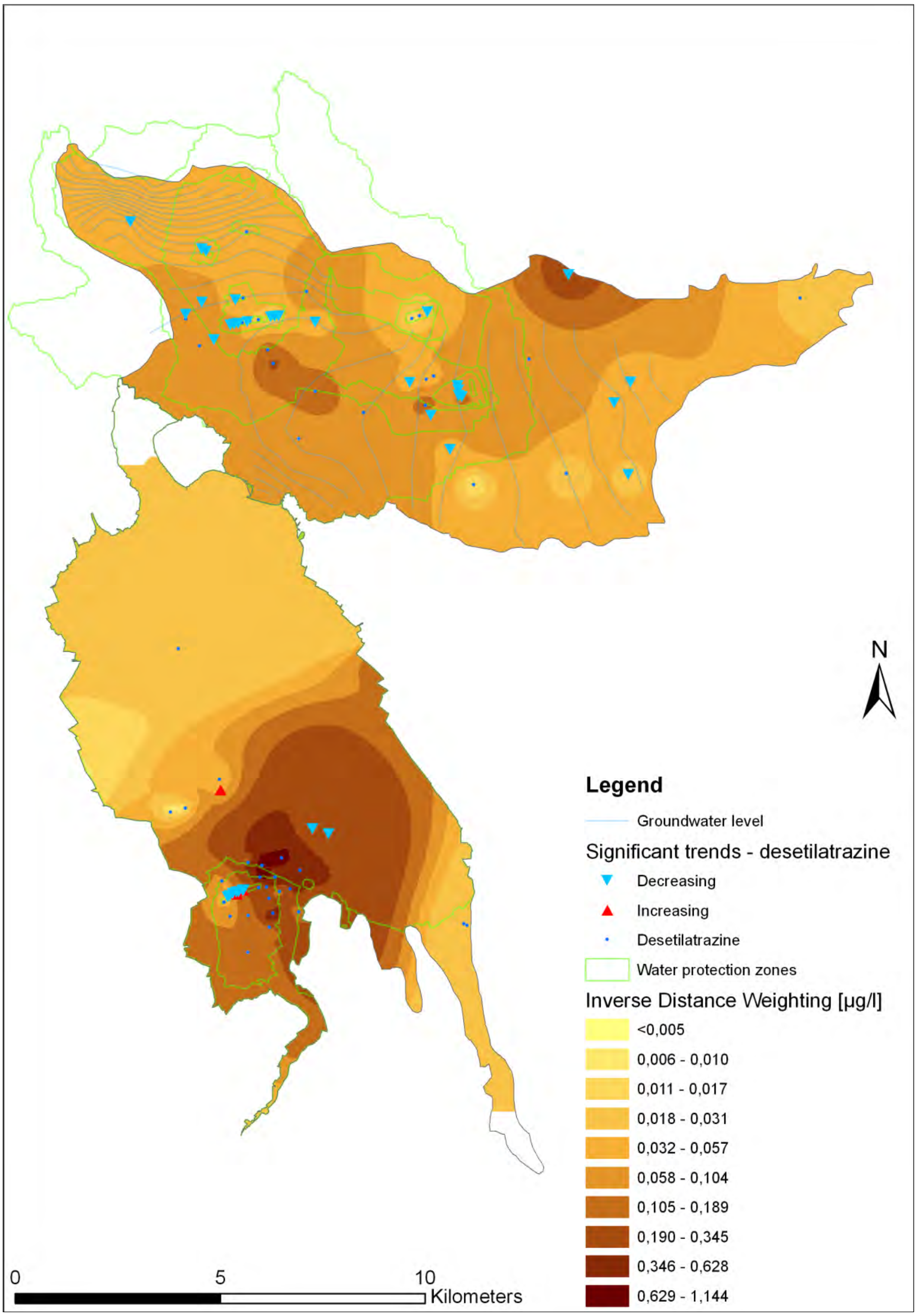
Legend
Groundwater level
Significant trends - chromium 6
Decreasing
Increasing
Chromium_6
Water protection zones
Inverse Distance Weighting [µg/l]
1
2 - 3
4 - 6
7 - 9
10 - 13
14 - 16
17 - 19
20 - 23
24 - 27
28 - 31
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - copper
Decreasing
Increasing
Copper
Water protection zones
Inverse Distance Weighting [µg/l]
1,0
1,1 - 1,3
1,4 - 1,5
1,6
1,7 - 1,8
1,9 - 2,0
2,1 - 2,3
2,4 - 2,8
2,9 - 3,4
3,5 - 4,3
0
5
10
Kilometers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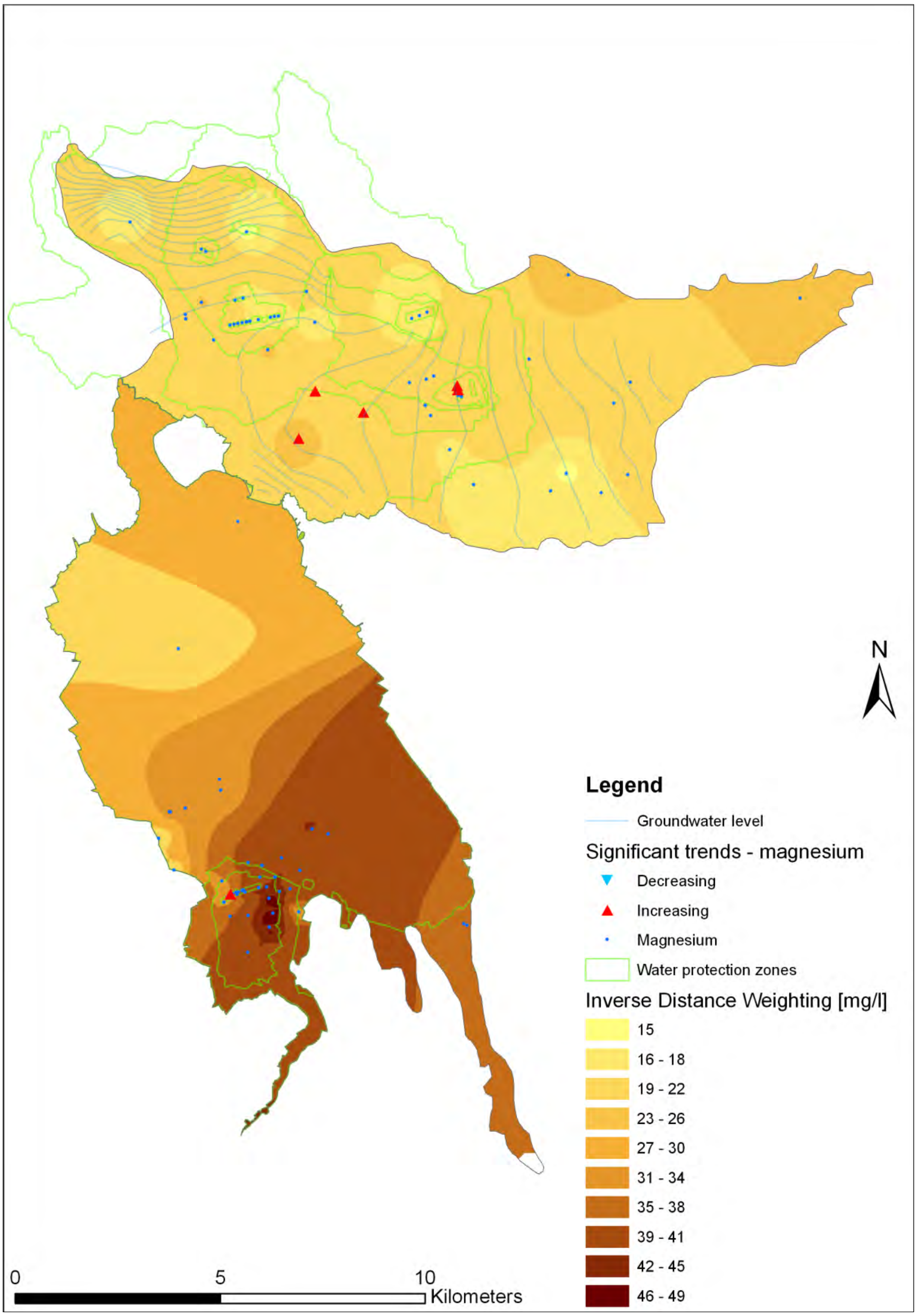
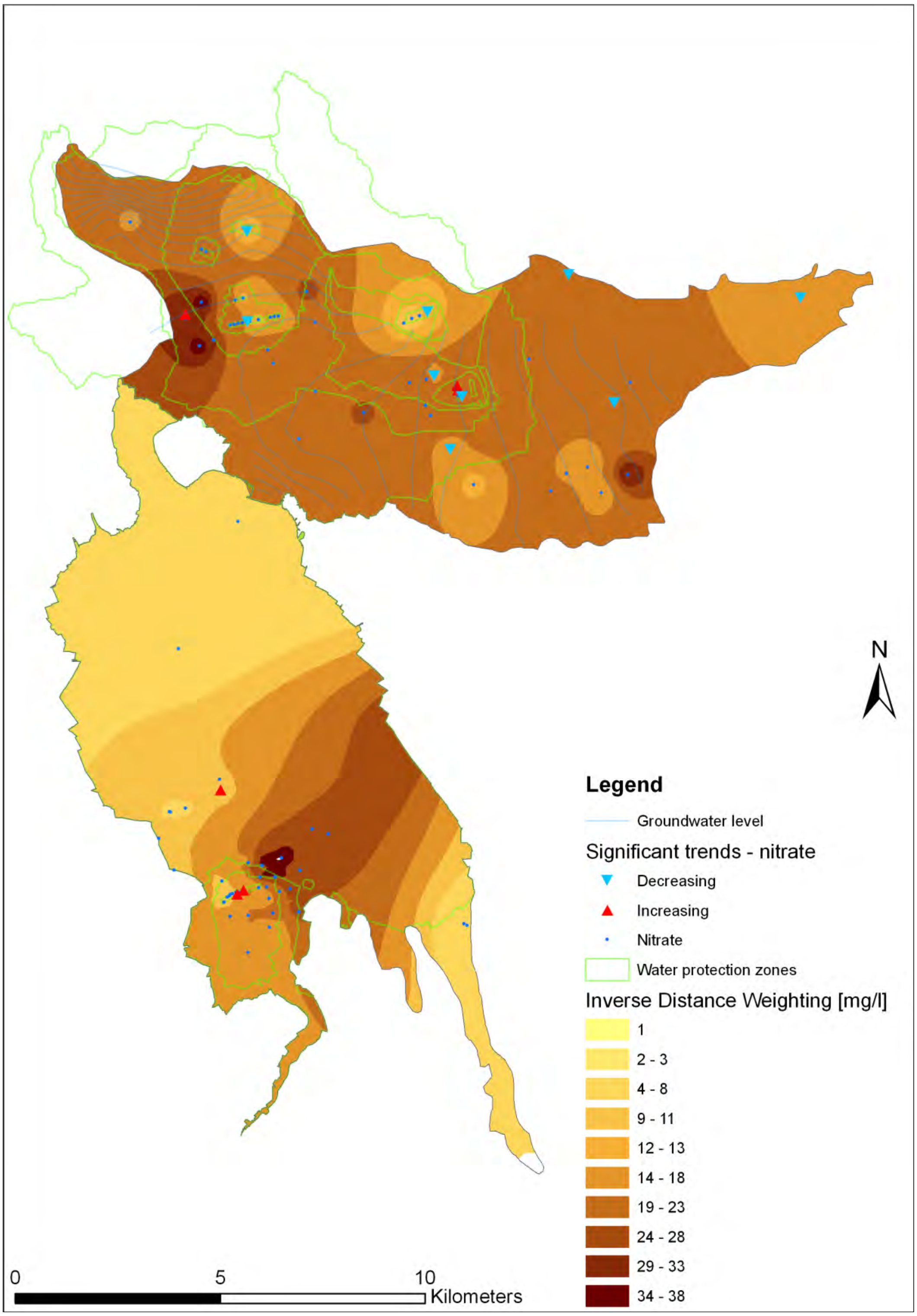
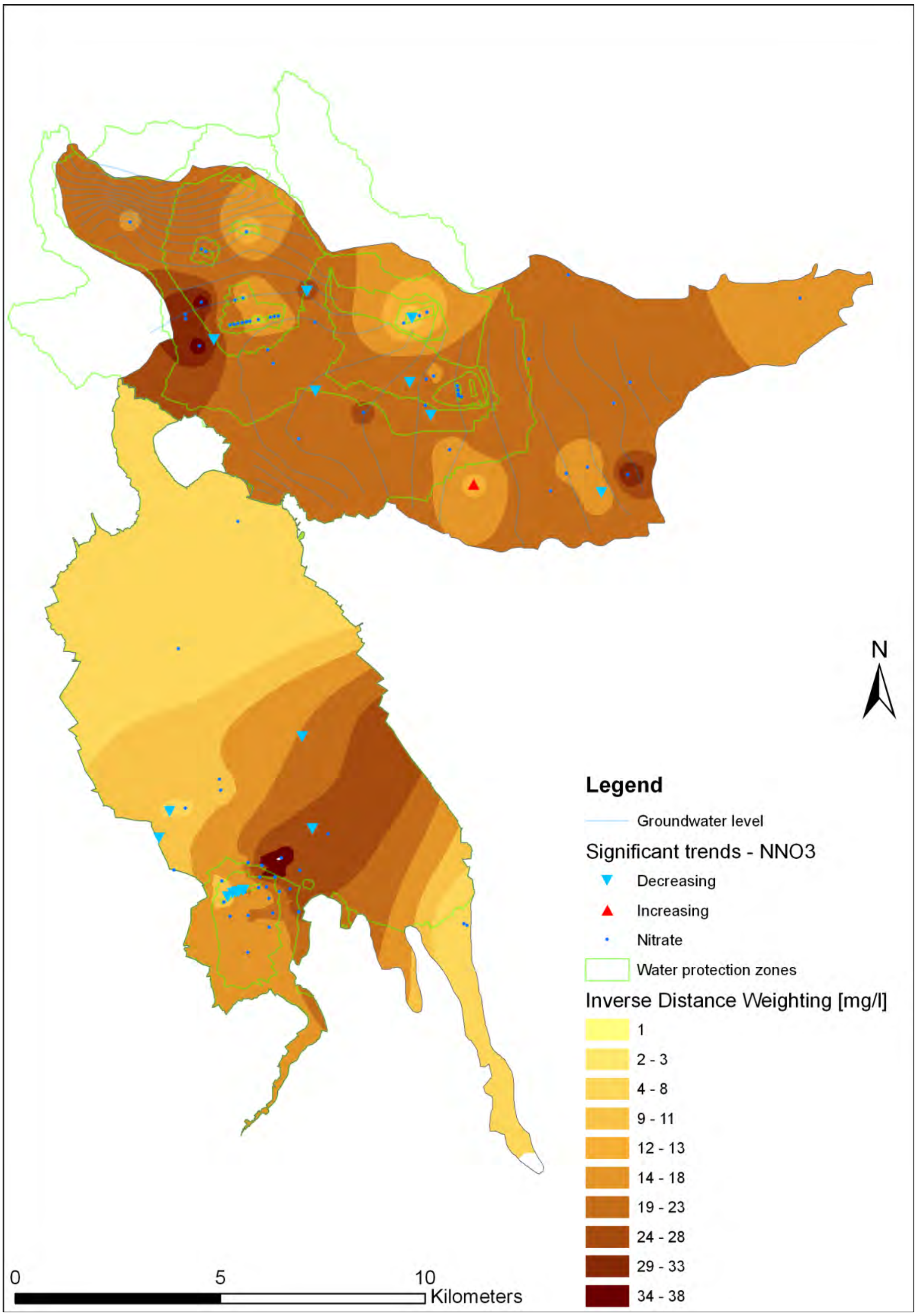
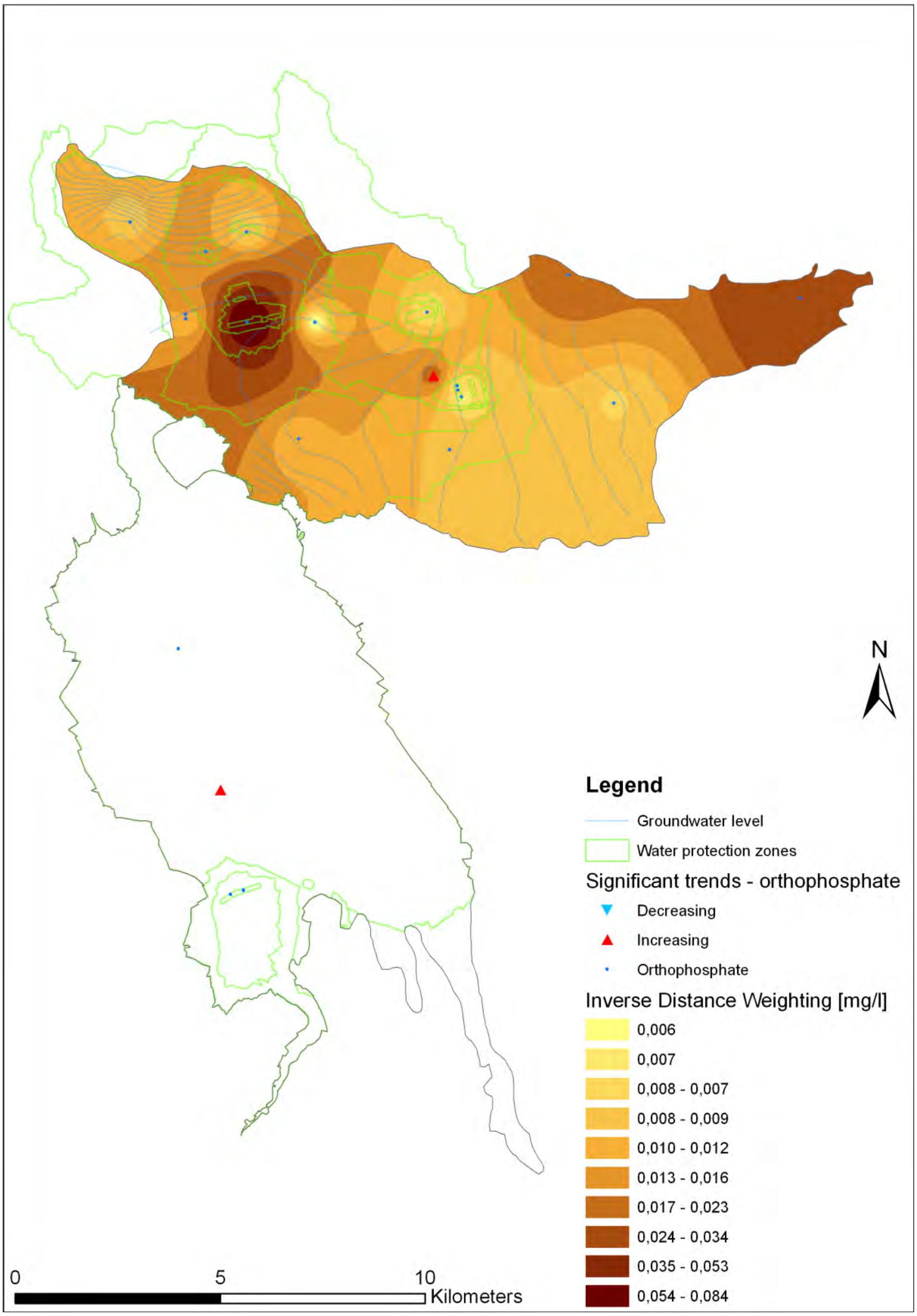
Legend
Groundwater level
Significant trends - desetilatrazine
Decreasing
Increasing
Desetilatrazine
Water protection zones
Inverse Distance Weighting [µg/l]
<0,005
0,006 - 0,010
0,011 - 0,017
0,018 - 0,031
0,032 - 0,057
0,058 - 0,104
0,105 - 0,189
0,190 - 0,345
0,346 - 0,628
0,629 - 1,144
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - magnesium
Decreasing
Increasing
Magnesium
Water protection zones
Inverse Distance Weighting [mg/l]
15
16 - 18
19 - 22
23 - 26
27 - 30
31 - 34
35 - 38
39 - 41
42 - 45
46 - 49
0
5
10
Kilometers



N
Legend
Groundwater level
Significant trends - nitrate
Decreasing
Increasing
Nitrate
Water protection zones
Inverse Distance Weighting [mg/l]
1
2 - 3
4 - 8
9 - 11
12 - 13
14 - 18
19 - 23
24 - 28
29 - 33
34 - 38
0
5
10
Kilometers


N
Legend
Groundwater level
Significant trends - NNO3
Decreasing
Increasing
Nitrate
Water protection zones
Inverse Distance Weighting [mg/l]
1
2 - 3
4 - 8
9 - 11
12 - 13
14 - 18
19 - 23
24 - 28
29 - 33
34 - 38
0
5
10
Kilometers


N
Legend
Groundwater level
Water protection zones
Significant trends - orthophosphate
Decreasing
Increasing
Orthophosphate
Inverse Distance Weighting [mg/l]
0,006
0,007
0,008 - 0,007
0,008 - 0,009
0,010 - 0,012
0,013 - 0,016
0,017 - 0,023
0,024 - 0,034
0,035 - 0,053
0,054 - 0,084
0
5
10
Kilometers