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Environmental health risk index, tool for the management of nitrates vulnerable zones

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Abstract. Nutrient pollution, originated from agricultural or household activities, is one of the main issues our modern world has to deal with. Due to the specific aspects this type of pollution implies the relative continuous character of the pollution process, the complex environment system implied (soil, surface waters, and ground waters), and the health risk raised to vulnerable population groups using well water for drinking purposes, these issues are difficult to manage and presume an integrated approach and a strategic perspective. In a specific approach included in the process of implementing the 91/676/CEE Directive, Romania has been initially assigned with nitrate vulnerable areas (NVZ), for 255 regions, representing 8.64% of the total surface of the country and, respectively, 13.93% of the total agricultural surface. The paper presents a methodology to establish an environmental health risk index as an intervention management tool for the designated NVZ, considering that Romania was advised by the European Commission to establish action plans against water resources' pollution by nitrates from agricultural source, for the entire country surface. The field results considered to build the risk index are provided by the project „Integrated Control of Nutrient Pollution", having the following objectives: (i) reducing nutrients discharge in water bodies; (ii) promoting behavioral shifts at regional level; (iii) providing support in strengthening regulation and institutional capacity system, coordinated by the Ministry of the Environment and Climate Changes, and financially supported by GEF, and IBRD. There were selected 87 rural localities representative for NVZ, with a population in range of 1,000-37,000 inhabitants, located in 34 counties all over the Romania. In each locality, water samples from private and public drinking water supplies were analyzed on site, using rapid field kits for nitrates, and sanitary inspections of the wells were carried out. The sampling points were recorded and represented in Geographic Information System (GIS) format. The model of establishing the risk index is based on the aggregation of data regarding water supply, coverage with sewage services, level of nitrates in shallow wells used for drinking purposes in rural areas, aquifer depth, health risk score based on sanitary field inspection, population information level, the presence of a manure disposal platform or any other similar facility, issues representative for reporting the information for decision makers and public.

Key Words: nitrate vulnerable areas, index, GIS, water resource.

Introduction. Nutrients' presence in the environment is normal and vital for the proper functioning of ecosystems; plants, animals and people need nutrients for growth and their survival. When the quantities of nutrients are too high, the balance is broken and the benefit is replaced by the pollution affecting the quality of shallow aquifers used for drinking purpose in rural areas, or yield to the eutrophication of surface waters. Polluting nutrients are represented by nitrogen and phosphorus compounds: nitrates, nitrites, ammonia, organic nitrogen, and phosphates.

Danube basin is also affected by this type of pollution, emissions of nitrogen and phosphorus leading to eutrophication processes extend to the western Black Sea shelf. During the period 1988-2005, the Danube River has brought an annual average of 35,000 tons of phosphorus and 40,000 tons of inorganic nitrogen (Trends in nutrient loads from the Danube River and trophic status of the black sea, September 2006). Out of the 14 countries within the Danube basin, Romania has the largest drained area (29% of the total area of the basin) and the largest population (27%) (Maps of the Danube River Basin District Management Plan 2009).

The European Union has the legal framework that allows the management of this problem, represented by:

- Water Framework Directive (2000/60/EC), which defines water as a heritage which must be protected and preserved. This Directive is a framework for sustainable water management, which involves its quantitative and qualitative management to support healthy ecosystems, and proposes achieving "good status" of water by 2015;

- Directive on the conservation of waters against pollution caused by nitrates from agricultural sources (91/676/EEC), which has two major implications: the protection of surface water intended for abstraction of drinking water (Directive 75/440/EEC) and the Directive on sludge from treatment plants (86/278/EEC);

- Directive on the quality of water intended for human consumption (98/83/EEC).

Romania, as an EU member state, has committed to implementing the obligations arising from EU directives mentioned above. Integrating the two Directives in Romanian legislation - 2000/60/EC and 91/676/EEC - was done by amending Law 107/1996 and GD 964/2000. These obligations relate to achieving ecological and chemical equilibrium of water, by management measures concerning organic pollutants, nutrients and hazardous substances.

Authorities in Romania are supported by technical assistance programs for the implementation of Directive 91/676/EEC on the basis of a loan from the World Bank with financial aid from Global Environment Facility (GEF) and from “Romanian Waters” National Administration (ANAR) budget by participation of the local authorities. In a specific approach included in the process of implementing the 91/676/CEE Directive, Romania has been initially assigned with nitrate vulnerable areas (NVZ), for 255 regions, representing 8.64% of the total surface of the country and, respectively, 13.93% of the total agricultural surface.

In vulnerable areas designated in 2003 were established based on criteria such as: the natural status of the soil, climate and hydrogeology involved in the transfer of nitrate to groundwater and surface water (Iordache et al 2013), taking into account the balance of nitrogen (nitrogen content of manure - nitrogen used by plant). There were identified three types of vulnerable areas:

- potentially vulnerable areas: the conditions for the transfer of nitrogen from water bodies is favorable, there is no positive nitrogen balance in the area and nitrate concentration of the groundwater measured in ANAR network is less than 50 mg L^{-1};

- areas vulnerable to actual sources: nitrate transfer conditions are favorable to water bodies and there is a positive nitrogen balance in the area;

- vulnerable areas of historical sources: the conditions for the transfer of nitrate from water bodies are favorable, there is no positive nitrogen balance of the area, there are or were livestock, and groundwater nitrate concentration measured by ANAR network is higher 50 mg L^{-1}.

Recently renewal designation of NVZ (December 2008) from agricultural sources, significantly increased their number to 1,963 communes, representing 60% of all surface of the country MO 1552/2008. This situation requires a tailored type of management witch is tested by the project "Integrated Nutrient Pollution Control", initiated by the Ministry of the Environment and Climate Change, having the following main objectives:

- reducing nutrient discharge into water bodies;
- promoting behavioral change at regional level;
- providing support to strengthen the regulatory framework and institutional capacity to enforce it.

Material and Method. The study was designed as an assessment of the access of rural population living in NVZ to public water supply and sanitation, and measurements of well water quality that is subject of contamination due to the current agricultural and sanitation practices. The study is meant to: (i) ground the environmental investments and public health interventions in hot spot areas; (ii) initiate the changing of behavior, and improve the current practices, for decreasing the pollution of water resource, and consequently to protect the health of the children exposed to high concentrations of nitrates due to the well water used to prepare the formula milk by caring out an information campaign for population.

The methodology to establish an environmental health risk index (RINA – Risk Index of Nutrients from Agriculture) as an intervention management tool for the designated NVZ, considering that Romania was advised by the European Commission to establish action plans against water resources' pollution by nitrates from agricultural source, for the entire country surface, is described further on. The field results considered to build the risk index, are provided by the project „Integrated Control of Nutrient Pollution".

The model of establishing the risk index is based on the aggregation of data regarding water supply, coverage with sewage services, level of nitrates in shallow wells used for drinking purposes in rural areas, aquifer depth (Scrădeanu & Alexandru 2007), health risk score based on sanitary field inspection, population information level, the presence of a manure disposal platform or any other similar facility, issues representative for reporting the information for decision makers and public.

The overlap of several information layers: (i) NVZ from agricultural sources; (ii) rural localities included in the study; (iii) location of water supplies that were investigated; (iv) concentration of nitrates in water samples; (v) risk areas for acute intoxication by nitrates of the new born children (Blue Baby Syndrome), was used as a tool to ground:

- the environmental decision: water resource protection, good agricultural code, investments in manure disposal platforms, investments in water and sewage infrastructure, pubels for domestic garbage;

- public health protection: awareness programs for target groups within the health risk areas, regarding the adequate behavior in order to prevent the occurrence of the illness cases, and train the trainers programs.

Results and Discussion. There were selected 87 rural localities representative for NVZ, with a population in range of 1,000-37,000 inhabitants, located in 34 counties all over the Romania. In each locality, water samples from private and public drinking water (DW) supplies were analyzed on site, using rapid field kits for nitrates (110092 Merckoquant® Nitrate, with the following rage of concentrations 10-25-50-100-250-500 mg L^{-1} NO_3). The results were compared with the MAC of 50 mg L^{-1} NO^{-}_3, as required by the Romanian legislation, Law no. 458/2002 regarding drinking water quality, with its further amendments. The sampling points were recorded and represented in Geographic Information System (GIS) format.

In Romania 45% out of total population is living in rural areas, and many localities from NVZ are not covered by public, centralized, drinking water (DW) and sewage systems (Table 1).

Table 1

Population coverage by public water supply and sewage systems

Crt. No.	*Locality*	*County*	*Population*	*Population connected to public DW systems %*	*DW Treatment Station*	*Population connected to sewage systems %*	*Waste Water Treatment Plant*
1.	Odorheiul Secuiesc	Harghita	33,000	99	yes	95	yes
2.	Gârla Mare	Mehedinţi	3,500	25	yes	10	yes
3.	Crăieşti	Mureş	883	-	yes	-	-
4.	Gorneşti	Mureş	5,856	70	yes	5	yes
5.	Bocsig	Arad	3,200	100	yes		
6.	Macea	Arad	5,680	90	yes	-	-
7.	Pecica	Arad	13,500	30	yes	10	yes
8.	Maşloc	Timiş	2,315	30	yes	-	-
9.	Parţa	Timiş	2,200	100	yes	-	-
10.	Peciu Nou	Timiş	5,213	90	yes	25	yes
11.	Şag	Timiş	3,000	90	yes	-	-
12.	Gătaia	Timiş	5,400	60	yes	20	-

In rural localities and poor peri-urban areas the sanitation is represented by pit latrines that assure the retention of solids (fecal material), but allow the liquid (urine) infiltration, causing the pollution with nutrients and pathogens of the shallow aquifers used for drinking purposes. Although the public sewage systems could be considered the adequate solution, in practice 90% of the waste water is not properly cleaned and is a cause of water resource pollution. EC Guidelines recommend sealed septic tanks and the transportation of their content to a waste water treatment plant. Romania adopted the same requirement by GD 352/2005, art 6, annex 1, paragraph (2). The accepted solutions for individual waste water treatment systems are those with no adverse effect on the environment such as stabilization ponds, and mechanical-biological treatment plants (that can include disinfection).

During the period June–September 2012, there were analyzed water samples from 408 wells used for drinking purpose. The mean values of the nitrates concentrations are shown in Table 2.

Table 2

NO^{-}_{3} levels in well water from rural localities designated as NVZ

Crt. No.	*Locality*	*County*	*Well water quality (% wells)*				
			0–10 mg L^{-1} NO_3	*11–25 mg L^{-1} NO_3*	*26–50 mg L^{-1} NO_3*	*51–100 mg L^{-1} NO_3*	*100–500 mg L^{-1} NO_3*
			$<$ MAC (50 mg L^{-1})			*$>$ MAC (50 mg L^{-1})*	
1.	Odorheiu Secuiesc	Harghita	60.00	20.00	20.00	-	-
2.	Gârla Mare	Mehedinţi	-	-	28.57	42.85	28.57
3.	Crăieşti	Mureş	33.33	16.66	-	33.33	16.66
4.	Gorneşti	Mureş	14.28	14.28	57.14	14.28	-
5.	Bocsig	Arad	-	28.57	42.85	14.28	14.28
6.	Macea	Arad	-	10.00	15.00	30.00	45.00
7.	Pecica	Arad	-	-	-	25.00	75.00
8.	Maşloc	Timiş	36.36	18.18	9.09	-	36.36
9.	Parţa	Timiş	22.22	-	11.11	22.22	44.44
10.	Peciu Nou	Timiş	14.28	14.28	-	-	71.42
11.	Şag	Timiş	50.00	8.33	16.66	8.33	16.66
12.	Gătaia	Timiş	50.00	-	25.00	-	25.00

As average, in approximately 47% of the analyzed wells the level of nitrates water samples exceeded the maximum admissible concentrate (MAC) of 50 mg L^{-1}.

The layers of information in GIS format: (i) rural localities included in the study; (ii) nitrates levels in well water samples, are shown in Figure 1.

The sanitary inspection carried out for the households from which well water sample were analyzed, show several vulnerabilities. The pollution by nitrates from agricultural sources is complemented by: (i) inadequate sanitation (human faces); (ii) lack of household and yard hygiene; (iii) inadequate location of the well towards the areas of constructed buildings and activities carried out – animal barn, manure disposal, pit latrine, domestic garbage disposal, vegetable garden, house; (iv) lack of organization of domestic and agricultural activities potentially polluting the aquifer that supplies water from the fountain (SSWM, Water Management Toolbox "Linking up Sustainable Sanitation, Water Management and Agriculture).

The solution to the problem of waste water proposed by the implementation plan of the Directive 91/271/EEC transposed into the Romanian legislation by GD 188/2002 is the connection of the rural population to waste water treatment plants, meaning the constructions of 2,346 such facilities for the agglomerations in range of 2,000-10,000 population equivalents, by the year 2018, witch doesn't seem as a realistic approach. It is more likely that the promotion of a sustainable sanitation could be a better alternative. The basic principle of this kind of sanitation is that „waste water should not be considered a waste, but a valuable resource. The sanitation systems should be organized in a socially acceptable and economically viable manner".

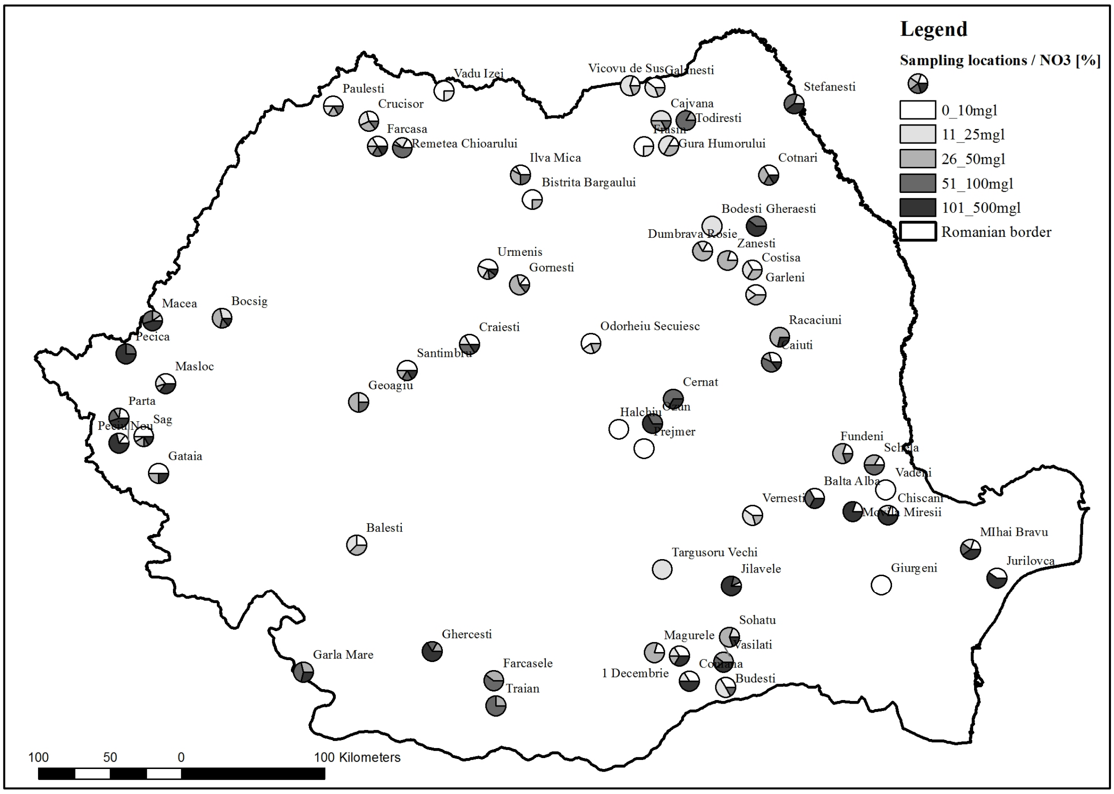

Figure 1. Nitrates levels in well water from NVZ.

For the purpose of RINA (Risk Index of Nutrients from Agriculture) calculation it was considered a sample of 12 localities on which it was calibrated the formula. The second stage of the study will contain the whole analysis of the 87 localities representative for NVZ. The components of the index have been designed to assess the risk to the population and as subordinate priority to the environment (eutrophication, impact on fauna, flora, etc). RINA's calculation formula is the following:

$$RINA = kr*WS+kr*SW+kr*N+kr*GWL+kr*WRS+kr*PK+kr*SF+kr*AP$$

where:

- Kr = Coefficient of relevance;
- WS = Water Supply;
- SW = Sewage;
- N = Nitrates;
- GWL = Ground water level;
- WRS = Well's risk score;
- PK = Population level of knowledge;
- SF = Storage facility;
- AP = Size of affected population.

Relevance Coefficient (kr) being a parameter that characterizes the locality, not the households, the components N, GWL, WRS and PK will be considered as average values from at least 10 sampling points with a relevant distribution in the village. Kr indicates the significance of the contribution of each parameter to the final component of risk index (Table 3).

Table 3

The weight of each parameter in the correlation coefficient

Component	*WS*	*SW*	*N*	*GWL*	*WRS*	*PK*	*SF*	*Size of AP*
Relevance coefficient (kr)	4	3	2	2	1	2	3	1 – (< 2,000) 2 – (2,001 – 5,000) 3 – (5,001 – 10,000) 4 (> 10,001)

Data concerning the coverage of population of the locality with central drinking water supply (WS) is quantified with 1 if the answer is NO, and (1-(%/100)) if the answer is YES.

Data concerning the population coverage with sewage systems (SW) is quantified with 1 if the answer is NO, and (1-(%/100)) if the answer is YES.

The nitrates' concentration in ground water (N), measured on site, receives a score according to its value in a range of concentration, as follows: 0 (0-50 mg L^{-1}); 1 (50.1–100 mg L^{-1}); 2 (100.1–250 mg L^{-1}), and 3 (> 250.1 mg L^{-1}).

Ground water level (GWL) measured on the field and registered on sanitary inspection form is quantified as follows: 1 (>10.1 m); 2 (5.1-10 m); 3(2.1-5 m); 4(0-2 m).

The risk score of the well (WRS) calculated based on the field observations registered on sanitary inspection form is quantified as follows: 0 (0-2); 1 (2.1-5.9); 2 (6-8.9); 3 (9-12).

Level of population knowledge (PK) regarding the pollution sources with nutrients and their impact on public health, and on the environment is quantified as follows, based on populations' answers at questionnaires: 0 (good level); 1 (average); 2 (poor).

The presence or absence of a disposal facility for manure (SF) is quantified as follows: 0 (platform compling with legal requirements); 1 (other similar storage facilities); 2 (absence of any mean to storage the manure).

The size of affected population (AP) is linked in the calculation formula with population coverage with drinking water supply (WS), and sewage systems (SW). In Table 4 you can see minimum and maximum range.

Further on there are shown some information needed for RINA's calculation (Tables 5 and 6).

Table 4

Risk assessment score criteria

Crt. No.	*Criteria*	*Score*	
		minimum	*maximum*
1.	Water Supply (WS)	0	4
2.	Sewage System (SW)	0	3
3.	Nitrates (NO_3) concentrations in ground water (N)	0	6
4.	Ground water level (GWL)	2	8
5.	Wells' risk score (WRS)	0	3
6.	Level of knowledge in population (PK)	0	4
7.	Presence/ absence of manure storage platfor or of similar facilities (SF)	0	6
8.	Size of affected population (AP)	0	28
	Total	2	62

Table 5

Information about the sample of localities used to calibrate RINA

Crt. No.	*Locality*	*County*	*Population*	*NO^{-}_3 in DW (mgL^{-1})**	*Ground water level (m)**	*Well Risk Score**	*Level of population information*	*Manure disposal facility*
1	Odorheiul Secuiesc	Harghita	37,000	19	8	2	Average	Yes
2	Gârla Mare	Mehedinţi	3,500	164	6	4	Average	Yes
3	Crăieşti	Mureş	883	82.5	2.33	3.66	Poor	Yes
4	Gorneşti	Mureş	5,856	46.42	5	4	Poor	Yes
5	Bocsig	Arad	3,200	78.57	17	4	Poor	Yes
6	Macea	Arad	5,680	202.5	4.72	4.12	Poor	No
7	Pecica	Arad	13,500	158.57	4	5.33	Average	Yes
8	Maşloc	Timiş	2,315	146.36	2.96	2.4	Poor	No
9	Parţa	Timiş	2,200	194.44	6	5	Poor	No
10	Peciu Nou	Timiş	5,213	289.28	4.4	6	Poor	Yes
11	Şag	Timiş	3,000	82	5.71	1.83	Poor	No
12	Gătaia	Timiş	5,400	77.5	3.4	4	Average	No

*) average value

Table 6

RINA calculation

Crt. no.	*Locality*	*County*	*WS*	*SW*	*N*	*GWL*	*WRS*	*PK*	*SF*	*AP*	*RINA*
1.	Odorheiul Secuiesc	Harghita	0	0.15	0	4	0	2	0	0.6	6.8
2.	Gârla Mare	Mehedinţi	2.8	3	4	4	1	2	0	11.6	28.4
3.	Crăieşti	Mureş	4	3	2	6	1	4	0	7	27.0
4.	Gorneşti	Mureş	1.2	2.85	0	6	1	4	0	12.15	27.2
5.	Bocsig	Arad	0	3	2	2	1	4	0	6	18.0
6.	Macea	Arad	0.4	3	4	6	1	4	6	10.2	34.6
7.	Pecica	Arad	2.8	2.7	4	6	1	2	0	22	40.5
8.	Maşloc	Timiş	2.8	3	4	6	1	4	6	11.6	38.4
9.	Parţa	Timiş	0	3	4	4	1	4	6	6	28.0
10.	Peciu Nou	Timiş	0.4	2.25	6	6	2	4	0	7.95	28.6
11.	Şag	Timiş	0,4	3	2	4	0	4	6	6.8	26.2
12.	Gătaia	Timiş	1.6	2.4	2	6	1	2	6	12	33.0

RINA values are in the range of 2-62, the higher the value is, the higher the risk is. There were established the following risk thresholds, and their significance for the population safety:

$2 \leq$ RINA ≤ 10 = low risk for the population living in locality
$11 \leq$ RINA ≤ 20 = average risk for the population living in locality
$21 \leq$ RINA ≤ 62 = high risk for the population living in locality.

Although the sample of localities was established only for the purpose of index calibration, it is easy to see that 8.33% of the localities have a RINA score indicating a low risk, 8.33% presents an average risk, and the rest of 83.33% are at high risk, values that reflects the situation met in the field.

For the cases in which the well water is already heavily contaminated by nitrates, short term and medium term solution have to be provided to the population, together with appropriate advice for technical and health issues. There are few alternatives to decrease the concentration of nitrates in well water, and avoid in this way the occurrence of Blue Baby Syndrome illness cases: (i) to drill deeper in order to supply the well from a clean aquifer; (ii) to mix the contaminated water with clean water, up to a dilution that comply with MAC for nitrates 50mg NO^{-}_{3}/l; (iii) to give up at the contaminated water source if there is an alternative, like the connection to a public centralized system; (iv) to treat the water in order to remove the excess of nitrates using ion exchange resins, or reverse osmosis, or any other appropriate technology for small individual water supply systems; (v) to protect the water courses and bodies against future pollution by restriction or banning the use of nitrogen based fertilizers within the hydro geological protection zones; (vi) to adopt new alternatives of sustainable sanitation for the prevention of ground water pollution.

Conclusions. Substantiation of RINA risk index (Risk Index of Nutrients from Agriculture) is based on the assumption that all risks to which man is subject are systematically identified, analyzed and evaluated, and it can be taken rational decisions on how to reduce the risk and its implications: the social and economic costs, the costs associated with ensuring the basis of an integrated management and secure environment, and on the other hand on how to use the benefits of risk reduction.

The GIS tool helps the corroboration of the data regarding NVZ that are managed by the environmental protection authorities within the implementation plan of the Nitrate Directive with the data regarding the illness cases generated by the consumption of water contaminated by nitrates that are managed by the public health authorities. GIS used as a decision making support could increase the efficiency of the environmental and public health interventions and investments to the hot spot areas. The inter-institutional cooperation is vital for solving these kinds of problems. Population information and education is also a basic brick for the long term behavioral changes.

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