EKOLOGIJA. 2005. Nr. 4. P. 13–19

Evaluation of the impact of anthropogenic factors on the pollution of shallow well water

Vida Rutkovienë,

Albinas Kusta,

Laima Èesonienë

Lithuanian University of Agriculture, Studentø 11, LT-53361 Akademija, Kaunas district, Lithuania
E-mail: albinas.kusta@lzua.lt

Pollution of shallow well water is an indicator of environmental pollution and is especially susceptible to the impact of anthropogenic factors. One third of Lithuanian population uses shallow well water for food making, daily living needs and farming activities. Water quality has a direct impact on human health. High rates of morbidity and mortality are partly related to the bad quality of shallow well water. Water enters shallow wells from shallow groundwater sources which are especially susceptible to chemical and microbiological pollution. Various anthropogenic factors such as the intensity of farming, potential pollution sources in the sanitary zone, well protection from environmental pollution may determine the fluctuation of water quality. Data on the intensity of farming were gathered, analysis of shallow well water pollution was carried out in 35 villages of Kaunas District, and water of 809 shallow wells was evaluated. A multiple linear regression analysis of the impact of environmental factors on shallow well water showed that the distance from the well to the outhouse, cowshed, manure clamp and kitchen garden, the water level in the well and the quality of well construction have the greatest influence on the pollution by nitrogen or organic compounds. Data obtained on the pollution of shallow wells allow to estimate the impact of anthropogenic factors on the changes of environment quality and to forecast the level of pollution.

Key words: shallow well, water quality, anthropogenic factors

INTRODUCTION

There are about 300 thousand shallow wells in Lithuania, which are used by one third of population (Kadûnas & Maðanauskas, 1992). Water enters shallow wells from shallow sources of groundwater which is especially susceptible to chemical and microbiological pollution (Hallberg et al., 1987; Fuest et al, 1998; Noland, Stoner, 2000). Some ecologists claim that about 80% of all diseases in the world and high morbidity rates in villages are related to the unsatisfactory quality of drinking water (Drinking, 1990). Drinking water pollution of anthropogenic nature is one of the key factors having a direct impact on human health. The relation between the quality of drinking water and human health is particularly close when bad quality shallow well water is used.

The type of the well, its depth, age and structural features can also influence its water quality. Water pollution is more common in old and shallow wells (Baker et al., 1994). Richards et al. report highly significant differences in nitrate concentrations as a function of well depth (Richards et al., 1996). The nitrate concentration in water, pH and water temperature depend on the depth and age of the well (Bruggeman et al., 1995). In the report, an inverse correlation between the well depth and nitrate concentration was found (Clawges, Vowinkkel, 1996). Glanville et al. (Glanville et al., 1997) observed a fairly strong negative correlation between nitrate and well depth ($p < 0.001$), too. Baker et al. (Baker et al., 1994) state several times that shallow wells are more likely to be contaminated than deep wells. In many cases, nitrate pollution increases with anthropogenic activities in the vicinity of the well, as well as due to an inappropriate location of the well (Fawcett, Lym, 1992). Analysis of Kutra et al. (Kutra et al., 2002) variograms formed on the basis of data of the year 2000 showed that the interface between two different wells exists at a distance of 142 meters. Farm buildings, including cowsheds, also greenhouses, gardens, outhouses, dumps and other pollution-aggressive objects are usually situated at the above mentioned distance from wells. The direction of groundwater flow is significant for the occurrence of contamination as well.

The goal of the current research was to determine the impact of anthropogenic factors such as the intensity of farming and water consumption, well construction, surroundings of wells on the pollution of shallow wells. Evaluation of the factors affecting the fluctuation of pollution allows to forecast the level of pollution.

MATERIALS AND METHODS

Shallow wells in Kaunas District village-type places were chosen for examination, because the majority of Lithuanian town inhabitants use water obtained from deep underground resources, while village inhabitants, on the contrary, use mostly bad quality groundwater occurring in the surface. Therefore it is of utmost importance to be aware of the impact of environmental factors on water quality. Kaunas District is one of the largest in Lithuania. It has a long tradition of intensive farming with an area of 1521 km^2 and a population of 81,700. The river Nemunas crosses the district and the river Nevëþis flows into the river Nemunas there.

Shallow well water quality was examined during the period 2003–2005, in 35 villages of Kaunas District; in total, water quality of 809 shallow wells was examined. The parameters such as nitrogen compounds, organic substances and pH were determined.

Chemical analyses were carried out at the Environmental Laboratory of the Lithuanian University of Agriculture. All analyses were made by standard methods: nitrates – according to LST ISO 7890-2 (1998), nitrites – to LAND 39 (2000), ammonium ions – LAND 38– (2000), organic substances were estimated by the permanganate value (P.V.) and pH was established potentiometrically.

In order to establish the dependence between the well water quality indicators, farming intensity and environmental conditions, 809 farmers were questioned about stock and poultry breeding, fertilizers used, sewage management, etc. The distance from the wells to cowsheds, manure clamps, outhouses, kitchen gardens was measured; the well construction, depth and water level and selling around were estimated.

Soil texture was determined in sites of typical relief, taking samples from various layers up to the saturation zone. Soil texture was determined at Soil Department of the Lithuanian State Land Survey Institute according to the FAO / ISRIC classification. According to the determined soil texture, the loam of average heaviness dominates in the upper layer of the ground (p_1) – the filtration coefficient is 0.05–0.1 m/d; in the second layer of the ground the loam of average heaviness dominates with the filtration coefficient 0.05 m/d. Because previous studies have determined (Èesoniene; 2004) that water quality is greatly influenced by the direction of groundwater, which does not always coincide with surface relief, the latter was neglected in this research.

The parameters of well construction and its surroundings were evaluated according to their conformity to the requirements set in the order of the Minister of Agriculture and the Lithuanian Minister of Environment "On approval of requirements to water protection from pollution by nitrogen compounds from agricultural sources" (the order issued by the Lithuanian Minister of Agriculture and the Minister of Environment, 2001). Well covering, ventilation, pit construction, ground surface slope, the lifting device and construction of the protection zone around the well were evaluated. The conformity with these requirements is evaluated using a 5-point system. Well depth and water level in the well measured from the ground surface, distances from a shallow well to potential pollution sources (such as cowsheds, outhouses, manure clamps and kitchen gardens) in farms were evaluated with a 1-metre accuracy.

For the calculation of the coefficients of environmental impact on chemical anilides, the SPSS 10.0 programme was used. Dependence between the dependent (concentration of pollutants in the water of shallow wells) and independent variables (environmental factors) was analysed using the method of multiple regression assuming the constant values of secondary independent factors (Rothman, 1998). The model of linear multiple regression is:

$$Y_i = A + B_1 x_{1i} + B_2 x_{2i} + \ldots + B_k x_{ki},$$

where Y_i is the dependent variable (nitrate concentration in the water of shallow wells), A is a constant, B is the non-standardized coefficient; x denotes independent variables (well depth and water level (in meters), distances (in meters) from the shallow well to potential sources of pollution (cowsheds, outhouses, manure clamps and kitchen gardens), surroundings of the well (in points), livestock farming and poultry breeding categorized: 1 – stored closer than 25 m; 2 – further than 25 m.

The model of multifactor regression relation is suitable for forecasts when there is no interrelation among all the independent variables. When there is a strong correlation among the variables, the problem of multicolinearity arises. The variable is multicolinear if the multiplier of the disperse decrease VIF > 4. In our case, the distances to cowsheds, manure clamps and outhouses are regarded as multicolinear variables (VIF > 4). Therefore, in order to avoid multicolinearity, the arithmetic average of these distances was calculated separately for each farmstead. Applying multiple regressions, the influence of each distance separately was statistically significant.

RESULTS

After evaluation of location selection for shallow wells, environmental risk factors falling into three groups were determined:

1. Well depth and water level in it.
2. Type of farming (livestock farming or crop production).
3. Selection of well location and its protection.

The average depth of the wells was 6.25 m, the depth of the shallowest well being 1.0 m, and of the deepest 19 m. The average water level from ground surface in the shallow wells was 3.1 m, the minimum being 0.2 m and the maximum 15 m.

The risk of water contamination is highest in farmsteads with livestock. In 61% of all farmsteads livestock is bred, dwellers of 78% of all farmsteads breed poultry.

Data on the environment of the farmsteads are presented in Table 1.

The investigations showed that in even 27% of farmsteads the distance (1–10 m) between the dug well and the kitchen garden was too short (evaluated according to their compliance to the mentioned order of the Lithuanian Minister of Agriculture and the Lithuanian Minister of Environment), and the distance between the dug well and the cowshed was not safe enough (11–25 m) in 43% of farmsteads, while in 30% the distance from the well to the outhouse was too short.

Evaluation of the well surroundings using a 5-point system is presented in Table 2.

Results of the evaluation show that environment of farmsteads was organised moderately well or well (33%), surroundings of 18% of all farmsteads were poorly organised, while only 11% of all farmsteads had very well organised surroundings. Surroundings of 5% of all farmsteads were rated as especially poorly organised.

Table 1. **Distance between wells and sources of pollution, %**

Source of pollution	Distance 1–10 m	Distance 11–25 m	Distance 26–50 m	Distance 51–200 m
Cowshed	6%	43%	34%	17%
Outhouse	4%	30%	42%	24%
Manure clamp	4%	28%	38%	30%
Vegetable garden	27%	25%	16%	32%

Table 2. **Evaluation of the well environment**

1 point	2 points	3 points	4 points	5 points
5%	18%	33%	33%	11%

Impact of shallow well environment on nitrate concentration

The impact of environmental factors on NO_3^- **(Y)** concentration in the water of shallow wells was calculated using the method of multifactor regression analysis. Results are presented in Table 3.

The coefficient b_j reflects the y value increase (decrease) when

Table 3. **Impact of environmental factors on NO_3^- (Y) concentration in the water of shallow wells**

Environmental factor	Non-standardized coefficients		Standardized coefficient		
	B	Standard error	beta	t	p
Constant	26720.7**(a)**	7905.49		3.380	0.001
* Livestock **(x_1)**	45.29 **(b_1)**	11.778	0.183	3.846	0.000
Poultry **(x_2)**	15.223 **(b_2)**	13.724	0.052	1.109	0.268
* Distance from the well to the cowshed, outhouse and manure clamp **(x_3)**	–0.613 **(b_3)**	0.219	–0.114	–2.795	0.005
* Distance to the vegetable garden **(x_4)**	–0.313 **(b_4)**	0.124	–0.103	–2.530	0.012
Depth of the well **(x_5)**	2.242 **(b_5)**	3.098	0.042	0.724	0.469
Water table in the well **(x_6)**	1.785 **(b_6)**	3.876	0.026	0.461	0.645
*The well installation (1–5 points) **(x_7)**	–9.040 **(b_7)**	5.208	–0.071	–1.736	0.043

Livestock and poultry breeding categorized: 1 – stored closer than 25 m; 2 – further than 25 m.
* The factor is statistically significant at $p < 0.05$.

Table 4. **Impact of environmental factors on NO_2^- (Y) concentration in the water of shallow wells**

Environmental factor	Non-standardized coefficients		Standardized coefficient		
	B	Standard error	beta	t	p
Constant	7.67* 10^{-2} **(a)**	0.057		1.336	0.182
* Livestock **(x_1)**	9.29 * 10^{-3} **(b_1)**	0.025	0.018	0.366	0.715
Poultry **(x_2)**	1.09 * 10^{-2} **(b_2)**	0.030	0.018	0.369	0.712
* Distance from the well to the cowshed, outhouse and manure clamp **(x_3)**	–9.37 * 10^{-4} **(b_3)**	0.000	–0.086	–2.031	0.043
* Distance to the vegetable garden **(x_4)**	–2.73 * 10^{-4} **(b_4)**	0.000	–0.043	–1.017	0.310
Depth of the well **(x_5)**	7.10* 10^{-3} **(b_5)**	0.007	0.063	1.052	0.046
Water table in the well **(x_6)**	–1.74 *10^{-2} **(b_6)**	0.008	–0.124	–2.067	0.039
*The well installation (1–5 points) **(x_7)**	–1,52* 10^{-2}**(b_7)**	0.010	–0.062	–1.462	0.144

* The factor is statistically significant at $p < 0.05$.

Table 5. **Impact of environmental factors on NH_4^+ (Y) concentration in the water of shallow wells**

Environmental factor	Non-standardized coefficients		Standardized coefficient		
	B	Standard error	beta	t	p
Constant	0.789 **(a)**	0.172		4.576	0.000
* Livestock **(x_1)**	3.77* 10^{-2} **(b_1)**	0.107	0.034	0.352	0.726
Poultry **(x_2)**	0.215 **(b_2)**	0.119	0.170	1.808	0.049
* Distance from the well to the cowshed, outhouse and manure clamp **(x_3)**	–6.15* 10^{-2} **(b_3)**	0.004	–0.230	–1.667	0.043
* Distance to the vegetable garden **(x_4)**	–1.49* 10^{-2} **(b_4)**	0.001	–0.097	–1.253	0.212
Depth of the well **(x_5)**	–1.17* 10^{-2} **(b_5)**	0.026	–0.047	–0.453	0.651
Water table in the well **(x_6)**	6.50* 10^{-2} **(b_6)**	0.032	0.211	2.040	0.039
*The well installation (1–5 points) **(x_7)**	–0,225 **(b_7)**	0.128	– 0.095	–1.125	0.262

* The factor is statistically significant at $p < 0.05$.

x_j increases by one unit, given the remaining x_k are fixed; t is the Student criteria according to which we determine if coefficients B_j statistically significantly differ from zero and decide whether the predictable values depend on x_j. The standardized beta coefficients are used by visibly determining the relative influence of the independent variables on the predictable Y. By their absolute value a higher beta coefficient indicates a greater dependence of Y on x_j. The factor is statistically significant at $p < 0.05$.

A multifactor regression analysis, which was carried out in order to estimate the impact of environmental factors on nitrate concentration in the water of shallow wells, demonstrated that nitrate concentration in the water of shallow wells depended mostly on the livestock, the distance from the well to the outhouse, cowshed, manure clamp and kitchen garden, and on the surroundings of the well. The depth and water table of the well as well as poultry breeding had no effect.

Impact of shallow well environment on nitrite concentration

The impact of environmental factors on NO_2^- **(Y)** as well as that of nitrate concentration in the water of

Table 6. **Impact of environmental factors on permanganate value (Y) in the water of shallow wells**

Environmental factor	Non-standardized coefficients		Standardized coefficient		
	B	Standard error	beta	t	p
Constant	16.605 **(a)**	2.097		7.918	0.000
* Livestock **(x_1)**	1.985 **(b_1)**	0.928	0.105	2.139	0.033
Poultry **(x_2)**	1.200 **(b_2)**	1.084	0.054	1.107	0.269
* Distance from the well to the cowshed, outhouse and manure clamp **(x_3)**	–9,64 *10^{-4} **(b_3)**	0.017	–0.002	–0.057	0.954
* Distance to the vegetable garden **(x_4)**	–1,01* 10^{-3} **(b_4)**	0.010	–0. 004	–0.103	0.918
Depth of the well **(x_5)**	6.79* 10^{-2} **(b_5)**	0.246	0.017	0.276	0.783
Water table in the well **(x_6)**	–0.24 **(b_6)**	0.308	–0.047	–0.780	0.436
*The well installation (1–5 points) **(x_7)**	–1.11 **(b_7)**	0.381	–0.123	–2.908	0.004

* The factor is statistically significant at $p < 0.05$.

Table 7. **Impact of environmental factors on pH (Y) in shallow well water**

Environmental factor	Non-standardized coefficients		Standardized coefficient		
	B	Standard error	beta	t	p
Constant	7.193 **(a)**	0.118		61.215	0.000
* Livestock **(x_1)**	1.46* 10^{-2} **(b_1)**	0.052	0.014	0.280	0.779
Poultry **(x_2)**	8.74* 10^{-3} **(b_2)**	0.061	0.007	0.144	0.886
* Distance from the well to the cowshed, outhouse and manure clamp **(x_3)**	–5.95* 10^{-4} **(b_3)**	0.001	–0.027	–0.630	0.529
* Distance to the vegetable garden **(x_4)**	–6.09 *10^{-4} **(b_4)**	0.001	–0.047	–1.109	0.268
Depth of the well **(x_5)**	–3.56* 10^{-2} **(b_5)**	0.014	–0.156	–2.580	0.010
Water table in the well **(x_6)**	4.95* 10^{-2} **(b_6)**	0.017	0.172	2.870	0.004
*The well installation (1–5 points) **(x_7)**	–2.16* 10^{-2} **(b_7)**	0.021	–0.043	–1.012	0.312

* The factor is statistically significant at $p < 0.05$.

shallow wells was calculated using the method of multifactor regression analysis. The results are presented in Table 4.

A multifactor regression analysis of the impact of risk factors (environmental factors) on the concentration of nitrates in the shallow well water indicated that the nitrite concentration was influenced by the distance from the well to the outhouse, cowshed and manure clamp, as well as by the well depth and the water level in it.

Impact of shallow well environment on ammonium ion concentration

The impact of environmental factors on the concentration of ammonium ions **(Y)** in shallow well water as well as that of nitrates and nitrites were calculated by multifactor regression analysis. The results are presented in Table 5.

Multifactor regression analysis of the impact of risk factors (environmental factors) on the concentration of ammonium ions in shallow well water indicated that the concentration of ammonium ions is influenced by poultry breeding, the distance from the well to the outhouse, cowshed, manure clamp, as well as by the water level in the well.

Impact of shallow well environment on organic compound concentration

The impact of environmental factors on the organic compounds **(Y)** as well as that of nitrates and nitrites in shallow well water was calculated by means of multifactor regression analysis. Results are presented in Table 6.

Multifactor regression analysis of the impact of risk factors (environmental factors) on the concentration of organic compounds in shallow well water has indicated that the permanganate value is influenced by livestock farming, the well construction and its protection.

Impact of shallow well environment on water pH
The impact of environmental factors on the pH **(Y)** in shallow well water, like that of nitrates and nitrites, was calculated using multifactor regression analysis. Results are presented in Table 7.

Multifactor regression analysis of the impact of risk factors (environmental factors) on the pH in shallow well water indicated that the well depth and the water level in it influenced the pH value.

DISCUSSION

Multiple regression analysis indicated that the concentration of nitrate, nitrite and ammonium ions in shallow well water was inversely related to the distance between the shallow well and the cowshed, outhouse, manure clamp and kitchen garden, because the water flowing downwards the groundwater gradient carries pollutants as well. Therefore, shallow well water quality is influenced by the pollution closest to the well. Our data are supported by research carried out by other scholars claiming that nitrate concentration increases due to intensive anthropogenic activity carried out in the vicinity of wells and due to inappropriate location of wells (Fawcett, Lym, 1992; Fenelon et al., 1995; Mitchell et al., 2003). Similarly to our case, an inverse correlation between nitrate concentration and well depth was determined in other studies (Hallberg, 1989; Clawges, Vowinkel, 1996). Livestock farming is an important factor considerably influencing the value of organic compounds and nitrate concentration in wells. A direct correlation between nitrate concentration in groundwater and intensive farming activity as well as the amount of nitrogen fertilizers was determined (Berka et al., 2001; Clawges, Vowinkel, 1996). When organic compounds resolve, nitrate ions are formed, which easily dissolve in water; they are mobile in the soil and quickly penetrate into groundwater. Large amounts of nutritive substances get into the environment when manure and sewage are handled and stored improperly. Examination of environmental pollution caused by litter manure handling (Strusevièienë, 2000) has determined that from manure clamped in the open field for 8 months 7% of nitrogen, 14% of phosphorus and potassium get with sewage into the environment. Manure, clamped on the soil, after a first stronger rain pollutes the soil, the ground and surface water. Within six months, 10–15% of nutritive substances are washed to the ground causing pollution of groundwater in those places exceeding the permitted norms many times (Aškinis, Strusevièius, 1997). From manure clamped in the open field, 7–10% of nutritive substances contained in manure get into the environment with sewage, and the pollution of water by organic substances exceeds the permitted values 10 times and more (Aškinis, Strusevièius, 1997; Strusevièienë, 2000).

The quality of shallow well water is also greatly affected by the construction of wells and their surroundings management. Bigger amounts of nitrites were found in deeper wells and bigger amounts of ammonium in shallower wells, possibly because of the processes of nitrification influenced by oxygen content in wells and their depth.

When wells are installed improperly, with a leaking cover, improper vessel and lifting device, organic substances get from the wells into the environment. Similarly, the quality of water deteriorates if the sanitary protection zone is inappropriately set, the soil surface gradient is too low and causes surface water seepage into the well.

Our data support the trend of the impact of environmental factors on water quality determined by other scholars and allow to draw conclusions on the importance of these factors in various environmental conditions, to forecast the pollution and to reduce it.

CONCLUSIONS

1. The following statistically relevant anthropogenic factors were determined to influence nitrate concentration in shallow well water: livestock farming (p = 0.0001) (statistically significant at $p < 0.05$), unsafe distances between the well and the cowshed, manure clamp, outhouse (p = 0.005) and kitchen garden (p = 0.012), as well as the construction and protection of the well (p = 0.043).

2. The following statistically relevant anthropogenic factors were found to influence nitrite concentration in shallow well water: water level in wells (p = 0.046) and unsafe distances between the well and the cowshed, manure clamp and outhouse (p = 0.043).

3. The following statistically relevant anthropogenic factors influence the pollution of shallow well water with ammonium ions: unsafe distances between the well and the cowshed, manure clamp and outhouse (p = 0.043), water level in wells (p = 0.039) as well as poultry breeding (p = 0.049).

4. The following statistically relevant anthropogenic factors exert an influence on pollution with organic substances: well construction and protection (p = 0.004) as well as livestock farming (p = 0.033).

5. The following statistically relevant anthropogenic factors were found to influence the pH value in

shallow well water: well depth (p = 0.010) and water level in wells (p = 0.004).

Received 14 October 2005

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Vida Rutkovienë, Albinas Kusta, Laima Èesonienë

ANTROPOGENINIØ VEIKSNIØ ÁTAKOS ÐACHTINIØ ÐULINIØ VANDENS TARÐAI VERTINIMAS

S a n t r a u k a

Ðachtiniø ðuliniø vandens tarða yra aplinkos tarðos indikatorius, ypaè jautrus antropogeniniø veiksniø átakai. Ðachtiniø ðuliniø vandená treèdalis Lietuvos gyventojø vartoja maistui, buities reikmëms bei ûkinei veiklai. Vandens kokybë turi tiesioginës átakos þmoniø sveikatai. Didelis kaimo þmoniø sergamumas ir mirtingumas dalinai susijæs su blogos kokybës ðachtiniø ðuliniø vandeniu. Ðachtiniai ðuliniai paprastai yra negilûs, vanduo á juos patenka ið sekliø gruntinio vandens iðtekliø, todël ypaè jautrus cheminei bei mikrobiologinei taršai. Ávairûs antropogeniniai veiksniai – ûkininkavimo intensyvumas, potencialûs tarðos ðaltiniai sanitarinëje zonoje, ðuliniø apsauga nuo aplinkos tarðos – gali lemti vandens kokybës kaità. Ûkininkavimo intensyvumo bei ðachtiniø ðuliniø vandens kokybës analizë atlikta 35 Kauno rajono gyvenvietëse, ávertinta 809 ðachtiniø ðuliniø vandens kokybë. Atlikta aplinkos veiksniø átakos ðachtiniø ðuliniø vandens tarðai daugialypë regresinë analizë parodë, kad didþiausià átakà tarðai azoto ir organiniais junginiais turi atstumai nuo ðulinio iki lauko tualeto, tvarto, mëðlo rietuvës ir darþo, vandens lygis ðulinyje bei ðulinio árengimo kokybë. Gauti duomenys apie ðachtiniø ðuliniø tarðà leidþia ávertinti antropogeniniø veiksniø átakà aplinkos kokybës pokyèiams bei prognozuoti tarðos lygá.

Raktaþodþiai: ðachtinis ðulinys, vandens kokybë, antropogeniniai veiksniai