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The Effect of Agricultural Practices on the Drinking Water Quality: A Case Study

Dmitriy Spitsov*, Larisa Nekrasova[1], Larisa Kondratenko[2], Sergey Pushkin[3] and Denis Klyuchnikov[4]

Department of Engineering Equipment of Buildings and Structures, Moscow Institute of Architecture, Moscow 107031, Russian Federation
[1]Laboratory of Environmental Hygienic Assessment and Prediction of Toxicity of Substances, Federal State Budgetary Institution "Centre for Strategic Planning and Management of Biomedical Health Risks" of the Ministry of Health of the Russian Federation, Moscow 119121, Russian Federation
[2]Department of Advanced Mathematics, Kuban State Agrarian University I. T. Trubilin Krasnodar 350000, Russian Federation
[3]Department of General Biology and Biodiversity, North Caucasus Federal University Stavropol 355017, Russian Federation
[4]Department of Geography, Ecology and Health Protection of Children, Far Eastern Federal University Vladivostok 690922, Russian Federation
✉ spitsov_v_dmitriy@rambler.ru

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Abstract: The problem of drinking water quality assessment and the impact of agricultural practices on it is relevant these days. A certain select area can serve as a convenient model object in the investigation. This work aims to assess the effect of agricultural practices on the quality of drinking water. The qualitative and quantitative composition of drinking water consumed by the habitants of Vladivostok, Russian Federation, was investigated in 2018. A total of 1000 samples were collected from wells, small rivers, channels located nearby the wastewater treatment facilities, from a river flowing near fields and livestock farms, and from a river with the minimal anthropogenic impact. To evaluate the drinking water suitability, the following parameters were addressed: the mineral level, hardness, alkalinity, permanganate oxidation, and the concentration of various salts and ions, specifically Ca^{2+}, Cl^-, SO_4, HCO_3, NO_2, Mg^{2+}, P, and NH_4-N. The concentration of organic compounds is affected by two factors, water temperature and pH. The mineral level in water near the farmland is 1.7-3 times higher than the norm ($p \leq 0.05$). Intermediate results (i.e., elevation of 1.5 times) were obtained for wells and small rivers ($p \leq 0.05$). In the preserve, all parameters are close to normal value. Thereby, almost all substances under study demonstrate elevation of at least 2-20 times. The reason for this situation is the human factor.

Key words: Water quality, hardness, alkalinity, permanganate oxidation.

Introduction

The world population has increased more than threefold over the span of 100 years, passing the seven billion mark (Anglian Water Services Ltd., 2016). As the population increases, the scaling-up of agricultural practices associated with food production takes place (Baffoe-Bonnie et al., 2012; Swire, 2018). The implication of such hard efforts is that theanthropogenic impact on the biosphere is constantly increasing (Tao

*Corresponding Author

and Fletcher, 2016). Agriculture is one of the major drivers of negative environmental transformations, meaning pollution from chemicals, agricultural product processing, and transportation. First off, these adverse effects inflict the potable water, a strategically important resource nowadays (Van der Heijden et al., 2012; Kim et al., 2017).

Currently, farmers are escalating the use of pesticides to fight against pests (Martineau et al., 2014; Vrain, 2015). For instance, the widespread use of pesticides has been reported since the late 70s of the last century (Voulvoulis et al., 2017). In Russia, this practice scaled-up 30-fold during the period from 1960 to 1990. Of 300 well-known pesticides, which are widely used in agriculture, only a tenth can be identified under laboratory conditions (Autin et al., 2013; Wynn et al., 2015). This means that in the laboratory to which we have access, the remaining pesticides cannot be determined, due to informational, financial, and methodological reasons.

The ecosystem fails to withstand the elevated concentration of pesticides in the soil so that some amount of chemicals may penetrate into the groundwater matrix (Bell, 2015). Just as other substances that enter the water passage due to agricultural activity, pesticides pose a serious threat to the human health everywhere. Hence, the average life span of people, who drink water of lower quality, is reduced, so is their level of wealth and comfort (Castle et al., 2017).

Normally, the surface water composition is affected by the humus component of soils as well as by the activity of microorganisms, plants, and animals in the region (Benson et al., 2014). Elements that are brought in by humans as part of agricultural practice are foreign to the system and can significantly change the qualitative and quantitative composition of water. The most common organic compounds that are found in water include phenols, humic components, hydrocarbons, and surfactants (Dolan, 2013; Dolan et al., 2013). If the amount of these substances goes beyond the permissible level, the water quality will deteriorate to the point when it becomes not safe to drink; the observations include the change of colour, taste, and odour as well as the presence of foam (Blackstock et al., 2010). The vast majority (80%) of organic compounds in the water are salts of fulvic and humic acids. The remaining portiontakes the major classes of organic compounds (Collins et al., 2016).

In Europe, for example, surface waters contain about 1400 organic compounds, of which about 800 can be found in drinking water and about 200 in artesian water (Davey et al., 2013). Some of these substances appear in the water during its preparation for municipal use, specifically during chlorination. Chemical reactions that take place during water disinfection can produce new compounds, increasing a carcinogenic risk (Gulson, 2015). Some of these substances also exhibit mutagenic activity. Chlorination is the process associated with the formation of volatile halogen compounds (Hossieni et al., 2012). However, there are other factors that influence the level of halogen-containing substances in the water: the pH level of water; water temperature (depends on the season); and the level of organic compounds (Leathes et al., 2008).

Alongside the organic matter, there could be a high concentration of microorganisms in the water, including those related to pathogenic microflora. Microorganisms begin their growth and reproduction wherever there is a high concentration of organic compounds (Lu et al., 2017). This resembles another characteristic of water polluted due to agricultural practices. Thus, agricultural activity has a multifactorial negative effect on the quality of drinking water.

The drinking water quality is linked to mortality and birth rates and this link becomes more evident with the impact of anthropogenic stress (MacDonald et al., 2012). Besides the shift in mortality/birth ratio towards mortality, the quality of drinking water negatively affects the quality of life of the population by weakening people's resistance to infectious diseases (McGonigle et al., 2014).

About one third of the total population lives in rural areas, where agricultural activities are pivotal. This number varies between different countries but substantially remains within the abovementioned range (Nicholls, 2014). Rural settlements stand out with the lack of centralized water supply and the drinking water needs of rural population are met through the presence of wells and springs as well as by the provision of bottled water. The quality of such water usually does not comply with the sanitary and epidemiological standards and the existing water disinfection technologies (e.g., chlorination) need to be revised to meet modern requirements (Nineham et al., 2015). The same conclusion applies to the rationalization of water consumption. Expectations revolving around the long-term campaign for water quality improvement can be described as follows: better quality of water will contribute to the mortality rate decrease; the rate of settlement abandonment will also decline; and the increasingly important food problem is projected to become less pressing.

The water quality improvement technologies must take into account the qualitative (chemical) and quantitative composition of water, which is set to purification and subsequent consumption (Olsson, 2018). In the worst-case rural scenario, water found beneath the ground surface is the only source of drinking water, while the surface waters contain an unacceptable level of organic compounds and other pollutants.

To sum up, the problem of drinking water quality assessment and the impact of agricultural practices on it remains relevant (Surridge et al., 2010). A certain select area can serve as a convenient model object in this investigation. The purpose of this work is to assess the effect of agricultural practices on the quality of drinking water in Vladivostok, Russian Federation.

Materials and Methods

Study Area and Sampling

The qualitative and quantitative composition of drinking water consumed by the habitants of Vladivostok, Russian Federation, was investigated in 2018. Six hundred samples were collected from three sampling sites: wells (200 samples), small rivers (200 samples) and channels located nearby the wastewater treatment facilities (200 samples). Two reference groups involved 200 water samples from a river flowing near fields and livestock farms and 200 samples from a river with the minimal anthropogenic impact. Hence, a total of 1000 samples were collected during three different seasons. Whithn each group, 70 samples were collected in winter at the water temperature of 1-1.5° C (total, 350 samples); 65 samples in spring at the water temperature of 8-15° C (total, 325 samples); and 65 samples in summer (total, 325 samples) at the water temperature of 20-25° C. The sampling of zoobenthos species and chemical water analysis were performed on the summer water samples (see Table 2 onwards).

Methods

The pH level of water was measured using a pH meter. To evaluate the drinking water suitability, the following parameters were addressed: the mineral level, hardness, alkalinity, permanganate oxidation, and the concentration of various salts and ions, specifically Ca^{2+}, Cl^{-}, SO_4, HCO_3, NO_2, Mg^{2+}, P, and NH_4-N. Water sampling was performed according to GOST 31862-2012 “Drinking Water. Sampling”. The subsequent laboratory tests were performed according to SanPin 2.1.4.1074-01 “Drinking water”, GN 2.1.5.1315-03 “Maximum Permissible Concentrations (MAC) of Chemical Substances Contained in Water of Water Bodies for Economic-Potable and Social-Domestic Water Use,” and GN 2.1.5.2280-07 (Amendments to GN 2.1.5.1315-03).

The level of chlorineand phosphorus containing pesticides was also determined. For this specific test, 40 samples were collected from two wells located near the farmland and the other 40 samples were collected from the other two wells that were located within the preserve. The final bunch was extracted from the Quaternary deposits at the depth of 50 m, Neogene deposits at 150 m depth, Cretaceous deposits at 230 m depth, and from the Triassic deposits at 320 m depth; all in all, 40 samples, 10 samples per site.

The macrozoobenthos were separated from all substrates, except for the well samples. The reason why these organisms were selected is that macrozoobenthos feed on both microorganisms living in the water and dissolved organic matter. Hence, the higher the number of macrozoobenthos in the water, the more polluted it must be.

Statistical Analysis

Data analysis was performed in Origin v. 8.0. The mean and the standard error (mean ± SEM) were calculated. The significance of differences was analyzed statistically using the Fisher t-test ($p \leq 0.05$). In addition, a number of biotic indices (markers of water pollution) were calculated: the Goodnight-Whitley index, the King and Ball index, the Mayer index, and the Woodiwiss index.

Results

It turned out that the pH value of different water samples fluctuates depending on the season factor (Table 1).

In winter, the pH value is the lowest at each site compared to other seasons and this difference is significant ($p \leq 0.05$). No reliable differences in pH were obtained within the site. An increase in the water temperature also affects the level of volatile halogen compounds (VHC). Hence, the lowest VHC mean value was recorded in winter, while the warmer seasons saw an increase in the mean level of VHC by contrast, 0.5-fold in spring ($p \leq 0.05$) and twofold in summer ($p \leq 0.05$). No VHC were found in water samples from the preserve, which concludes the presence of high-quality drinking water at that site. Thus, the water temperature has an inverse relationship with the quality of drinking water. Perhaps, chlorine reacts with organic components faster with the increase in water temperature. The correlation between the pH of water and the VHC concentration was also established (Table 1). Thereby, the VHC concentration is affected by two factors, water temperature and pH. Note that the pH must fall within the range specified in GOST and not hit the lower extreme; otherwise, the water may become harmful to human health and cause damage to the pipes.

The concentration of organic compounds was found the lowest in samples from the preserve (Table 2), higher in samples collected from wells and small rivers ($p \leq 0.05$), and even higher in water taken at sites near the wastewater treatment facilities and fields ($p \leq 0.05$).

As it can be seen from data in Table 2, the concentration of organic components is linked more to the pollution load, rather than the presence of chlorine. For instance, the pollution load near fields and farms as well as wastewater treatment facilities is higher so that the concentration of organic components there is higher too. A high level of organic components, in turn, correlates with the biomass of macrozoobenthos (Table 3).

The Goodnight-Wheatley index measures the level of water pollution. According to data in Table 3, the most serious situation in terms of water pollution can be observed near the wastewater treatment facilities, farms, and fields. In the region with less anthropogenic impact, the contamination problem is less pronounced. Water from the wells is less polluted but still only four times cleaner compared to water bodies near the farmland ($p \leq 0.05$). Other indices show an inverse relationship with higher values associated with the cleaner water and vice versa.

Other parameters like hardness, mineral level, and the concentration of salts and ions were also found elevated across the sampling sites (Table 4).

The mineral level in water near the farmland is 1.7-3 times higher than the norm ($p \leq 0.05$). Intermediate

Table 1: Seasonal variation in water pH at the sampling sites

Sampling site	*Water temperature, °C*	*pH*	*Volatile halogen compounds (μg/l), mean for all sites*
1. Wells 2. Small rivers 3. Near wastewater treatment facilities 4. Near fields and livestock farms 5. Natural preserve	1-1.5	7.4 (1), 7.5 (2), 7.4 (3), 7.5 (4), 7.6 (5)	65.3±9.4
	8-15	7.9 (1), 8.0 (2), 8.0 (3), 7.9 (4), 8.0 (5)	94.5±7.8
	20-25	8.5 (1), 8.4 (2), 8.5 (3), 8.5 (4), 8.5 (5)	125.9±12.3

Table 2: The concentration of organic compounds in water during the summer: Fulvic Acid, FA; Humic Acid, HA

Sampling site	*Organic compounds, mg/dm^3*	*pH and chlorine*
Wells	2.4 (HA), 4.5 (FA)	8.5, zero chlorine
Small rivers	2.5 (HA), 4.6 (FA)	8.4, zero chlorine
Near wastewater treatment facilities	2.9 (HA), 5.0 (FA)	8.5, 4.4 mg/l of chlorine
Near fields and livestock farms	3.3 (HA), 5.7 (FA)	8.5, zero chlorine
Natural preserve	2.0 (HA), 3.7 (FA)	8.5, zero chlorine

Table 3: Some biotic indices of water quality at the sampling sites

Sampling Site	*Goodnight-Whitley Index**	*King and Ball Index***	*Mayer Index****	*Woodiwiss Index*****
Wells	23.45	2.59	8	4
Small rivers	42.59	3.44	9	5
Near wastewater treatment facilities	85.64	0.99	4	2
Near fields and livestock farms	95.23	0.87	3	1
Natural preserve	11.37	25.6	21	8

Note: * – percentage values; **, ***, **** – scores.

Table 4: Underlying indicators of water-quality conditions for different sampling sites

Sampling site	*Mineral level, mg/dm³*	*General Hardness, mmol/dm³*	*Ca*	*Mg*	*HCO_3*	*Cl*	*SO_4*	*NO_2*	*PO_4*	*NH_4*	*Fe*
Wells	1509	13	115	70	250	45	225	0.012	0.05	0.09	0.05
Small rivers	1487	15	127	79	322	56	456	0.17	0.23	0.27	0.07
Near wastewater treatment facilities	1774	24	256	187	666	235	1786	0.45	0.48	0.55	0.12
Near fields and livestock farms	2945	29	287	199	775	124	2322	1.23	1.67	1.13	0.11
Natural preserve	1050	8	109	52	347	14	102	0.001	0.02	0.02	0.01
Normal value	1000	7	-	50	-	350	500	3	3.5	1.5	0.3

results (i.e., elevation of 1.5 times) were obtained for wells and small rivers ($p \leq 0.05$). In the preserve, all parameters are close to normal value. Water hardness also exceeds the norm by four times near the farmland and wastewater treatment facilities ($p \leq 0.05$), and by two times in samples taken from wells and small rivers ($p \leq 0.05$). Water hardness in the preserve samples falls within the normal range. The Ca level in water near the farmland is higher more than twofold compared to preserve samples ($p \leq 0.05$). The concentration of Mg and hydrocarbonates is 2.5 to threefold higher ($p \leq 0.05$), and the concentration of Cl, SO_4, NO_2, PO_4, NH_4, and Fe is 10 to 20-fold higher ($p \leq 0.05$).

Thereby, almost all substances under study demonstrate elevation of at least 2-20 times. The reason for this situation is the human factor. Once the pesticides are applied, decomposed organic matter is washed away and the substances in point enter the water passage, increasing the concentration of thereof in the water. Decomposition process results in the release of ammonia and out-of-control multiplication of microorganisms. These processes were not observed in water samples from the preserve, as agricultural activity is not performed there. Hence, agricultural practices are a negative contribution to quality water.

The concentration of pesticides in aquifers is also elevated. According to the present findings, the Quaternary deposits in the upper horizons contain pesticides at 10-20 times lower concentration compared to the deep Triassic, Cretaceous and Neogene deposits. This indicates a vertical migration of substances entering the water passage.

Discussion

Pesticides and pesticide waste are considered the major soil contaminants in rural areas (Allen et al., 2011; Ermakov et al., 2017). Over the last two years, about 1000 new pesticides have been registered (Dillon et al., 2011). These substances decompose slowly and have the ability to accumulate in aquifers (Dillon et al., 2013). In these conditions, microorganisms in both the soil and water die and the rate of premature mortality from poor quality water increases. The second generation pesticides are characterized by accumulation in the human body, which also results in death or poisoning (Drogui et al., 2012). Organic compounds that contain phosphorus cause the development of cardiovascular diseases, headache, and widening of the blood vessels. Another class of organic compounds, organochlorines, causes the development of central nervous system disorders, liver dysfunction, and the upper respiratory disorders (Edwards et al., 2009). Nevertheless, pesticides still find a widespread use, as they allow for the effective control of pests and weeds.

Seven pesticides that have been found in wells can act on the human body in combination. Among them, p, p'-Dichlorodiphenyl-trichloromethylmethane (DDT), o, p'-Dichlorodiphenyl dichloroethane (DDD), p, p'-Dichlorodiphenyl dichloroethylene (DDE), α-Hexachlorocyclohexane (α-HCH), β-Hexachlorocyclohexane (β-HCH), γ-Hexachlorocyclohexane (γ-HCH), and aldrin. One pesticide, specifically p, p′-DDT, can strengthen the other, escalating the intoxication. A toxic effect can be expected even if each individual pesticide does not exceed the acceptable level. Considering the knowledge of this matter as poor, strict pesticide management is required (Fenemor et al., 2011). In the absence of thereof, unfavourable population trends are possible.

Over the past three decades, the amount of pesticides per capita has increased 5-fold and the number of genetic disorders has increased 10-fold (Fritsch and Benson, 2013). Degradation processes that occur within one generation is not the only problem; due to an uncontrolled use of pesticides, one can expect an increase in the overall genetic burden. For instance, traces of organochlorine pesticides come in higher concentrations in each subsequent link of the food chain. Hence, a human being, as a top of the food chain, will be the most vulnerable to the negative effect of pesticides (Giakoumis et al., 2018; Hessamhassani, 2019).

However, recent years have seen a decline in agricultural activity (Ingram, 2008), non-uniform through, as some parts of the contrary tend to produce more agricultural products. The European Russia is no exception. This study, however, shows that higher agricultural loads result in the increase in almost all ions and salts as well as the physical parameters of water, e.g., hardness, mineral level, etc.

In the long run, the use of agricultural practices activate horizontal and vertical migration of organic and other substances, which enter the water passage. The migration depth can reach 350 m. Impeding such processes is not easy because of the cumulative nature of substances. The conclusion of these phenomena is the water quality deterioration (Jess et al., 2014).

Conclusions

Agriculture is a wide-ranging practice, which contributes to the accumulation of cations, anions, various pesticides and organic acids in the environment. The concentration of such substances near livestock farms exceeds the maximum permissible level by 2 to 25 times. Pesticides penetrate to a depth of 350 m, accumulating with depth. Horizontal migration occurs at a more rapid pace and is associated primarily with the products of agricultural activity that enter the water passage, with the organic matter decomposition, and with the out-of-control reproduction of microorganisms, including pathogenic species.

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