Using the Kaban Lakes Integrated Assessment Model for Investigating Potential Levels of Antibiotic Pollution of the Nizhniy Kaban and Sredniy Kaban Lakes

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Abstract The Kaban Lakes Integrated Assessment Model (KLIAM) was enhanced in order to assess the possible content of antibiotics in the Kaban lakes, located within the city borders of Kazan City, Tatarstan Republic in the Russian Federation, and potential for adverse environmental effects. The Kaban Lakes Integrated Assessment Model simulations suggest that the concentrations in the Nizhniy Kaban lake and Sredniy Kaban lake may exceed the predicted no effect concentration (PNEC) and low-risk limits set by EU and the WHO. Many missing data could be assumed or approximated, and simulation runs were conducted. The results are consistent with other global studies in terms of average concentrations observed elsewhere in rivers and lakes. The results suggest that the study should be followed up with lake water analysis and an assessment of antibiotic loads to the Kaban lakes. It is concluded that the results are too uncertain to initiate any policy action at the present moment and that an assessment supported by measurements would be warranted.

Keywords System dynamics · Supply · Sustainability · Kaban lakes · Antibiotics

1 Introduction

The Kaban lakes are located within the city limits of Kazan, Russia, and they are the largest natural lakes in the Tatarstan Republic. They are important parts of the city landscape and important resource for the recreation resources of the city. They are located in a pleasant environment, and a redevelopment of the area surrounding the Kaban lakes is planned for the next decade. The Kaban lakes have been eutrophic for a long time because of a long history of industry pollution and sewage flowing freely from the city to the Kaban lakes. Kazan earned itself a reputation for having bad water, something that can still noticed in the inhabitants habits by an outsider (Vishlenkova 2005). The Kaban lakes still suffer from this, and more professional efforts are needed to improve the water quality of the Kaban lakes, such as making swimming and bathing a pleasant experience or getting tap water to have stable drinking water quality. Table 1 shows some data describing the Kaban lakes. The Kaban lakes are frozen over by ice from December to the end of March. The Kaban lakes experience a typical continental climate, with warm summers ($25 \degree C$ to $30 \degree C$) and cold winters ($−10 \degree C$ to $−35 \degree C$). There is a lot of urban development around the Kaban lakes. Both
Kaban lakes have been and are still exposed to the kind of pollution that comes from an urban-industrial environment and a highly populated area. This implies very bioactive substances like medications and endocrine disruptive substances, as well as urban dust, hydrocarbons from vehicles, and leakage from city sewage (Laxminarayan et al. 2013). The rate of discovery of new antibiotic substances is declining after 1980 (Sverdrup et al. 2020).

### 2 Objectives and Scope

The objective is to use the process-oriented model system Kaban Lakes Integrated Assessment Model (KLIAM) model for investigating possible antibiotic pollution in the Nizhniy Kaban and Sredniy Kaban lake system. This model tool will be used to develop different aspects of the Kaban lake management plan and measures to be taken. The model will have predictive capability, in order to be able to forecast possible outcomes of measures taken in the lake catchments and in the lakes themselves. The KLIAM model should be able to handle short-term variations (within a year) and long-term aspects (100–200 years). Antibiotic pollution in waterways is a global problem, in particular where big rivers pass through large population centers (Gilbert 2019; Boxall and Wilkinson 2019; Wilkinson and Boxall 2019; Behdinan and Hoffmann 2015; Laxminarayan et al. 2013), but a small river or lake (Kaban lakes) in a big city (Kazan) will most probably share the same type of issues. We intend to assess if this is relevant for the Kaban lakes system. During the last two decades, antibiotic use in Russia has increased significantly towards Central European levels (van Boeckel et al. 2014; Moisenko 1994, Obukhova and Lartseva 2014, 2018, Gabdulhakova et al. 2016). The small lake Verkhniy Kaban lake to the south of the Sredniy Kaban lake is separated from these lakes hydrologically and will not be addressed in this study.

### 3 Methods

This paper closely follows a publication in Water, Air, Soil Pollution by the same authors (April 2020): Using a System Dynamics Model for Investigating Potential Levels of Antibiotics Pollution in the Volga River (H. U. Sverdrup, L.L. Frolova, A.E. Sverdrup), Water Air Soil Pollut 2020; 231:173 (https://doi.org/10.1007/s11270-020-04526-w). For modeling of the eutrophication of lakes, we follow the state-of-the-art methods (Chapra 1991; Chapra and Reckhow 1983; Barkman and Sverdrup 1994; Barkman et al. 1994; Aldeyab et al. 2008; Heberer et al. 1998). The methodology used here uses systems analysis for conceptualization, as the preparation for building a simulation model using the STELLA software. KLIAM is a system dynamics model for the environmental status of lakes in cultural landscapes. The main standard methods of systems analysis and system dynamics modeling are used (Albin 1997, Forrester 1971, Meadows et al. 1974, Roberts et al. 1982, Senge 1990; Senge et al. 2008; Haraldsson and Sverdrup 2005; Haraldsson 2004; Binder et al. 2003; Sverdrup et al. 2018). We analyze the system using stock-and-flow charts and

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**Table 1** Hydrological and physical characteristics of the Kaban lakes, Kazan, Russia

| Object                                      | Lake area (km²) | Lake volume (mill m³) | Average depth (m) | Max depth (m) | Inflow (mill m³ yr⁻¹) | Average water residence time (yr) | Catchment size (km²) |
|---------------------------------------------|-----------------|-----------------------|--------------------|---------------|-----------------------|-----------------------------------|----------------------|
| Nizhniy Kaban lake                          | 0.456           | 3.82                  | 8.4                | 17.3          | 4.88¹                | 0.59                              | 9.68                 |
| Sredniy Kaban lake                          | 1.313           | 10.01                 | 6.4                | 19.0          | 24.35¹               | 0.39                              | 38.63                |
| Channel from Sredniy Kaban lake to Nizhniy  | 0.064           | 0.16                  | 2.5                | 4.4           | 4.00²                | 0.04                              | 1.10                 |
| Kaban lake                                  |                 |                       |                    |               | 1.56³               |                                   |                      |
| Channel from Sredniy Kaban lake to Nizhniy  | 0.032           | 0.02                  | 0.65               | 0.8           | 0.63⁴                | 0.03                              | 1.30                 |
| Bulak channel                               |                 |                       |                    |               | 5.31                 |                                   |                      |
| Pump to Kazanka from Nizhniy Kaban lake     | –               | –                     | –                  | –             | 6.95                 | –                                 | –                    |
| Pump to Volga from Sredniy Kaban lake        | –               | –                     | –                  | –             | –                    | –                                 | –                    |

¹ From the catchment, ² between the lakes, ³ net water exchange, ⁴ Bulak catchment input
causal loop diagrams. The mass balance expressed differential equations resulting from the flow charts and the causal loop diagrams will be numerically solved using the STELLA® modeling environment (Kim 1992; Senge 1990; Haraldsson 2004; Haraldsson and Sverdrup 2005; Sverdrup et al. 2018). A system dynamics model forces a compilation of the known data for the lake system and relates them to each other in a consistent way using mass balances and changes in stocks and flows. It forces the system model to be mass balance consistent and works with causal relationships. A different scheme would be statistical approaches, but then it must be remembered that correlation is not necessarily causation. Statistical approaches have limited prediction capability and thus have limited use in future planning. With a causality-based, mass balance consistent simulation model, possible future outcomes can be studied (Roberts et al. 1982; Chapra and Reckhow 1983). With a causal model structure, the real causal factors behind a pollution problem may be addressed. This is not done with the same robustness with a statistical approach.

The global tonnage of antibiotic substance production and predicted future production was taken from Sverdrup et al. (2020) using data from Davies and Davies (2010); Allen et al. (2010); van Boeckel et al. 2014, 2015; Klein et al. (2017); World Health Organization (2015a, b), 2017); Emerson de Lima Procopio et al. (2012); and Samah et al. (2006). The antibiotic use projections were derived from the World Health Organizations scenarios (2015a, b; 2017).

4 On Antibiotics

Antibiotics began with the discovery of penicillin in 1928 (Fleming 1929; Gaynes 2017) in Great Britain and sulfonamide (Domagk 1935) in 1932 in Germany. This changed the success of the treatment of bacterial infections dramatically (Tan and Tatsumura 2015). The substance used is specific for the microorganism and with limited toxicity to humans (Andersson 2006, Gualerzi et al. 2013, Cassir et al. 2014; Gore 2015; Hurd et al. 2004, Leekha et al. 2011, Phillips et al. 2003, Shea 2003, Tan and Tatsumura 2015, Ventola 2011, Zaffiri et al. 2012; Ling 2015). The rate of development of antibiotics has dropped since the 1980s, and the number of effective antibiotics has dwindled significantly in the subsequent years. As the resistance increases, the number of infectious cases that can be treated will dwindle.

In 2013, a total of 131,000 mt of antibiotic substances were used worldwide in agriculture, while the total production of antibiotic substances was about 167,000 mt (Sverdrup et al. 2020), leaving 66,000 t for human use. The implication is that 78% of all antibiotics produced in 2013 were used in agriculture, mostly for “growth promotion” (WHO 2015a, b; 2017). Antibiotic production is projected to reach 200,000–350,000 t per year by 2030 (Davies and Davies 2010; Allen et al. 2010; van Boeckel et al. 2014; 2015; Klein et al. 2017; WHO 2015a, b; 2017). The data on antibiotic usage and production is difficult to find, and the accuracy remains largely unknown.

The available data suggests that 80% of all antibiotics are used in food production (WHO 2015a, b, 2017). For rural animal husbandry on small-scale farms based on natural grazing, antibiotics in animal husbandry are not needed. Antibiotic need increases in the setting of animal crowding and industrial rearing practices in order to avoid infections under what in reality are unsustainable conditions for the animals. Antibiotics are also used to eliminate microbial competition for food substrates in pigs and chickens, so-called “growth promoters.” Meat from farms using antibiotics will contain residual antibiotics, which poses a potential risk for developing microbial antibiotic resistance (Ceccini et al. 2015; Fair and Tor 2014; Ventola 2011, WHO 2015a, b, 2017, Interagency Coordination Group on antimicrobial resistance 2019; Greenfield et al. 2018; Halling-Sørensen et al. 1998; Heinemann et al. 2000). The input data situation on both types of antibiotics and amounts is problematic, with limited information published. We have leaned on what we could find in the WHO and EU reports to a significant degree and the preparations we did for the earlier study (Sverdrup et al. 2020). Thus, a general antibiotic product mix similar to Central and Eastern Europe was assumed. This is explained in the earlier study (Sverdrup et al. 2020). There are many ways in which antibiotics end up in the environment and in waterways and drinking water:

1. The use of antibiotics in medical treatment of infections, exiting with excrements and urine, enters the sewage (ANSES 2011; Ashton et al. 2004; Brown and Nathwanu 2005).
2. Old medications are sometimes put in to garbage and find its way to landfills (ANSES 2011; Ashton et al. 2004).
3. Medications get flushed down the toilet, ending up in the sewage (Ashton et al. 2004; Castiglioni et al. 2013).
4. Most antibiotics are used in agriculture; human use is the less significant overuse. This occurs with industrialized cattle feedlots, poultry, and pork production and more recently, also in industrialized salmon fish farming (Aarestrup et al. 2001; Ahem et al. 1990; Alder et al. 2006; van Boeckel et al. 2014, 2015, van Bunnik and Woolhouse 2017; Chee-Sanford et al. 2009; Cogliani et al. 2011, Economou and Gousia 2015; Gilchrist 2006; Heilig et al. 2002, Marshall and Levy 2011, Zurek and Ghosh 2014, Higuera-Llantén et al. 2018; Wegener 2003, 2012). The antibiotics end up in the manure contaminate food and enter the human food chain (Landers et al. 2012; Phillips et al. 2003; Shea 2003; Silbergeld et al. 2008; WHO 2009; 2011).

The development of antibiotic resistance is a very serious problem for modern health care, and the threat is near and very substantial in terms of potential loss of life (Belkova et al. 2013; Cassini et al. 2019; Davies and Davies 2010; de Kraker et al. 2016; Penesyan et al. 2015; Podolsky 2018; Price et al. 2015; Watkinson et al. 2007, 2009). The flow chart for stock of effective antibiotics and lost antibiotics to resistance was taken from Sverdrup et al. (2020). A part of the lost may possibly be salvaged by keeping them out of use for 100 years (Sverdrup et al. 2020).

4.1 Analyzing the Situation

The pathways for antibiotic substances in human medical use and in agricultural commercial use were taken from Sverdrup et al. (2020). There is leakage from human use to the natural environment through the waste disposal system. More than half of all raw sewage is never ever treated in any way. From agricultural use, antibiotics leak to rivers, lakes, soils, and oceans, and there is almost no treatment of effluents ever anywhere. The agricultural use is 4 times larger than all human uses. The use of antibiotics in society is driven by a number of reinforcing loops. These have been shown in Fig. 1. The first loop is marked with R1. Indicated with R2 is a reinforcing loop driven by economic incentives, running over increased animal production, more profits, more antibiotic demand, and more antibiotic usage in agriculture. The efficient treatment of infections spurs more use to create more successful medical cures. As microorganisms develop antibiotic resistance, more antibiotic substances are developed and the system kept running (R3). However, it was soon found out that the use of antibiotics would increase fodder yield and production rates in animal production. This leads to higher profits, which has been a strong drive for more antibiotic use in meat production (R5). This has led to political lobbying to prevent legislation that would limit the antibiotic use (R4). Finally, the resistance problem is made substantially worse by antibiotic pollution in addition to massive use on animals, forming many balancing loops in the system. The standard type of wastewater treatment is not very effective in reducing antibiotics in sewage water. Once specialized wastewater treatment is introduced, a balancing loop is created. B1 and B2 are the policy loops, where the observation of adverse pollution leads to political lobbying, legal regulation, and technical measures ending up with less antibiotics in the water. B3, B4, and B5 are the balancing loops where more use leads to more resistance, leading to having less effective antibiotics available.

5 Model Description

Figure 7 shows an overview of the hydrological flows in the system. Data for the system is shown in Table 1. The lakes are characterized by their short water retention times, less than a year in all of them. The Nizhniy Kaban lake and Sredniy Kaban lake are connected with the Bulak channel (Krestovnikov 1870; Filtzer 2008; Vishlenkova 2005; Kalimullin 2005; Kalimullin and Vinogradov 2015; Mingazova 1999; Mingazova et al. 2019; Derevenskaya et al. 2015). The simulation model has several main parts (Fig. 5):

1. The hydrological module
2. The chemistry model where phosphorus, nitrogen, alkalinity, and particle matter dynamics is calculated
3. The biology module where the plankton dynamics is calculated
4. The oxygen module where the oxygen saturation in the lake is simulated
5. The city pollution inputs to the Kaban lakes
6. The environmental impacts assessment module

Inside each box in the diagram, a model is situated. Each lake module includes inflow from the catchment, flow between the lakes, outflow to Volga River, and pumping to Kazanka River from Nizhniy Kaban lake.
and pumping to Volga from Sredniy Kaban lake. The pumping is done to control level variations in the lake (Mingazova 1999; Mingazova et al. 2019; Derevenskaya et al. 2015). There is a natural outflow from Sredniy Kaban lake to Volga. The normal height over the sea is 52 m for Sredniy Kaban lake, and Volga is on the average 49-m above sea level. That may however vary with about 2-m up or down, depending on the seasons. Water is also pumped from Nizhniy Kaban lake to the Kazanka River. There is no natural outlet from Nizhniy Kaban lake to the Kazanka River at present.

Figure 2 shows the Nizhniy Kaban lake seen towards the Kazan city center around the year 2000. The city is now embedded in the city, but 200 years ago (1800), the area was a rural countryside. A hundred years ago (1900), the lake had meat procession plants and heavy industry on its shore lines (Dunaev 1833).

Figure 3a and b shows the Sredniy Kaban lake as seen from the air. Note that the water is green due to a high concentration of plankton and algae in the lake water. There is a lot of urban development and industries around the lake. Both lakes are exposed to the kind of pollution coming from an urban-industrial environment and a highly populated area. The land use around the lakes has changed a lot over time, from a rural agricultural type to an industrial type, and then been partly deindustrialized and become more residential urban. In earlier times, the lake area had a lot of farms and meat industry (Krestovnikov 1870; Vishlenkova 2005; Mingazova 1999; Mingazova et al. 2019; Derevenskaya

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**Fig. 1** A causal loop diagram for the problem discussed in the text. Five reinforcing loops (R1–R5) keeps the system running (modified from Sverdrup et al. 2020). Policy acts through 5 linked retarding feedback loops (B1–B5).
et al. 2015; Gurelits and Zemyanov 2017), which since has been decreased as the area has been redeveloped in modern times. The data available was semiquantitative.

Water flow in the lakes is a combination of both natural flow and in modern times by management by pumping. The capacity of both the pumps at the Nizhniy Kaban lake and at the outlet of the Sredniy Kaban lake has been reported to be 25 million m³ per year. The peak pump performance is unknown to us but probably in the range of 0.77–1 m³/s (Fig. 4).

The antibiotic loads to the lakes are not known and have never been measured. We made a suggestion for a
load, based on the fact that each cure takes 500 mg every day, lasting for 14 days (WHO 2011; Fokin et al. 2011; Ratchina et al. 2009; Ratchina 2015; Sverdrup et al. 2020).

This was combined with data for infection incidence, measured, assumed, and guessed, and how many of those that would get antibiotics treatment (WHO 2011; Sverdrup et al. 2020). This was backchecked on general statistics on per capita use of antibiotics in Russia per capita (van Boeckel et al. 2014; Fokin et al. 2011; Ratchina et al. 2009; Ratchina 2015). The mass balance for the lakes used in the model for antibiotic substances is (Sverdrup et al. 2020):

$$\text{inflow} + \text{sediment desorption} = \text{accumulation} + \text{decomposition} + \text{sediment adsorption} + \text{outflow} + \text{sedimentation} \quad (1)$$

Inflow is water inflow times the concentration in it; accumulation is the increase in the lake water stock; sorption is adsorption to organic matter in the sediments; decomposition is microbial decomposition in the water by microorganisms; desorption is when the organic matter in the sediments releases adsorbed antibiotics to the water body; and sedimentation is when antibiotics follow dead plankton to the bottom. Some of the antibiotics will desorb to organic matter and slowly release again back into the water. Some will be buried in the sediments. The rate of decomposition of antibiotics is given by the equation (Sverdrup and Stjernquist 2002; de Vries et al. 1998; Chapra 1991):

$$r = k_{\text{Decomp}} \cdot [\text{antibiotics}] \cdot V \cdot f(T) \quad (2)$$

The decomposition rate coefficient $k_{\text{Decomp}}$ was set as an average based on the most used antibiotics reported in the available literature (Cycon et al. 2019). $V$ is the lake volume, and $f(T)$ is a function adjusting the rate when the temperature changes. The total intake of antibiotic substances for Russia in general was available. Ratchina et al. 2009; Ratchina 2015 reports DDD = 15,000 international units per 1000 persons. This is supported by the studies of Fokin et al. (2011), Belkova et al. (2013), and ESAC (2009). We have made approximate estimates, based on this best available information (Figures 5, 6 and 7).

The input from the human population and the agricultural activities in the Kaban lake catchments in our first approximation was done using the expression:

$$\text{Antibiotics input}_{\text{Lake catchment}} = \text{Medical input} + \text{Agricultural input} \quad (3)$$

The medical input was determined using the following formula:
where \( DDD \) is the dose per inhabitants (for Russia, we have set at a maximum \( DDD = 15 \) dosages per person per year in 2010, based on Ratchina et al. 2009, Ratchina 2015) and Fokin et al. (2011). Before then, it is scaled up (Fig. 8e). \( P \) is the population in the catchment which is a varying fraction of the total population in Kazan, one for Nizhniy Kaban lake and one for Sredniy Kaban lake, and \( S \) is the dosage strength, which varies a lot between the different substances and that we have set at \( S = 500 \) mg (500 mg/DDD). The agricultural input to the lake is determined by how much is used in agriculture minus what is decomposed in the soil on the way to the lake. We assume in the model that this transition through the soils takes on the average 7 years (Chapra 1991, Bakker et al. 1998, Sverdrup et al. 2020).

\[
\text{Medical input}_{	ext{Lake catchment}} = DDD \cdot P_{\text{Lake catchment}} \cdot S
\]

\[
\text{Agricultural input}_{\text{Lake}} = \text{Agricultural use} - \text{soil decomposition}
\]
in the aqueous phase (de Vries et al. 1998, Bakker et al. 1998, Chapra 1991). We have assumed that it decomposes in the aqueous phase and in the adsorbed phase. This we assume based on the fact that the antibiotics absorb the most to organic matter (Chapra 1991), that the organic matter in itself gets decomposed, and that the antibiotic gets digested with it (Chapra 1991; Chapra and Reckhow 1983). Figure 8 shows some of the feedback functions used in the model for different processes described in the text. These curves serve instead of...
equations and are typical of the system dynamics methodology. They allow for the use of empirically observed feedback relationships.

6 Results

The results of the simulations have been shown in Figs. 9, 10, 11, and 12. Figure 9 shows the simulation results for antibiotic concentration in the lakes for 2016 to 2020. There is a buildup of the concentration during the winter with low temperatures in the water and a quick decomposition in the summer, when the concentrations go down. The terms PNEC (0.1 $\mu$g/l), low risk (0.3 $\mu$g/l), and significant risk (1 $\mu$g/l) are limits recommended by EU and WHO. The antibiotic concentration levels in both Kaban lakes appear to be above what is considered a safe level of 0.1 $\mu$g/l, in Nizhniy Kaban lake during certain parts of the year (Fig. 10) and in Sredniy Kaban lake all the time (Fig. 11). The variation in the signal is mainly caused by the seasonal variations in flow and temperature. Low risk is a limit where the effects have been evaluated to low or at the no observed effect concentration (NOEC) limit, and the significant risk is where some effect seems likely. The low-risk line should not be transgressed if the lake is used for bathing. The PNEC limit of 0.1 $\mu$g/l is required if the water body is to be used for drinking water (WHO 2011). Some countries demand half the PNEC limit, 0.05 $\mu$g/l. The term PNEC is defined as follows: proposed no effect concentration. They are based on being set below the NOEC: the no observed effect concentration; these are the studies that sometimes have run for many years (WHO 2011; 2015a, b). Some antibiotics are decomposed in the lake after arrival, a significant amount in the warm period.

Figure 12 shows the net decomposition of antibiotics in both Kaban lakes, including the decomposition in the soils in the catchments. The annual variation in the signal is caused by the seasonal variations in flow and temperature; the amplitude trend is caused by the rise and decline in the antibiotic load to the lake system. During peak decomposition, larger amounts of antibiotics are decomposed than what is added through lake pollution inflow. This cause is a negative value and there is net antibiotic removal. During the cold period of the year, the decomposition is significantly less and the decomposition will be significantly less than the inflow.

7 Discussion

The model simulation results shown here are made with a lot of assumptions concerning the input data and the parameterization. Many of the key inputs are known in outline only and had to be estimated making assumptions with significant uncertainty, using experience and state-of-the-art approaches (Chapra 1991; Chapra and Reckhow 1983; Barkman et al. 1994). The conclusions based on the predictions are uncertain and must be used with great caution. No survey of antibiotic pollution known to us has been made in the Kaban lake system. However, the results do show that further investigation of the Kaban lakes system is justified and probably necessary.

The generalized results are consistent with the findings in other studies (Boxall and Wilkinson 2019;
Wilkinson and Boxall (2019; Gilbert 2019) and our assessment for the Volga River. The literature (Ratchina 2015; Obukhova and Lartseva 2014, 2018; Belkova et al. 2012, 2013) suggests that there may be an antibiotic issue with the Volga River, which we confirmed in our earlier study (Sverdrup et al. 2020). However, very little literature is available in the scientific literature on this aspect of the Kaban lake system (Sverdrup et al. 2020).
If antibiotics really are a problematic situation at the Kaban lakes, it could not be verified by a comparison with empirical data from the Kaban lakes, as we found no such measurements in the reports available to us. If the general principles used for Volga are relevant for the Kaban lakes (we think it is), then that supports that there is possibly an issue for the Kaban lakes system. But only water sampling and actual measurements can tell.

The decomposition in the soil and decomposition in the water vary with the temperature (Chapra 1991, Years

Fig. 9 The simulation results for antibiotic concentration in the lakes. 3 PNEC suggested by the WHO, 4 low risk for antibiotic resistance line, 5 high risk for antibiotic resistance line. The limits are the adaptations from the WHO guidelines (2011, 2015a, b)

Fig. 10 Shows the Srednyi Kaban lake concentration of antibiotics. The terms PNEC (0.1 microgram/l), low risk (0.3 microgram/l) and significant risk (1 microgram/l) are limits recommended by EU and WHO. The antibiotics concentration level in Srednyi Kaban lake appear to be above what is considered a safe level for most of the year.

If antibiotics really are a problematic situation at the Kaban lakes, it could not be verified by a comparison with empirical data from the Kaban lakes, as we found no such measurements in the reports available to us. If the general principles used for Volga are relevant for the Kaban lakes (we think it is), then that supports that there is possibly an issue for the Kaban lakes system. But only water sampling and actual measurements can tell.

The decomposition in the soil and decomposition in the water vary with the temperature (Chapra 1991, Years

Fig. 11 Shows the Nizhniy Kaban lake concentration of antibiotics. The terms PNEC (0.1 μg/l) and low risk (0.3 μg/l) are limits recommended by EU and WHO. The antibiotic concentration level in Nizhniy Kaban lake exceeds the PNEC limit and the low risk occasionally.
Sverdrup et al. 2002, 2020. The simulated concentrations are significantly lower in the warm period of the year and higher in the cold period. In the cold period, the decomposition in the lakes and in the soils will be very low.

8 Conclusions

The study suggests that the antibiotic concentration in the Nizhniy Kaban and Sredniy Kaban lakes may be above the limits proposed by the WHO and the EU for no effect concentration (PNEC). Our simulations involve many assumptions and guesswork for substitution missing data and the predictions are thus very uncertain. The simulations show clearly that such calculations are possible, and the missing point now is an access to better data. Thus, they are suggestive of what may be taking place, but with no certainty that this is really so. More measurements are needed on antibiotic loads and pathways of substances from the sewage to the lakes, in order to make better simulations and future risk assessments. The results as shown in Figs. 9, 10, 11, and 12 would make us suggest that such measurements are made during several parts of the year.

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